TECHNICAL DEEP DIVE

Anki Vector

A LOVE LETTER TO THE LITTLE DUDE

AUTHOR RANDALL MAAS

OVERVIEW This fascicle explores how the Anki Vector was realized in hardware and software.

drawing by Steph Dere

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Preface

The Anki Vector is a charming little robot – cute, playful, with a slightly mischievous character. It is everything I ever wanted to create in a bot. Sadly Anki went defunct shortly after releasing Vector.

This book is my attempt to understand the Anki Vector and its construction. The book is based on speculation. Speculation informed by Anki's SDKs, blog posts, patents and FCC filings; by articles about Anki, presentations by Anki employees; by PCB photos, and hardware teardowns from others; and by experience with the parts, and the functional areas.

1.1. VERSION(S)

The software analyzed here is mostly version 1.5 and version 1.6 of Vector. There are incremental differences with each version; I have not always described the places that only apply to a specific version. Version 1.6 was a release rushed to customers as Anki ceased operation. This release includes more software elements that are unused, but are nonetheless telling.

1.2. CUSTOMIZATION AND PATCHING

What can be customized – or patched – in Vector?

- The firmware in the main processor may be customizable; that will be dicussed in many areas of the rest of the document
- The base-board is not field updatable, without expertise. The STM32F030 firmware can be extracted with a ST-Link ($25), and the the firmware can be disassembled — the microcontroller is conducive to this. Shy of recreating the firmware, the patches replace a key instruction here and there with a jump to the patch, created in assembly (most likely) code to fix or add feature, then jump back. (STM32's come with a boot loader, but the ST-Link is easier and inexpensive.)
- The cube firmware can be updated, but that seems both hard and not useful.

2. ORGANIZATION OF THIS DOCUMENT

- CHAPTER 1: PREFACE. This chapter describes the other chapters.
- CHAPTER 2: OVERVIEW OF VECTOR'S ARCHITECTURE. Introduces the overall design of the Anki Vector.

PART I: ELECTRICAL DESIGN.

- CHAPTER 3: VECTOR'S ELECTRICAL DESIGN. A detailed look at the electrical design of Vector.
- CHAPTER 4: ACCESSORY ELECTRICAL DESIGN. A look at the electrical design of Vector's accessories.

PART II: BASIC OPERATION.

- CHAPTER 5: ARCHITECTURE. A detailed look at Vector's overall software architecture.

- Chapter 6: Power Management. A detailed look at Vector's startup, shutdown and other power management architecture.
- Chapter 7: Audio Input and Output
- Chapter 8: LCD Display

Part III: Communication. This part provides details of Vector's communication protocols. These chapters describe structure communication, the information that is exchange, its encoding, and the sequences needed to accomplish tasks. Other chapters will delve into the functional design that the communication provides interface to.

- Chapter 9: Communication. A look at the communication stack in Vector.
- Chapter 10: Bluetooth LE. The Bluetooth LE protocol that Vector responds to.
- Chapter 11: SDK Protocol. The HTTPS protocol that Vector responds to.
- Chapter 12: Cloud. A look at how Vector syncs with remote services.

Part IV: Maintenance. This part describes items that are not Vector's primary function; they are practical items to support Vector's operation.

- Chapter 17: Settings, Preferences and Statistics.
- Chapter 18: Software Updates. How Vector's software updates are applied.
- Chapter 20: Diagnostics. The diagnostic support built into Vector.

References and Resources. This provides further reading and referenced documents.

Appendices: The appendices provide extra material supplemental to the main narrative. These include tables of information, numbers and keys.

- Appendix A: Abbreviations, Acronyms, & Glossary. This appendix provides a gloss of terms, abbreviations, and acronyms.
- Appendix B: Tool Chain. This appendix lists the tools known or suspected to have been used by Anki to create, and customize the Vector, and for the servers. Tools that can be used to analyze Vector
- Appendix C: Fault and Status Codes. This appendix provides describes the system fault codes, and update status codes.
- Appendix D: File System. This appendix lists the key files that are baked into the system.
- Appendix E: Bluetooth LE Protocols. This appendix provides information on the Bluetooth LE interfaces to the companion Cube, and to Anki Vector
- Appendix F: Servers. This appendix provides the servers that the Anki Vector and App contacts
- Appendix G: Features. This appendix enumerates the Vector OS "features" that can be enabled and disabled.
- Appendix H: Phrases. This appendix reproduces the phrases that the Vector keys off of.
- Appendix J: Pleo. This appendix gives a brief overview of the Pleo animatronic dinosaur, an antecedent with many similarities.

Note: I use many diagrams from Cozmo literature. They're close enough

2.1. ORDER OF DEVELOPMENT

A word on the order of development; the chapters are grouped in sections of related levels of functionality and (usually) abstraction.

Most chapters will description a vertical slice or stack of the software. The higher levels will discuss features and interactions with other subsystems that have not been discussed in detail yet. For instance, the section on the basic operation of Vectors hardware includes layers that link to the behavior and communication well ahead of those portions. Just assume that you'll have to flip forward and backward from time to time.

The communication interface is held to its own section with the relevant interactions, commands, structures and so on.

CHAPTER 2

Overview of Vector

Anki Vector is a cute, palm-sized robot; a buddy with a playful, slightly mischievous character. This chapter provides an overview of Vector:

- Overview
- Ancestry: Cozmo

3. OVERVIEW

Vector is an emotionally expressive animatronic robot that we all love.

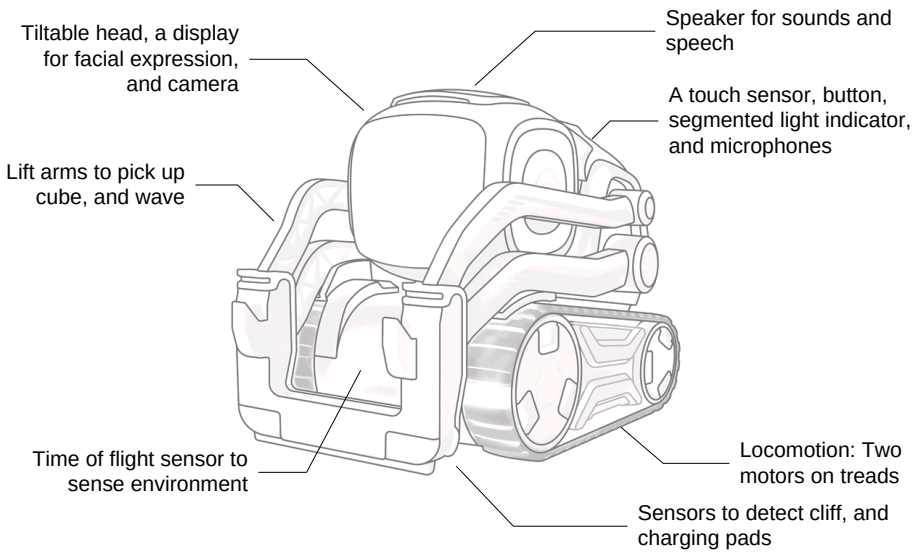

Figure 1: *Vector's main features*

He can express emotions thru expressive eyes (on an LCD display), raising and lower his head, sounds, wiggling his body (by using his treads), or lifting his arms… or shaking them.

Vector can sense surrounding environment, interact and respond to it. Recognize his name[1], follow the gaze of a person looking at him, and seek petting.[2]

3.1. FEATURES

Although cute, small, and affordable,[3] Vector's design is structured like many other robots.

He has a set of operator inputs:

- A touch sensor is used detect petting

[1] Vector can't be individually named.
[2] Admittedly this is a bit hit and miss.
[3] Although priced as an expensive toy, this feature set in a robot is usually an order of magnitude more, usually with less quality.

- Internal microphone(s) to listen, hear commands and ambient activity level
- A button that is used to turn Vector on, to cause him to listen – or to be quiet (and not listen), to reset him (wiping out his personality and robot-specific information).
- He can detect his arms being raised and lowered.[4]

He has a set of indicators/annunciators:

- Segmented lights on Vector's backpack are used to indicate when he is on, needs the charger, has heard the wake word, is talking to the Cloud, can't detect WiFi, is booting, is resetting (wiping out his personality and robot-specific information).
- An LCD display, primarily to show eyes of a face. Robot eyes were Anki's strongest piece of imagery. Vector smiles and shows a range of expressions with his eyes.
- Speaker for cute sounds and speech synthesis

He has other means to express affect as well:

- His head can be tilted up and down to represent sadness, happiness, etc.
- His arms flail to represent frustration
- He can uses his treads to shake or wiggle, usually to express happiness or embarrassment

He has environmental sensors:

- A camera is used to map the area, detect and identify objects and faces.
- Fist-bump and being lifted can be detected using an internal *inertial measurement unit* (IMU)
- A forward facing "time of flight" proximity sensor aids in mapping and object avoidance
- Ground sensing proximity sensors that are used to detect cliffs and the edge of his area; these may also be used in following lines on his charger.

His internal sensing includes:

- Battery voltage, charging; charging temperature
- IMU for orientation position (6-axis)
- Encoders provide feedback on motor rotation

His other articulation & actuators are:

- Vector drives using two independent treads to do skid-steering
- Using his arms Vector can lift, or flip a cube; he can pop a wheelie, or lift himself over a small obstacle.
- Vector can raise and lower his head

Communication (other than user facing):

- Communication with the external world is thru WiFi and Bluetooth LE.
- Internally RS-232 (CMOS levels) and USB

[4] and possibly a pat on his head?

Motion control

- At the lowest level can control each of the motors speed, degree of rotation, etc. This allows Vector to make quick actions.
- Combined with the internal sensing, he can drive in a straight line and turn very tightly.
- Driving is done using a skid-steering, kinematic model
- To do all this, the motion control takes in feedback from the motor encoder, IMU-gyroscope. May also use the image processing for SLAM-based orientation and movement.

Guidance, path planning

- Vector plans a route to his goals – if he knows where his goal is – along a path free of obstacles; he adapts, moving around in changing conditions.
- A*, Rapidly-Expanding Random Tree (RRT), D*-lite
- Paths are represented as arcs, line segments, and turn points

Mapping and Navigation:

- Maps are built using *simultaneous location and mapping* (SLAM) algorithms, using the camera and IMU gyroscope movement tracking, time of flight sensor to measure distances, and particle system algorithms to fill in the gaps.
- The maps are represented uses quad-tree (position, pose)

Behaviour system:

- Variety of behaviors animations
- Goals, linking up to the guidance system to accomplish them
- A simple emotion model to drive selection of behaviours

Vision. Vision is Anki's hallmark: they used vision where others used beacons and mechanics

- Illumination sensing
- Motion sensing
- Links to Navigation system for mapping, (SLAM etc)
- Recognizing marker symbols in his environment
- Detecting faces and gaze detection allows him to maintain eye contact

4. PRIVACY AND SECURITY

Vector's design includes a well-thought out system to protect privacy. This approach protects from strangers the:

- Photos taken by Vector
- The image stream from the camera
- The audio stream from the microphone — if it had been finished being implemented
- Information about the owner
- Control of the robot's movement, speech & sound, display, etc.

Vector's software is protected from being altered in a way that would impair its ability to secure the above.

5. COZMO

We shouldn't discuss Vector without mentioning the prior generation. Vector's body is based heavily on Cozmo; the mechanical refinements and differences are relatively small. Nathaniel Monso's team designed Cozmo's hardware. Vector's software architecture also borrows from Cozmo, and extends it greatly. Andrew Stein was Cozmo's original (but not only) software developer. Brian Chapados's team developed the Android and iOS applications.

Many of Vector's behaviours, senses, and functions were first implemented in Cozmo (and/or in the smartphone application). One notable difference is that Cozmo did not include a microphone.

6. ALEXA INTEGRATION

Vector includes Amazon Alexa functionality, but it is not intimately integrated. Vector only acts like an Echo Dot. By using the key word "Alexa," Vector will suppress his activity, face and speaking, and the Alexa "echo dot" functionality takes over. Vector has no awareness of Alexa's to-do list, reminders, messages, alarms, notifications, question-and-answers, and vice-versa.

The most likely reason for including Alexa is the times: everything had to include Alexa to be hip, or there would be great outcry. Including Alexa may have also been intended to provide functionality and features that Anki couldn't, to gain experience with the features that Amazon provides, and (possibly) to more tightly integrate those features into Anki products while differentiating themselves in other areas.

Alexa clearly took a lot of effort to integrate, and a lot of resources:

> "[Alexa Voice Service] solutions for Alexa Built-in products required expensive application processor-based devices with >50MB memory running on Linux or Android"[5]

Alexa's software resources consume as much space Vector's main software. And the software is not power efficient. Even casual use of Alexa noticeably reduces battery life, and (anecdotally) increases the processor temperature.

[5] https://aws.amazon.com/blogs/iot/introducing-alexa-voice-service-integration-for-aws-iot-core/
Alexa's SDK and services have continued to evolve. New Alexa SDKs allow simpler processors and smaller code by acting as little more than a remote microphone.

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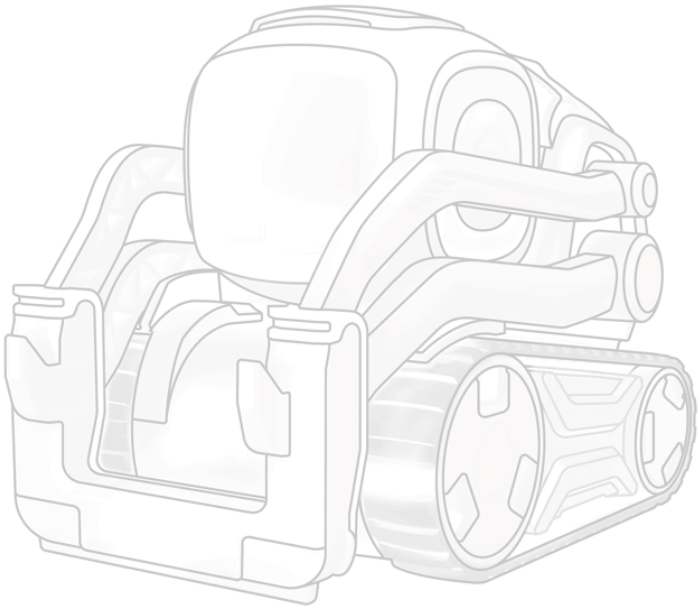
PART I

Electronics Design

This part provides an overview of the design of the electronics in Vector and his accessories

- VECTOR'S ELECTRICAL DESIGN. A detailed look at the electrical design of Vector.
- ACCESSORY ELECTRICAL DESIGN. A look at the electrical design of Vector's accessories.



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CHAPTER 3

Electronics design description

This chapter describes the electronic design of the Anki Vector:

- Design Overview
- Detailed design of the main board
- Detailed design of the base-board
- Power characteristics

7. DESIGN OVERVIEW

Vector's design includes numerous some to sense and interact with his environment, other to interact with people and express emotion and behaviour.

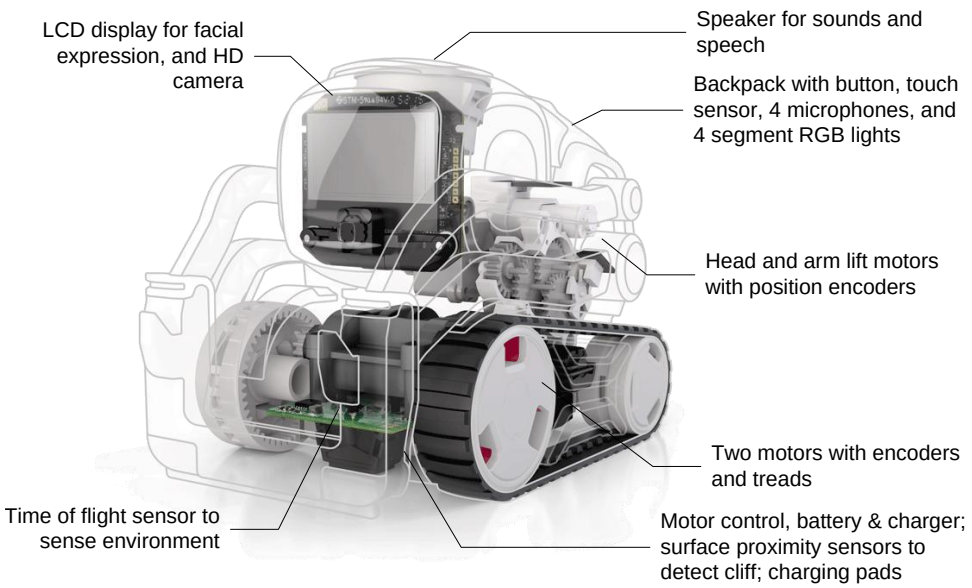

Figure 2: *Vector's main elements*

Vector's functional elements are:

Element	Description
backpack	The top of Vector, where he has a button, segmented lights, and a touch sensor.
battery	There is an internal battery pack (3.7v 320 mAh) that is used as Vector's source of energy.
button	A momentary push button is used to turn Vector on, to cause him to listen – or to be quiet (and not listen) – to reset him (wiping out his personality and robot-specific information).
camera	Vector uses an HD camera to visualize his environment, and recognize his human companions.
charging pad	Two pads on the bottom are used to replenish the energy in the battery pack from the dock.
LCD display	An IPS LCD, with an active area is 23.2mm x 12.1mm. It has a resolution of 184 x 96 pixels, with RGB565 color.
microphones	There are 4 internal microphone(s) to listen to commands and ambient activity level. Employs beam forming to localize sounds.
motors & encoders	There are four motors with single-step optical encoders to measure their position and approximate speed. One motor controls the tilt of the head assembly. Another controls the lift of his arms. Two are used to drive him in a skid-steering fashion.
segmented RGB lights	There are 4 LEDs used to indicate when he is on, needs the charger, has heard the wake word, is talking to the Cloud, can't detect WiFi, is booting, is resetting (wiping out his personality and robot-specific information).
speaker	A speaker is used to play sounds, and for speech synthesis
surface proximity sensors	4 infrared proximity sensors are used to detect the surface beneath Vector – and to detect drop offs ("cliffs") at the edge of his driving area.
time of flight sensor	A time of flight sensor is used to aid in mapping (by measuring distances) and object avoidance.
touch sensor	A touch allows Vector to detect petting and other attention.

Table 1: *Vector's main elements*

Vector has 6 circuit boards

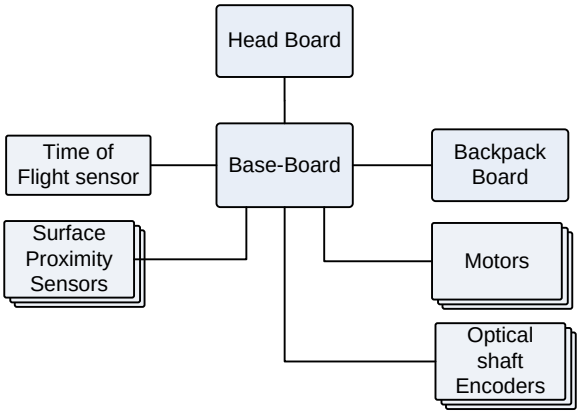

Figure 3: *Circuit board topology*

The main two boards are the head-board where the major of Vector's processing occurs, and the base-bard, which drives the motors and connects to the other boards.

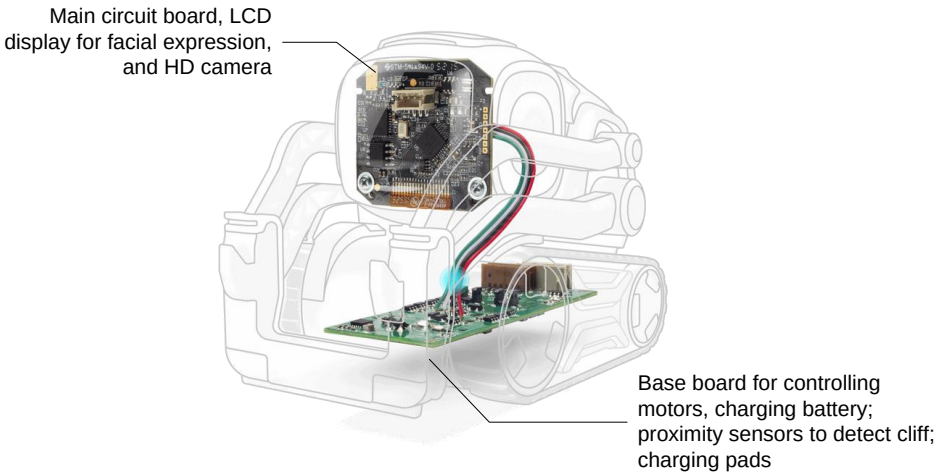

Figure 4: *Vector's main microcontroller circuit boards*

The table below summarizes the boards:

Table 2: *Vector's circuit boards*

Circuit Board	Description
backpack board	The backpack board has 4 RGB LEDs, 4 MEMS microphones, a touch wire, and a button. This board connects to the base-board.
base-board	Drives the motor. power management battery charger
encoder-boards	The two encoder boards have single opto-coupler encoder each. The encoder is used to monitor the position of the arms and head, either as driven by the motor, or by a person manipulating them.
head-board	The head board includes the main processor, flash & RAM memory storage, an IMU, and a PMIC. The WiFi and Bluetooth LE are built into the processor. The camera and LCD are attached to the board, thru a flex tape. The speaker is also attached to this board.
time of flight sensor board	The time of flight sensor is on a separate board, allowing it to be mounted in Vector's front.

7.1. POWER SOURCE AND DISTRIBUTION TREE

Vector is powered by a rechargeable battery pack, and the energy is distributed by the base-board:

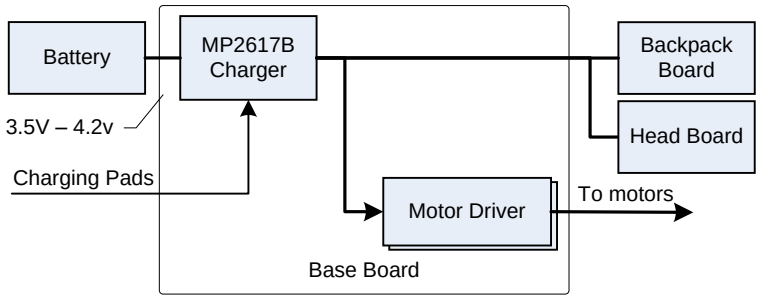

Figure 5: *Power distribution*

The MP2617B is a central element to managing the battery. It acts as a battery charger, a power switch and power converter for the whole system.

- When Vector is going into an *off* state – such as running too low on power, going into a ship state before first use, or has been turned off by a human companion – the MP2617B charger and power converted can be signaled to turn off
- When Vector is turned off the boards are not energized. The exception is that the high side of the push button is connected to the battery. When closed, the signals the MP2617B to connect the battery to the rest of the system, powering it up.
- The MP2617B is also responsible for charging the battery. There are two pads that mate the dock to supply energy to charge the battery.

In many rechargeable lithium ion battery systems there is a coulomb counter to track the state of charge. Vector does not have one. The need for recharge is triggered solely on the battery voltage.

Excessive current demand – such as from a stalled motor – can trigger a system brown-out and shutdown.

8. THE BACKPACK BOARD

The backpack board is effectively daughter board to the base-board. It provides extra IO and a couple of smart peripherals:

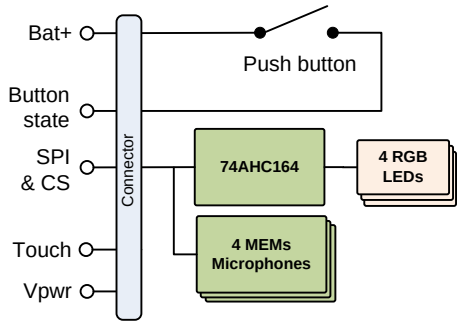

Figure 6: *Backpack board block diagram*

The table below summarizes the functional elements of the backpack board:

Table 3: *Backpack board functional elements*

Elements	Description
74AHC164	A SPI-based GPIO expander. This is used to drive the RGB LEDs.
microphones	There are 4 internal MEMS microphone(s). The microphones are accessed via SPI, in an output only mode. These are designated MK1, MK2, MK3, MK4
push button	A momentary push button is connected to the battery terminal, allowing a press to wake Vector, as well as signal the processor(s).
RGB LEDs	There are 4 RGB LEDs to make up a segmented display. Each segment can be illuminated individually but may share a colour configuration with its counterparts.
touch sensor	A touch-sensing wire (and passive components)

8.1. BACKPACK CONNECTION

The backpack connection includes:

- Power and ground connections. This includes connection to the battery rail.
- The touch wire as an analog signal to the base-board
- A quasi digital signal out from the momentary push button
- (at least) Two chip selects
- A SPI-like set of clock, master-out-slave-in (MOSI) and *two* master-in-slave-out (MISO) signals

8.2. OPERATION

The touch sensor conditioning and sensing is handled by the base-board. The touch sense wire is merely an extension from the base-board through the backpack board.

The push-button is wired to the battery. When pressed, the other side of the push button signals both base-board microcontroller, and (if Vector is off) the charger chip to connect power. The theory of operation will be discussed further in the base-board section below.

The 74AHC164 serial-shift-register is used as a GPIO expander. It takes a chip select, clock signal and serial digital input, which are used to control up to 8 outputs. The inputs determine the state of 8 digital outputs used to control the RGB LEDs. More on this below.

Each of the 4 MEMS microphones take a chip select, clock signal, and provide a serial digital output. The clock signal (and one of the chip selects) is shared with the 74AHC164.

The base-board sets the digital outputs, and reads 2 microphones at a time. It reads all four microphones by alternating the chip selects to select which two are being accessed. (This will be discussed in the base-board section).

8.2.1 The LED controls

Backpack LED control scheme

8 outputs are not enough to drive 4 RGB LEDs (each with 3 inputs) independently. 3 of the LEDs are always the same colour – but illuminated independently. The 4th LED may have a different colour and is illuminated independently.

- D1 has separate red and green signals from the 74AHC164. It may share blue with the others.
- 3 signals from the 74AHC164 – Red, Green, and Blue – are shared for D2, D3, D4.[6]
- D2, D3, and D4 each have individual bottom drives

With care the LEDs can be individually turned on and off (the low sides), and selected for a colour (the red, green, and blue signals).

[6] If I'm seeing the chip right, the ground, green and blue are wired together but that doesn't make sense in the truth-table to get the effect of the LED patterns

9. THE BASE-BOARD

The base board is a battery charger, smart IO expander, and motor controller. It connects the battery to the rest of the system and is responsible for charging it. It is based on an STM32F030 which acts as second processor in the system.

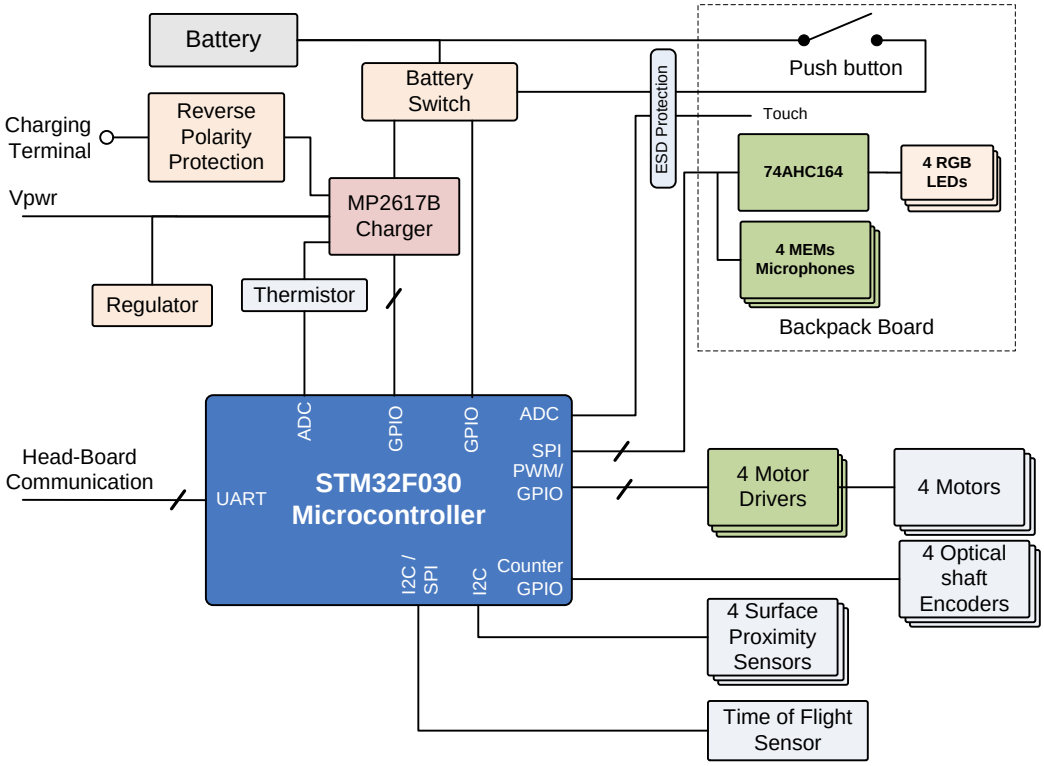

Figure 7: *Base-board block diagram*

The functional elements of the base-board are:

Table 4: *The base-board functional elements*

Element	Description
battery	An internal, rechargeable battery pack (3.7v 320 mAh)
battery switch	Used to disconnect the battery to support off-mode (such as when stored) and to reconnect the battery with a button press.
charging pad	Two pads on the bottom are used to replenish the energy in the battery pack from the dock.
motor driver	There are four motor drivers, based on an H-bridge design. This allows a motor to be driven forward and backward.
motors	There are four motors with to measure their position and approximate speed. One motor controls the tilt of the head assembly. Another controls the lift of his arms. Two are used to drive him in a skid-steering fashion.
MP2617B charger	The Monolithic Power Systems MP2617B serves as the battery charger. It provides a state of charge to the microcontroller.
optical shaft encoder	An opto-coupler, in conjunction with a slotted disc on a motor's shaft, which is used to measure a motors speed.
regulator	A 3.3v used to supply power to the microcontroller and logical components.
reverse polarity protection	Protects the circuitry from energy being applied to the charging pads in reverse polarity, such as putting Vector onto the charging pads in reverse.
STM32F030	The "brains" of the baseboard, used to drive the motors, and RGB LEDs; to sample the

microcontroller	microphones, time of flight sensor, proximity sensor, temperature, and the touch sense;, and monitoring the battery charge state. It communicates with the head-board.
surface proximity sensors	4 infrared proximity sensors are used to detect the surface beneath Vector – and to detect drop offs ("cliffs") at the edge of his driving area.
thermistor[7]	A temperature sense resistor used measure the battery pack temperature; it is used to prevent overheating during recharge.
VL53L1 time of flight sensor	A ST Microelectronics VL53L1 time of flight sensor is used to measure distance to objects in front of Vector. This sensor is connected by I^2C.

9.1. POWER MANAGEMENT

The battery charging is based on a MP2617B IC, which also provides some protection functions. There is no Coulomb counter; the state of charge is based solely on the battery voltage.

9.1.1 Battery pack

Vector's single-cell lithium battery is connected to the baseboard and laid on top of the PCBA. The battery is not removable. The battery label has it as a 3.7v 320mAh pack. It is rechargeable. The pack is not a "smart" battery – it only has positive and negative leads but lacks an onboard temperature sensor or BMS.

9.1.2 Protections

The charging pads have reverse polarity protection.

The MP2617B has an over-current cut off. If the current exceeds ~5A (4-6A), the battery will be disconnected from the system bus. Such a high-current indicates a short. There is no fuse.

The MP2617B has a low voltage cut off. If the battery voltage drops below ~2.4 (2.2-2.7V) the battery will be disconnected from the system bus (TBD) until the battery voltage rises above ~2.6V (2.4-2.8V).

The MP2617B has a temperature sense. If the temperature exceeds a threshold, charging is paused until the battery cools. The temperature sense is not on the battery. It is likely on the circuit board, or possibly top of the battery retention.

[7] Not identified. The customer service screen does show a battery pack temperature, indicating that this is reported.

9.1.3 Battery connect/disconnect

To preserve the battery there is a need to isolate the battery from the rest of the system when in an off state. If there is minute current draw, the battery will irreversibly deplete while in storage even before the first sale. This constraint shapes the battery disconnect-reconnect logic. The schematic below shows one way to do this:

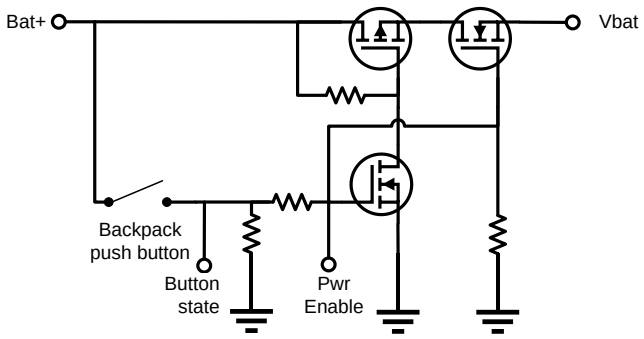

Figure 8: *A representative battery connect switch*

Two MOSFETS (a PFET and NFET)[8] act as a switch. These are in a single package, the DMC2038LVT. (This part is also used in the motor drivers.)

- When the system is in an off state, the MOSFETs are kept in an off state with biasing resistors. The PFET's gate is biased high with a resistor. The NFET gate is biased low, to ground. There is no current flow. Two MOSFETS are needed due to internal body diodes. The PFET body diode would allow current to flow from the battery (from the source to the drain). However, this current is blocked by the NFET body diode, which has a different polarity
- The push button can wake the system. When the button is closed, the battery terminal (Bat+) is connected to the gate of the NFET, turning it on. A second NFET is also energized, pulling the PFET gate to ground, turning it on as well. When the button is open, Bat+ is not connected to anything, so there is no leakage path draining the battery.
- To keep the system energized when the button is open, the STM32F030 MCU must drive the Pwr Enable line high, which has the same effect as the button closed. The gate threshold voltage is 1V, well within the GPIO range of the MCU.
- The MCU can de-energize the system by pulling Pwr Enable line low. The switches will open, disconnect the battery.
- The MCU needs to be able to sense the state of the button while Pwr Enable is pulled high. The MCU can do this by sampling the Button State signal. This signal is isolated from from Pwr Enable by a large resistor and pulled to ground by smaller resistor. This biases the signal to ground while the button is open.

This circuit also provides reverse polarity protection. It will not close the switch if the battery is connected backwards.

9.1.4 Charging

charging station pads

The charging station pads are connected to a MP2617B charger IC thru a reverse polarity protection circuit. The reverse polarity protection[9] is a DMG2305UX PFET in a diode

[8] Q11 and/or Q12
[9] Q14

configuration. This approach has much lower losses than using an equivalent diode.

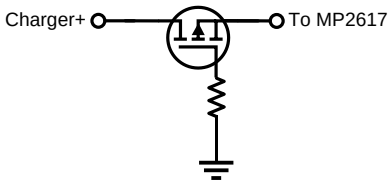

Figure 9: *A representative PFET based reversed polarity protection*

supplying power from the charging station

The MP2617B internally switches the charger input voltage to supply the system with power, and to begin charging the battery. This allows the charger to power the system even when the battery is depleted, or disconnected.

The presence of the dock power, and the state of MP2617B (charging or not) are signaled to the microcontroller.

charging states

The charger goes through different states as it charges the battery. Each state pulls a different amount of current from the charging pads and treats the battery differently.

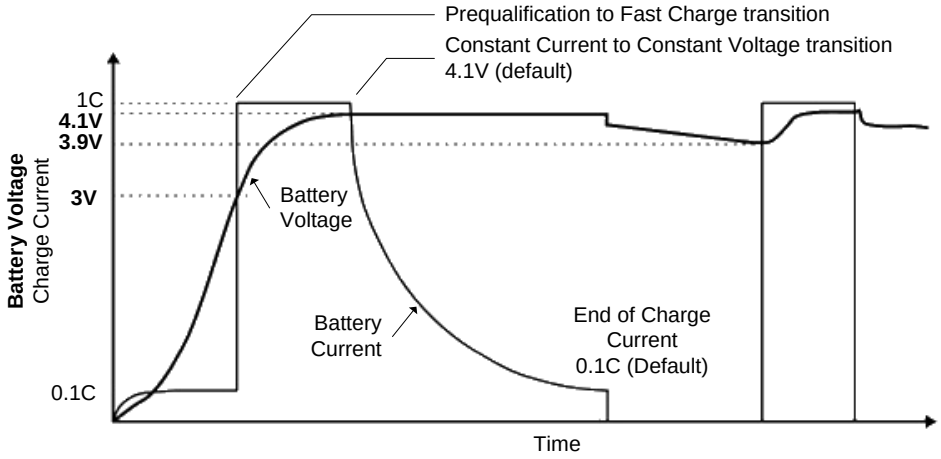

Figure 10: *Charging profile* (adapted from Texas Instruments)

constant current constant voltage

The basic idea is that the charger first applies a low current to the battery to bring it up to a threshold; this is called *prequalification* in the diagram. Then it applies a high current, call *constant current*. Once the battery voltage has risen to a threshold, the charger switches to *constant voltage*, and the current into the battery tapers off. I refer to the data sheet for more detail.

The MP2617B measures the battery temperature using a thermistor. If the temperature exceeds a threshold, charging is paused until the battery cools. The microcontroller also samples this temperature.

input current limits

The MP2617B supports limiting the input current, to accommodate the capabilities of external USB power converts. There are four different possible levels that the IC may be configured for: 2A is the default limit, 450mA to support USB2.0 limits, 825mA to support USB3.0 limits, and a custom limit that can be set by resistors. The input limit appears to be set for either default (up to ~2A input), or a programmable input.

Is the charger damaging the battery?

Commentary. In my testing, using a USB battery pack charging pulls up to 1A during the constant current, then falls off to 100mA-200mA during constant voltage, depending on the

head-board's processing load. Stepped down to the ~4V battery the applied current at peak is approximately 1A.[10] This seems far too high.

Battery cells are normally charged at no more than a "1C" rate – in this case, the battery maximum charge rate should be 320mA at max. The IC data sheet supports a charging rate up to 2A.

My speculation is that, intentionally or unintentionally, the charger is configured for the default input limit of 2A and supports a faster charge. It is possible that the impact to battery life was considered low. My analysis could be wrong. As a preventative measure, I have a current limiter between my USB power adapter and Vector's charging dock.[11]

9.1.5 Brown-out

motor stall & brown out effects

The motor stall current is enough to cause Vector to brown-out and shut down unexpectedly. This indicates two possible mechanisms:

- If the system browns out the STM32F030, the MCU will no longer hold the power switch closed, and the system power will be disconnected.
- If the current exceeds a threshold, the MP2617B will disconnect power to the system. This threshold is very high – ~5A – and is unlikely to ever be encountered in operation.

Commentary: It may be interesting to modify either the MCU's Vdd to have a larger retaining capacitor, or to add a current limiting mechanism for the motors, such as an inline resistor.

9.2. ELECTRO-STATIC DISCHARGE (ESD) PROTECTION

The base-board employs a Vishay GMF05, TVS diode (U4) for electro-static discharge (ESD) protection, likely on the pushbutton and touch input.

9.3. STM32F030 MICROCONTROLLER

The base-board is controlled by a STM32F030C8 microcontroller (MCU). This processor essentially acts as a smart IO expander and motor controller.

The MCU's digital inputs:

- 4 optical shaft encoders, one for each motor (left, right, head, lift)
- Momentary push button
- 4 IR proximity sensor used to detect cliffs
- 2 charger state

The MCU's digital outputs:

- 4 motors enable
- 4 motors direction
- charger enable
- 3 chip selects

[10] Other reports suggest up to 2As into the battery, possible with the use of high-power USB adapters intended to support tablet recharge.

[11] 1Ω on the USB power. I tried 1Ω -14Ω; these should have limited the current to 1A and 500mA respectively. Instead, Vector would only pull 40mA - 370mA; in many cases, not enough to charge.

The MCU's analog inputs:

- Touch
- Battery voltage
- Temperature sensor (picks off the thermistor used by the MP2617)

The communication:

- 2 SPI, to LED outputs, from microphones. Uses an SPI MCLK to clock out the state, and MOSI to send the state of that IO channel
- I2C for communication with the time of flight sensor
- UART, for communication with the head board

Note: The microcontroller does not have an external crystal[12] and uses an internal RC oscillator instead.

9.3.1 Manufacturing test connector

The base-board does include pads that appear to be intended for programming and test at manufacturing time.

9.3.2 Firmware updates

The microcontroller includes a boot loader, allowing the firmware to be updated by the head-board. The firmware is referred to as "syscon".

9.4. SENSING

9.4.1 Time of Flight sensor

The MCU interfaces with a ST Microelectronics VL53L1 time of flight sensor, which can measure the distance to objects in front of vector. It "has a usable range 30mm to 1200mm away (max useful range closer to 300mm for Vector) with a field of view of 25 degrees."[13]

These sensors work by timing how long it takes for a coded pulse to return. The time value is then converted to a distance. Items too close return the pulse faster than the sensor can measure. The measured distance is available to the microcontroller over I^2C.

9.4.2 Proximity sensing

Has 4 IR proximity sensors that are used to used to detect drops offs, or "cliffs." The exact model hasn't been identified, but the Everlight EAAPMST3923A2 is a typical proximity sensor. The sensor is an LED and IR detector pair. The sensor reports, via I^2C, the brightness sensed by the detector. This are often pulsed, to reject to sunlight; and use a configurable threshold to reduce sensitivity to ambient light.

9.4.3 Touch sensing

The touch sensing works by alternating pulsing and sampling (with the ADC) the touch wire. The samples will vary "by various environmental factors such as whether the robot is on its charger, being held, humidity, etc."[14]

[12] as far as I can see
[13] Anki SDK, in the proximity.py file

9.5. MOTOR DRIVER AND CONTROL

Each motor driver is an H-bridge, allowing a brushed-DC motor to turn in either direction.

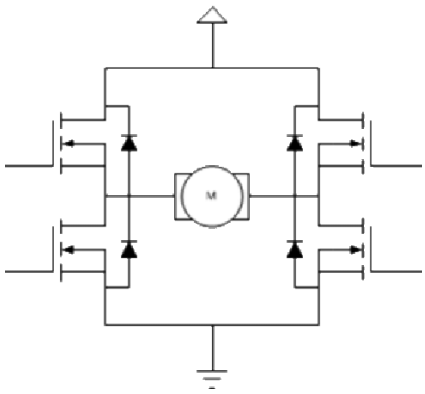

Figure 11: *Motor driver H-bridge*

Each side of the H-bridge based on the DMC2038LVT, which has a P-FET and N-FET in each package. Two of these are needed for each motor.

The MCU (probably) independently controls the high side and low side to prevent shoot thru. This is done by delaying a period of time between turning off a FET and turning on a FET.

The motors can be controlled with a control loop that takes feedback from the optical encoder to represent speed and position.

9.6. COMMUNICATION

The base-board communicates with the head-board via RS-232 3.3V (3 Mbits/sec[15]). As the MCU does not have a crystal, there may be communication issues from clock drift at extreme temperatures; since Vector is intended for use at room temperature, the effect may be negligible.

The firmware can be updated over the serial communication by the head-board.

SPI communication with 2 microphones simultaneously

The communication with the backpack board is special. Two microphones are read at a time, using a shared SPI clock and chip select. The process can be:

1. The first chip select is asserted
2. A 16-bit SPI transfer is initiated on two SPI ports nearly simultaneously; the clock and data output (MOSI) on the second is ignored. This may be done carefully in code with as little as 1-instruction cycle skew.
    a. This transfer sends the state of the RGB LED's to the 74AHC164 chip
    b. The receiver accepts 16-bits each from the microphone 1 and 3.
3. After completion, the first chip select is de-asserted, and the second chip select is assert.
4. A 16-bit SPI transfer is initiated on two SPI ports nearly simultaneously; the clock and data output (MOSI) on the second is ignored. This transfers 16-bits each from the microphone 2 and 4.
5. After completion, the second chip select is de-asserted

[14] Anki SDK, in the touch.py file
[15] Value from analyzing the RAMPOST program. Melanie T measured it on an oscilloscope and estimated it to be 2Mbps.

The microphones are sampled a rate of 15625 samples/sec.

10. THE HEAD-BOARD (THE MAIN PROCESSOR BOARD)

The head-board handles the main processing. It is powered by a quad-core Arm-A7 Qualcomm APQ8009 microprocessor. The processor also connects to Bluetooth LE and WiFi transceivers, an HD camera, LCD display, speakers and an IMU.

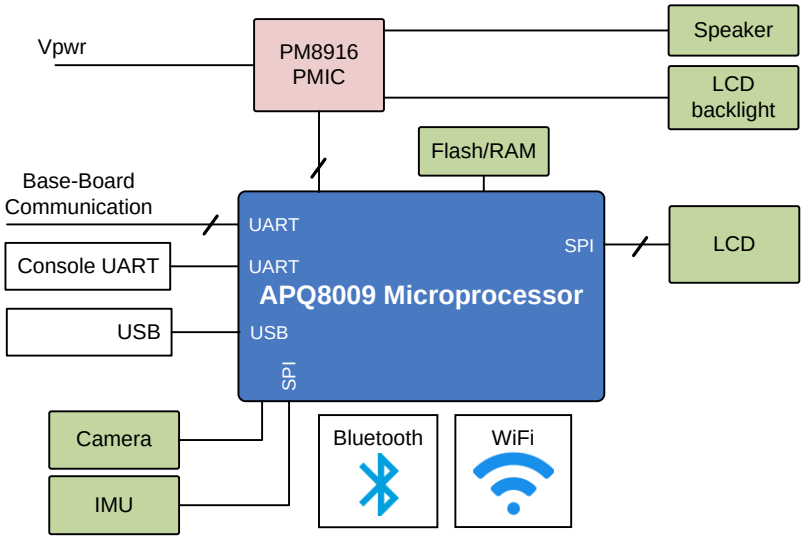

Figure 12: *Head-board block diagram*

The head-board's functional elements are:

Element	Description
Bluetooth LE transceiver	A Bluetooth LE transceiver is built into the package
camera	Vector uses a 720P camera to visualize his environment and recognize his human companions.
flash/RAM	Flash and RAM are provided by single external package, a Kingston 04EMCP04-NL3DM627 mixed memory chip with 4 GB flash and 512MB RAM.
inertial measurement unit (IMU)	The headboard includes a 6-axis IMU – gyroscope and accelerometer – used for navigation and motion control.
LCD display	An IPS LCD, with an active area is 23.2mm x 12.1mm. It has a resolution of 184 x 96 pixels, with RGB565 color.
microprocessor	The head-board is based on a Qualcomm APQ8009 (Snapdragon 212). The processor is a quad-core Arm A7 (32-bit) CPU.
power management IC (PMIC)	The PM8916 power management IC provides voltage regulation for the processor, flash/RAM and other parts; it also provides audio out to the speaker and controls the LCD backlight.
speaker	A speaker is used to play sounds, and for speech synthesis
WiFi transceiver	An 802.11AC WiFi transceiver is built into the processor package

Table 5: *The head-boards functional elements*

10.1. SPEAKERS

The speaker is driven at 16bits, single channel, with a sample rate of 8000-16025 samples/sec.

10.2. CAMERA

Vector has a 720p camera with a 120° field of view. The camera is calibrated at manufacturing time.

The cameras power control is on GPIO #83

10.3. THE LCD

LCD display

Vector's LCD is a backlit IPS display. The processor is connected to the LCD via SPI. The backlight is PWM controlled by the PM8916 PMIC.

US Patent 20372659

The prior generation, Cozmo, used an OLED display for his face and eyes. OLEDs are susceptible to burn-in and uneven dimming or discoloration of overused pixels. Anki addressed this with two accommodations. First it gave the eyes regular motion, looking around and blinking. Second, the LCD's illuminated rows were regularly alternated to give a retro-technology interlaced row effect, like old CRTs.

Vector's IPS display gives a smoother imagery that is much less susceptible to burnin, at the expense of higher power.

10.4. TRIM, CALIBRATION SERIAL NUMBERS AND KEYS

Each Vector has a set of per unit calibrations:

- The camera is calibrated
- The IMU is calibrated
- The motor power is calibrated[16]

There are per unit keys, MAC addresses and serial numbers

- Each processor has its own unique key, used to with the Trust Zone
- The WiFi and Bluetooth have assigned, unique MAC addresses.
- Each Vector has an assigned serial number

10.5. MANUFACTURING TEST CONNECTOR/INTERFACE

It is a common practice to include at least one interface on a product for use during manufacture. This is used to load firmware, unique ids – WiFi MACs, serial number –, to perform any calibration steps and to perform run-up checks that the device functions / is assembled correctly. It is intended to be a fast interface that doesn't cause yield fallout. Typically (but there are exception) this is not radio based, as they can interfere or have fiddly issues.

The USB interface is used to load firmware. The microprocessors include a built in bootloader (ABOOT), which includes support for loading firmware into the devices flash.

For the other functions, there are three possibilities

- There is a UART, that provides a boot console, but does not accept input
- There is a USB connector that probably is used to load firmware.
- The WiFi, once MAC addresses have been loaded into the unit

[16] Todo: look into what this means. Is there a current sense for power? R43 looks like a sense resistor.. is that what it is for?

Bluetooth LE is very unlikely due to the mismatch between its capabilities and the data rates necessary for video used to calibrate the camera.

11. RESOURCES

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https://www.st.com/en/embedded-software/32f0-touch-lib.html
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https://github.com/pyrohaz/STM32F0-SoftTouch

ST Microelectronics. VL531L1 Long distance ranging Time-of-Flight sensor
https://www.st.com/content/ccc/resource/technical/document/application_note/group0/ed/0d/4
https://www.st.com/resource/en/datasheet/vl53l1x.pdf

US Patent 20372659 A1; Nathaniel Monson, Andrew Stein, Daniel Casner, *Reducing Burn-in of Displayed Images*, Anki, 2017 Dec 28

CHAPTER 4

Accessory Electronics design description

This chapter describes the electronic design of the Anki Vector accessories:

- The charging station
- The companion cube

12. CHARGING STATION

The charging station is intended to provide energy to the Vector, allowing it to recharge.

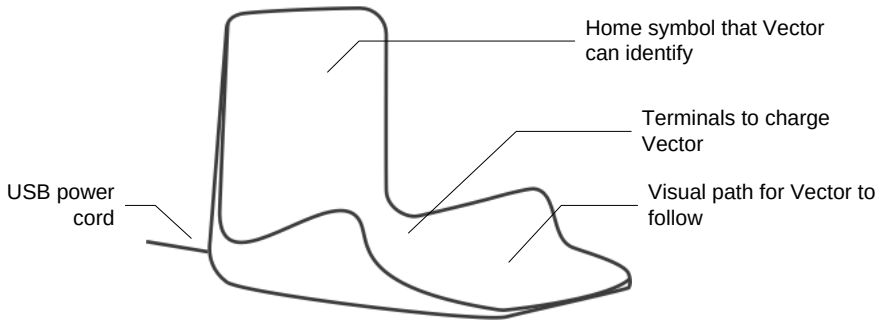

Figure 13: *Charging station main features*

The charging station has a USB cable that plugs into an outlet adapter or battery. The adapter or battery supplies power to the charging station. The base of the station has two terminals to supply +5V (from the power adapter) to Vector, allowing him to recharge. The terminals are offset in such a way to prevent Vector from accidentally being subject to the wrong polarity. Vector has to be backed into charging station in mate with the connectors. Vector face-first, even with his arms lifted, will not contact the terminals.

The charging station has an optical marker used by Vector to identify the charging station and its pose (see chapter TBD).

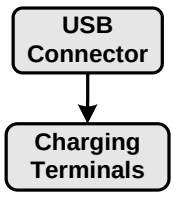

Figure 14: *Charging station block diagram*

13. CUBE

This section describes the companion cube accessory. The companion cube is a small toy for Vector play with. He can fetch it, roll it, and use it to pop-wheelies. Each face of the cube has a unique optical marker used by Vector to identify the cube and its pose (see chapter TBD).

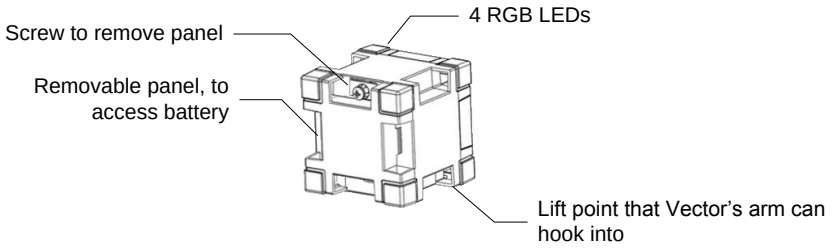

Figure 15: *Cube's main features*

Although the companion cube is powered, this is not used for localization or pose. The electronics are only used to flash lights for his owner, and to detect when a person taps, moves the cube or changes the orientation.

The cube has holes near the corners to allow the lift to engage, allowing Vector to lift the cube. Not all corners have such holes. The top – the side with the multicolour LEDs – does not have these. Vector is able to recognize the cubes orientation by symbols on each face, and to flip the cube so that it can lift it.

The electronics in the cube are conventional for a small Bluetooth LE accessory:

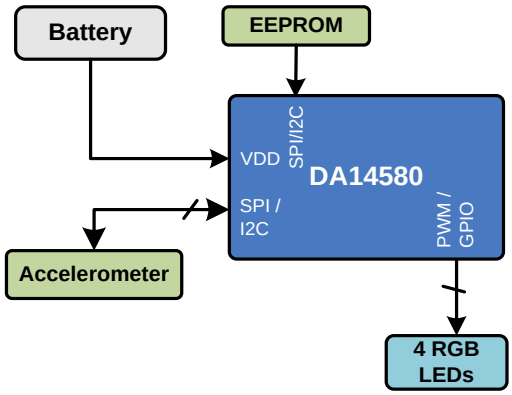

Figure 16: *Block diagram of the Cube's electronics*

The Cube's electronic design includes the following elements:

Element	Description
accelerometer	Used to detect movement and taps of the cube.
battery	The cube is powered by a 1.5 volt N / E90 / LR1 battery cell.[17]
crystal	The crystal provides the accurate frequency reference used by the Bluetooth LE radio.
Dialog DA14580	This is the Bluetooth LE module (transmitter/receiver, as well as microcontroller and protocol implementation).
EEPROM	The EEPROM holds the updatable application firmware.
RGB LEDs	There are 4 RGB LEDs. They can flash and blink. Unlike the backpack LEDs, two LEDs can

Table 6: *The Cube's electronic design elements*

[17] The size is similar to the A23 battery, which will damage the cubes electronics.

have independent colors.

The communication protocol is given in Appendix E.

13.1. OVER THE AIR FIELD UPDATES

The DA14580 has a minimal ROM boot loader that initializes hardware, moves a secondary boot loader from "One Time Programmable" ROM (OTP) into SRAM, before passing control to it. The firmware is executed from SRAM to reduce power consumption. The secondary boot loader loads the application firmware from I2C or SPI EEPROM or flash to SRAM and pass control to it.

If the application passes control back to the boot loader – or there isn't a valid application in EEPROM –a new application can be downloaded. The boot loader uses a different set of services and characteristics to support the boot loading process.

13.2. RESOURCES

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PART II

Basic Operation

This part provides an overview of Vector's software design.

- THE SOFTWARE ARCHITECTURE. A detailed look at Vector's overall software architecture and main modules.
- STARTUP. A detailed look at Vector's startup and shutdown processes
- POWER MANAGEMENT. A detailed look at Vector's startup, shutdown and other power management architecture.
- AUDIO INPUT AND OUTPUT.

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CHAPTER 5

Architecture

This chapter examines Vector's software architecture:

- The architecture
- The emotion-behaviour system
- The communication infrastructure
- Internal support

14. OVERVIEW OF VECTOR'S COMMUNICATION INFRASTRUCTURE

Vector's architecture has a structure something like:

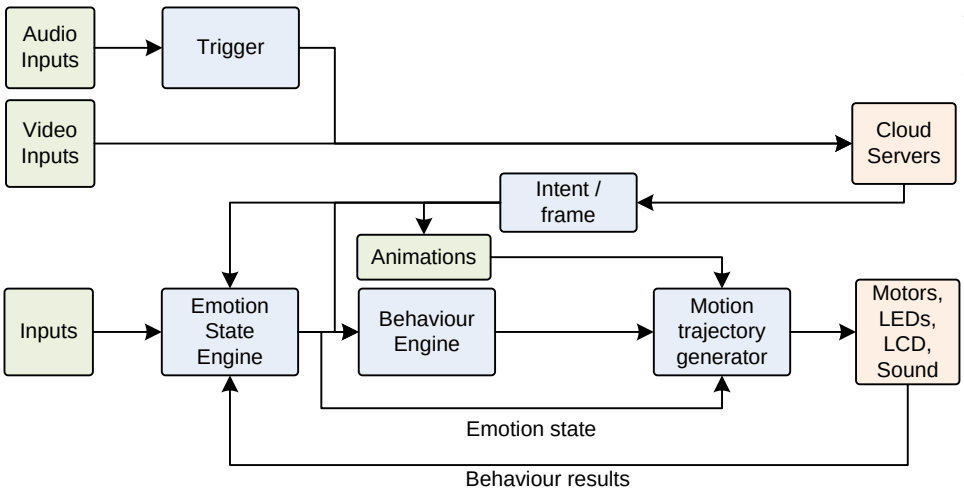

Figure 17: *The overall functional block diagram*

Fast control loops — to respond quickly — are done on the Vector's hardware. Other items, processing heavy including (but not limited to) speech recognition, natural language processing, and training for faces are sent to the cloud.

Vector is built on a version of Yocto Linux. Anki selected this for a balance of reasons: some form of Linux is required to use the Qualcomm processor, the low up front (and royalty) costs, the availability of tools and software modules. The Qualcomm is a multi-processor, with four main processing cores and a GPU. Vector runs a handful of different application programs, in addition to the OS's foundational service tasks and processes.

explored in Casner, *and* Wiltz

14.1. APPLICATION SERVICES ARCHITECTURE

The application is divided into the following services

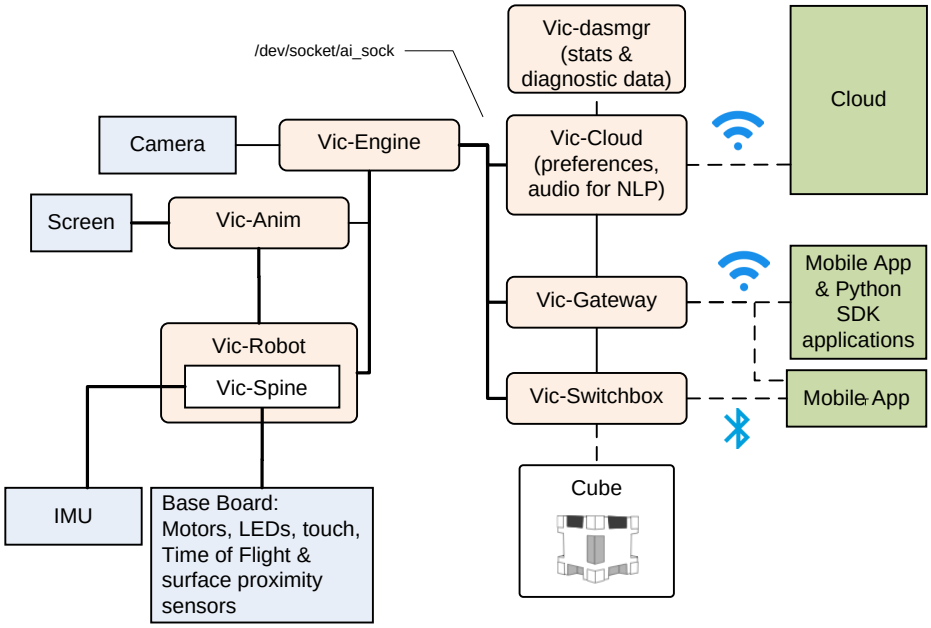

Figure 18: *The overall communication infrastructure*

There are multiple applications that run:

Services	Speculated purpose
vic-anim	Probably plays multi-track animations (which include motions as well as LCD display and sound) config file: `/anki/etc/config/platform_config.json` /anki/data/assets/cozmo_resources/webserver/webServerConfig_anim.json
vic-bootAnim	LCD and sound animations during boot
vic-cloud	Probably connects to the cloud services for natural language
vic-dasmgr	Gathering data on processor and feature usage, possibly intended to serve as a foundation for gathering data when performing experiments on settings and features.
vic-engine	The behaviour / emotion engine. Hooks into the camera face recognizer.
vic-gateway	Responsible for the local API/SDK services available as gRPC services on https.
vic-robot	Basic power management. Resets watchdog timer. Internally has "vic-spine" that manages the sensors.
vic-switchboard	Supports the Bluetooth LE communication interface, including the mobile application protocol (see chapter 9). Routes messages between the other services? Manages the access keys

Table 7: *Vector processes*

15. STORAGE SYSTEM

Vector's system divides the storage into many regions, primarily based on whether the region is modifiable (and when), and which subsystem manages the data. Appendix D describes the flash

partitions and file system structure. See chapter 6 for a description of the partitions used for system start up and restore.

Most of the partitions on the flash storage are not modifiable – and are checked for authenticity (and alteration). These partitions hold the software and assets as delivered by Anki (and Qualcomm) for a particular release of the firmware. They are integrity checked as part of the start procedure. (See Chapter 6 for a description.)

Data that is specific to the robot, such as settings, security information, logs, and user data (such as pictures) are stored in modifiable partitions. Some of this data is erased when the unit is "reset" to factory conditions

These are described below.

15.1. EMR

The EMR partition holds the following information.

- Electronic serial number (ESN). This the same serial number as printed on the bottom of Vector
- Hardware FER (?)
- Model number
- Lot code
- Playpen ready flag
- Playpen passed flag
- Packed out flag
- Packed out date

This information is not modified after manufacture; it persists after a device reset or wipe.

15.2. OEM PARTITION FOR OWNER CERTIFICATES AND LOGS

The OEM partition is a read/writeable ext2 filesystem. It is used to hold the SDK certificate folders:

cloud/${serialNum}empty?

Table 8: *OEM partition file hierarchy*

Folder	Description
	The top level holds the log files.
cloud	Holds the SDK TLS certificate and signing keys
nvStorage	holds some binary ".nvdata" files

The cloud folder has the following times:

File	Description
AnkiRobotDeviceCert.pem	The
AnkiRobotDeviceKeys.pem	The
Info${serialNum}.json	A configuration file that
${serialNum}	empty

Table 9: *OEM cloud folder*

With newer firmware, the folder may also hold some other calibration information.

The Info${serialNum}.json file has the following structure:

Field	Type	Description
CertDigest	base64 string	
CertSignature	base64 string	
CertSignatureAlgorithm	string	The name of openSSL signature algorithm to use, "sha256WithRSAEncryption"
CommonName	string	'vic:' followed by the serial number. (This is also called the "thing id" in other structures.
KeysDigest	base64 string	

Table 10: *Cloud Info${serialNum} structure*

16. SECURITY

Vector's design includes a well thought-out system to protect against disclosing (providing to strangers):

- Photos taken by Vector
- The image stream from the camera
- The audio stream from the microphone — if it had been finished being implemented
- Information about the owner
- Control of the robots movement, speech & sound, display, etc.

Vector's software is protected from being altered in a way that would impair its ability to secure the above.

16.1. ENCRYPTED FILESYSTEM

The file system with the user's data — photos, accounts information, Wi-Fi passwords, and so one — is encrypted.

This is to prevent disclosure of sensitive information about the user and home networks.

16.2. AUTHENTICATION

The web services built into Vector require a token. This is used to prove that you have authenticated (with the more capable — and not physically accessible — servers). This authentication is to protect:

- Photos already on Vector
- The image stream from the camera
- The audio stream from the microphone — if it had finished being implemented
- The sensitive owner information
- Controlling the robot

(That is to say, to prevent disclosure)

17. CONFIGURATION AND ASSET FILES

The Anki vector software is configured by JSON files. Some of the JSON files were probably created by a person (for the trivial ones). Others were created by scripting / development tools; a few of these were edited by developers. These JSON files are clearly intended to be edited by people:

- The files are cleanly spaced, not in the most compact minimized size
- The JSON parser supports comments, which is not valid JSON. Many files have comments in them. Many have sections of the configuration that are commented out.

18. REFERENCES & RESOURCES

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CHAPTER 6

Startup

This chapter is about Vector's power management:

- The startup process
- The shutdown steps

19. STARTUP

Vector's startup is based on the Android boot loader and linux startup.[18] These are otherwise not relevant to Vector, and their documentation is referred to. The boot process gets quite far before knowing why it booted up or being able to response in complex fashion.

1. The backpack button is pressed, or Vector is placed into the charger. This powers the base board, and the head-boards.
2. The base-board displays an animation of the backpack LEDs while turning on. If turned on from a button press, may not fully commit. If the button is released before the LED segments are fully lit, the power will go off. If the held that long, the base-board keeps the battery switch closed.

19.1. QUALCOMM'S PRIMARY AND SECONDARY BOOTLOADER

Meanwhile, on the head-board:

1. "Qualcomm's Primary Boot Loader is verified and loaded into [RAM] memory[19] from BootROM, a non-writable storage on the SoC. [The primary boot loader] is then executed and brings up a nominal amount of hardware," — Nolen Johnson
2. The primary boot loader checks to see if a test point is shorted on the board, the unit will go into emergency download (EDL) mode. It is known the when F_USB pad on the head-board is pulled to Vcc, USB is enabled; this may be the relevant pin. — Roee Hay
3. If the primary boot loader is not in EDL mode it "then verifies the signature of the next boot loader in the chain [the secondary bootloader], loads it, [and] then executes it." The secondary boot loader is stored in the flash partition SBL. — Nolen Johnson
4. If the secondary boot loader does not pass checks, the primary boot loader will go into emergency down load mode.
5. "The next boot loader(s) in the chain are SBL*/XBL (Qualcomm's Secondary/eXtensible Boot Loader). These early boot loaders bring up core hardware like CPU cores, the MMU, etc. They are also responsible for bringing up core processes .. [for] TrustZone. The last

[18] An ideal embedded system has a fast (seemingly instant) turn on. Vector's startup *isn't* fast. The steps to check the data integrity of the large flash storage – including checking the security signatures – and the complex processes that linux provides each contribute to the noticeable slow turn on time. Checking the signatures is inherently slow, by design.
[19] The boot loader is placed into RAM for execution to defeat emulators.

purpose of SBL*/XBL is to verify the signature of, load, and execute aboot/ABL [Android boot loader]."
The Android boot loader (aboot) is stored on the "ABOOT" partition.
The secondary bootloader also supports the Sahara protocol; it is not known how to activate it.

Note: The keys for the boot loaders and TrustZone are generated by Qualcomm, with the public keys programmed into the hardware fuses before delivery to Anki or other customers. The signed key pair for the secondary boot loader is not necessarily the same signed key pair for the ABOOT. They are unique for each of Qualcomm's customer. Being fuses they cannot be modified, even with physical access.

19.2. ANDROID BOOTLOADER (ABOOT)

1. "Aboot brings up most remaining core hardware then in turn normally verifies the signature of the boot image, reports the verity status to Android Verified boot through dm-verity… On many devices, Aboot/ABL can be configured to skip cryptographic signature checks and allow booting any kernel/boot image."

    a. On other devices, aboot reads the DEVINFO partition for a structure. It checks the header of the structure for a magic string ("ANDROID-BOOT!") and then uses the values internally to indicate whether or not the device is unlocked, whether verity-mode enabled or disabled, as well as a few other settings. By writing a version of this structure to the partition, the device can be placed into unlock mode. — Roee Hay

    Vector does *not* support this method of unlocking.

    b. "The build system calculates the SHA256 hash of the raw boot.img and signs the hash with the user's private key… It then concatenates this signed hash value at the end of raw boot.img to generate signed boot.img." — Qualcomm LM80 P0436

    c. "During bootup, [Aboot[20]] strips out the raw boot.img and signed hash attached at the end of the image. [Aboot] calculates the SHA256 hash of the complete raw boot.img and compares it with the hash provided in the boot.img. If both hashes match, kernel image is verified successfully."

2. ABoot can either program the flash with firmware via boot loader mode, or load a kernel. The kernel can be flagged to use a recovery RAM disk or mount a regular system.

3. If recovery mode, it will load the kernel and file systems from the active RECOVERY partitions.

4. ABoot loads the kernel and RAM file system from the active "BOOT" partition and passes it command line to perform a check of the boot and RAM file system the signatures.[21] The command line is stored in the header of the boot partition; it is checked as part of the signature check of the boot partition and RAM file system.

Many of these elements will be revisited in Chapter 18 where updating aboot, boot, and system partitions are discussed.

[20] The Qualcomm document speaks directly about Little Kernel; ABoot is based on Little Kernel.
[21] The check specifies the blocks on the storage to perform a SHA256 check over and provides expected signature result.

19.3. REGULAR SYSTEM BOOT

The boot partition kernel and RAM disk begin an Anki-specific system check:

1. The RAM file system contains two programs: init and /bin/rampost. init is a shell script and the first program launched by the kernel. This script calls rampost to turn on the LCD, its backlight and initiate communication with the base-board. (This occurs ~6.7 seconds after power-on is initiated).
    a. rampost will perform a firmware upgrade of the base-board if its version is out of date. It loads the firmware from syscon.dfu (Note: the firmware in the base-board is referred to as syscon.)
    b. rampost checks the battery voltage, temperature and error flags. It posts any issues to /dev/rampost_error
    c. All messages from rampost are prefixed with "@rampost."
2. Next, init performs a signature check of the system partition to ensure integrity. This is triggered by the command line which includes dm-verity options prefixed with "dm=". If the system does not pass checks, init fails and exits.[22]
    a. Note: none of the files systems in fstab marked for verity checking, so this is the only place where it is performed.
3. The main system filesystem is mounted and launches the main system initialization.

The regular boot uses systemd to allow of the startup steps to be performed in parallel. The rough start up sequence is:

1. Starts the Qualcomm Secure Execution Environment Communicator (dev-qseecom.device) and ION memory allocator (dev-ion.device)
2. The encrypted user file system is checked and mounted (via the mount-data service). This file system is where the all of the logs, people's faces, and other information specific to the individual Vector are stored. The keys to this file system are stored in the TrustZone in the MPU's SOC fuse area. This file system can only be read by the MPU that created it.
3. The MPU's clock rate is limited to 533Mhz, and the RAM is limited to 400MHz to prevent overheating.
4. The camera power is enabled
5. If Vector doesn't have a robot name, Vic-christen is called to give it one.
6. After that several mid-layer communication stacks are started:
    a. usb-service any time after that
    b. the WiFi connection manager (connman)
    c. The time client (chronyd), to retrieve network time. (Vector does not have a clock that keeps time when turned off)
    d. init-debuggerd
7. multi-user, sound, init_post_boot

[22] TBD what happens for recovery?

8. The “Victor Boot Animator” is start (~8 seconds after power on). This is probably the sparks.
9. Victor Boot completes ~20.5 after power on, and the post boot services launches
10. vic-crashloader
11. vic-robot
12. Once the startup has sufficiently brought up enough the next set of animations the sound of boot
13. VicOS is running ~32 seconds after power on. The boot is complete, and Vector is ready to play

19.4. ABNORMAL SYSTEM BOOT

If there is a problem during startup – such as one of the services is unable to successfully start, a fault code associated with that service is stored in `/run/fault code` and the fault code displayed. See chapter 20 for a description of the display of fault codes and diagnostics. See Appendix C for fault codes.

20. SHUTDOWN

- Turning Vector off manually
- Vector turning off spontaneously due to brown-out or significant loss of power
- Vector turning off (under low power) by direction of the head-board

Vector cannot be turned off via Bluetooth LE, or the local gRPC SDK access. There are no exposed commands that do this. Using a verbal command, like “turn off” does not direct Vector to shut off (disconnect the battery). Instead it goes into a quiet mode. Although it may be possible for a Cloud command to turn Vector off, this seems unlikely.

However, there is likely a command to automate the manufacture and preparation for ship process.

20.1. TURNING VECTOR OFF (INTENTIONALLY)

Tracks the reason for shutdown:

***Table 11:** Vector shutdown codes*

Element	Description & Notes
SHUTDOWN_BATTERY_CRITICAL_TEMP	Vector shut down automatically because the battery temperature was too high.
SHUTDOWN_BATTERY_CRITICAL_VOLT	Vector shut down automatically because the battery voltage was too low.
SHUTDOWN_BUTTON	Vector was shut down by a long button press.
SHUTDOWN_GYRO_NOT_CALIBRATING	Vector shut down automatically because of an IMU problem(?)
SHUTDOWN_UNKNOWN	Vector shut down unexpectedly; the reason is not known. Likely a brown-out or battery voltage dipped low faster than Vector could respond to.

It is not clear where the shutdown code is stored

20.2. UNINTENTIONALLY

The base-board is responsible for keeping the battery connected. However brownouts, self-protects when the voltage get to too low, and bugs can cause the battery to be disconnected.

20.3. GOING INTO AN OFF STATE

When Vector wants to intentionally turn off, it cleans up its state, to gracefully shutdown the linux system and tells the base-board to disconnect the battery.

21. REFERENCES & RESOURCES

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Part 3: Memory-based Attacks & PBL Extraction
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Part 4: Runtime Debugger
https://alephsecurity.com/2018/01/22/qualcomm-edl-4/
Part 5: Breaking Nokia 6's Secure Boot
https://alephsecurity.com/2018/01/22/qualcomm-edl-5/

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lm80-p0436-1_little_kernel_boot_loader_overview.pdf

https://github.com/ alephsecurity
A set repositories researching tools to discover commands in Sahara and EDL protocols

https://github.com/openpst
A set of repositories researching and implementing an interface to the Sahara protocol.

CHAPTER 7

Power management

This chapter is about Vector's power management:

- The battery management
- Charger info

Vector, in the advertising material, aspires to be on all the time. In practice, he will be turned on to play with, turned off when done playing – or when his battery runs low, or before being shipped.

22. POWER MANAGEMENT

22.1. BATTERY MANAGEMENT

There isn't a coulomb counter to track the remaining energy in the battery. At the broadest strokes, the battery voltage is used to predict the battery state of charge.

22.1.1 Battery levels

Vector maps the battery voltage into a battery level, taking into account whether or not the charger is active:

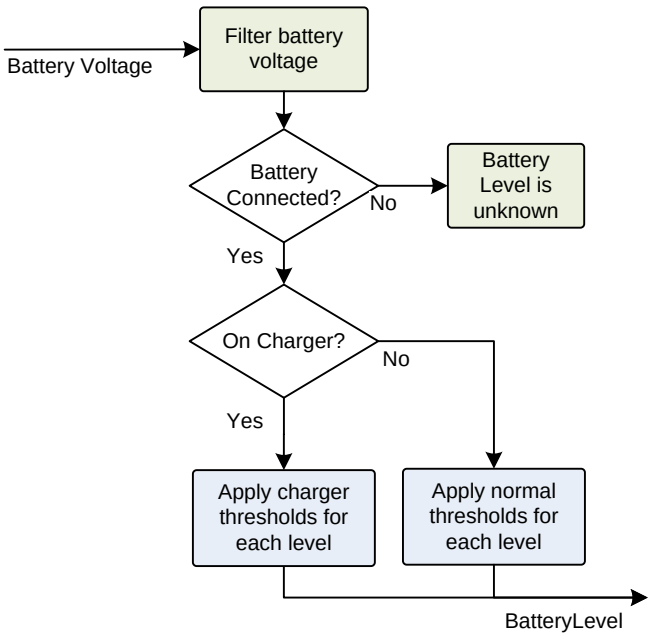

Figure 19: *The battery level classification tree*

Note: The battery voltage is filtered because the voltage will bounce around with activity by the motors, driving the speaker and processors.

The BatteryLevel enumeration is used to categorize the condition of the Cube and Vector batteries:

Element	Description & Notes
BATTERY_LEVEL_FULL	Vector's battery is at least 4.1V
BATTERY_LEVEL_LOW	Vector's battery is 3.6V or less; or if Vector is on the charger, the battery voltage is 4V or less.
BATTERY_LEVEL_NOMINAL	Vector's battery level is between low and full.
BATTERY_LEVEL_UNKNOWN	If the battery is not connected, Vector can't measure its battery. This enumeration is (probably) reserved for the case where the Cube is not in contact, thus its battery level is not known

Table 12: *BatteryLevel codes[23] as they apply to Vector*

The battery levels are organized conventionally:

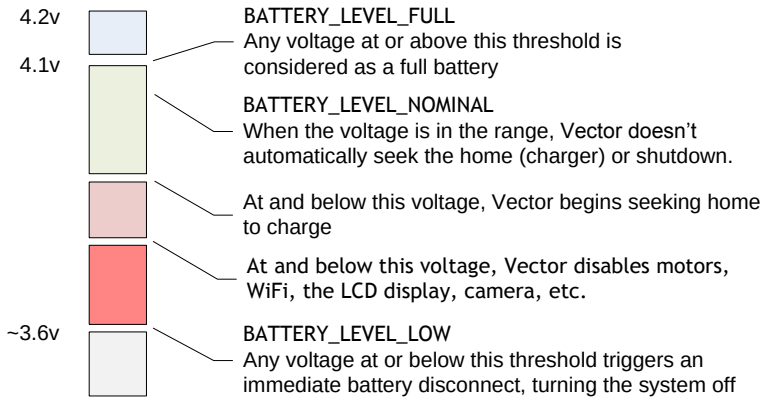

Figure 20: *The battery thresholds*

22.1.2 Battery Statistics

The battery management collects a set of battery related statistics and state information, with named key-value pairs.

Element	Description & Notes
battery.battery_level_changed	This is set when the battery level has changed from event posting.
battery.cooldown	Indicates that Vector is or needed to pause charging and activity to let the battery cool down.
battery.encoder_power_stats	?? Strange name. Is this the voltage seen on the charger input and charging duration stats?
battery.fully_charged_voltage	The battery voltage seen when the charger reported the battery to be fully charged.
battery.is_charging_changed	This is set when the state of charging has changed from event posting.
battery.on_charger_changed	

Table 13: *Battery statistics, possibly posted to DAS*

[23] The levels are from robot.py

battery.saturation_charging	
battery.temp_crossed_threshold	
battery.temperature_stats	Information about the range of battery temperatures that have been observed; e.g. min/max, average, etc.
battery.voltage_reset	
battery.voltage_stats	Information about the range of battery voltages that have been observed; e.g. min/max, average, etc.

{commentary: Are these posted to DAS?}

22.2. RESPONSES, SHEDDING LOAD / POWER SAVING EFFORTS

Vector's main (power-related) activity modes are:

- active, interacting with others
- calm, where primarily sitting still, waiting for assistance or stimulation
- sleeping

Depending on the state of the battery – and charging – Vector may engage in behaviours that override others.

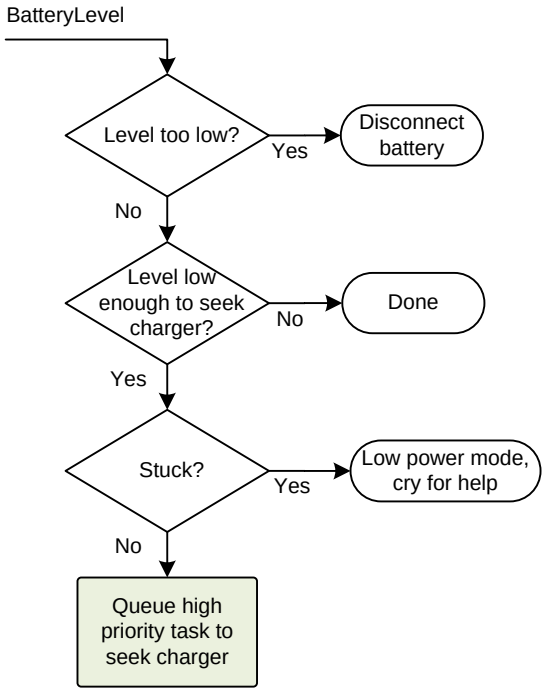

Figure 21: *The response to battery level*

If Vector is unable to dock (or even locate a dock) he sheds load as he goes into a lower state:

- He no longer responds to his trigger word or communicates with WiFi servers
- He turns off camera and LCD; presumable the time of flight sensor as well.
- He reduces processing on the processor

CHAPTER 8

Audio

This chapter is about the sound input and output system:

- The audio input
- The audio filtering, and triggering of the speech recognition
- The audio output
- Text to speech

23. AUDIO INPUT

The audio input is used to both give Vector verbal interaction, and to give him environmental stimulation:

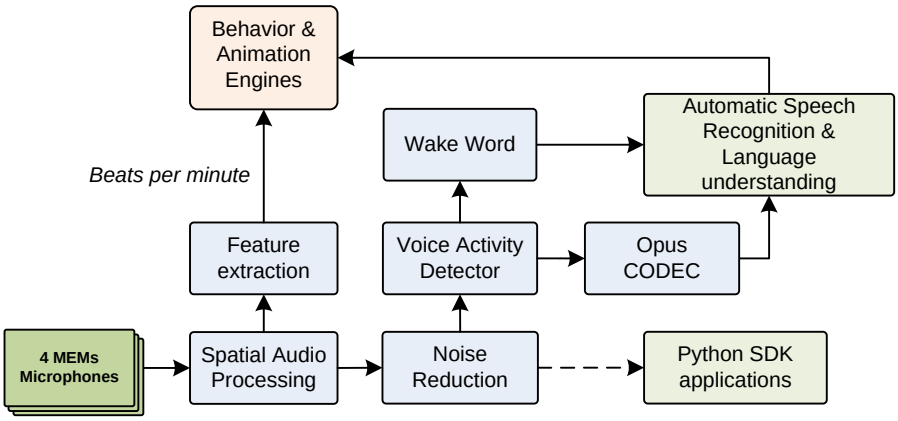

Figure 22: *The audio input functional block diagram*

- Spatial audio processing localizes the sound of someone talking from the background music.
- The feature extraction detects the tempo of the music. If the tempo is right, Vector will dance to it. It also provides basic stimulation to Vector.
- Noise reduction makes for the best sound.
- Voice activity detector usually triggered off of the signal before the beam-forming.
- A wake word is used to engage the automatic speech recognition system.
- The speech recognition system is on a remote server. The audio sent to the automatic speech recognition system is compressed to reduce data usage.

The responsibility for these functions is divided across multiple processes and boards in Vector:

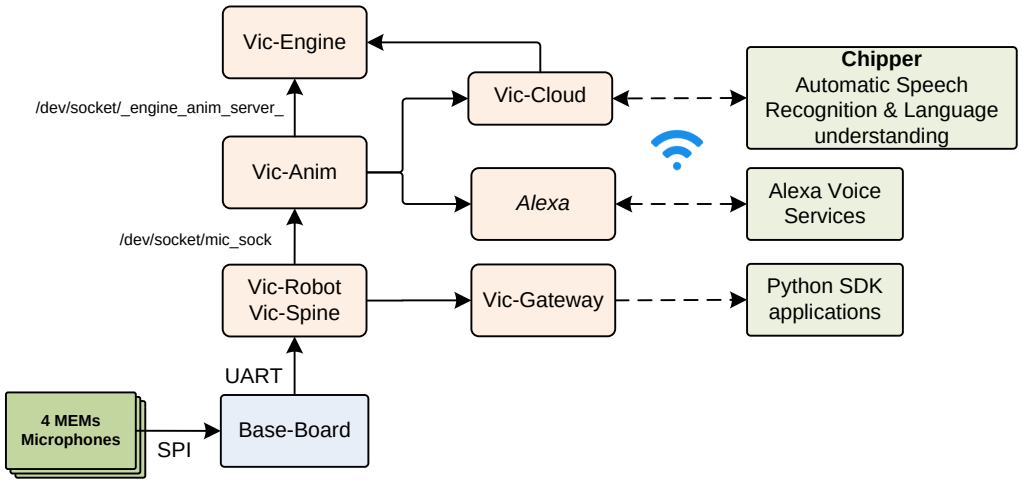

Figure 23: *The audio input architecture*

Note: providing the audio input to the SDK (via Vic-gateway) was never completed. It will be discussed based on what was laid out in the protobufs specification files.

The audio processing blocks, except where otherwise discussed, are part of Vic-Anim. These blocks were implemented by Signal Essence, LLC. They probably consulted on the MEMs microphones and their configuration. The Qualcomm family includes software support for these tasks, as part of the Hexagon DSP SDK; it is not known how much of this Signal Essence took advantage off.

23.1. THE MICROPHONES

The microphone array is 4 MEMs microphones that sample the incoming sound and transfer the samples to base-board. The audio is sampled by the base-board at 15,625 samples/sec. The audio is transferred to the Vic-spine module (part of Vic-robot) in regular communication with the head-board. The audio samples are extracted and forward to the Vic-Anim process.

The audio samples, once received, are processed at 16,000 samples/sec. ("As a result, the pitch is altered by 2.4%.") The signal processing is done in chunks of 160 samples.

Note: The Customer Care Information Screen (CCIS) shows the microphones to be about 1024 when quiet. If this is center, the max would be 2048… or 11 bit. Probably is 12 bit.

23.2. SPATIAL AUDIO PROCESSING

The spatial audio processing is uses multiple microphones to pick-out the wanted signal and cancel out the unwanted. Note: The spatial audio processing is bypassed until voice activity has been detected.

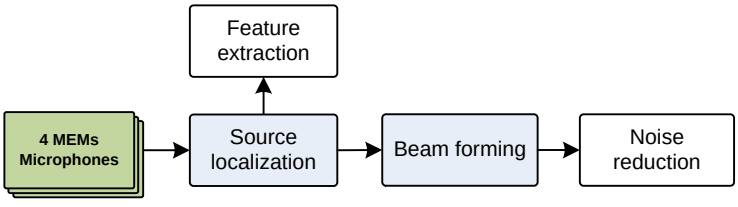

Figure 24: *Typical spatial audio processing*

THE SOURCE LOCALIZATION estimates direction of arrival of the person talking.

BEAM-FORMING combines the multiple microphone inputs to cancels audio coming from other directions.

The output of this stage includes:

- A histogram of the directions that the sound(s) in this chunk of audio came from. There are 12 bins, each representing a 30° direction.
- The direction that is picked for the origin of the sound of interest
- A confidence value for that direction
- A measure of the background noise

23.3. NOISE REDUCTION

Noise reduction identifies and eliminates noise and echo in the audio input

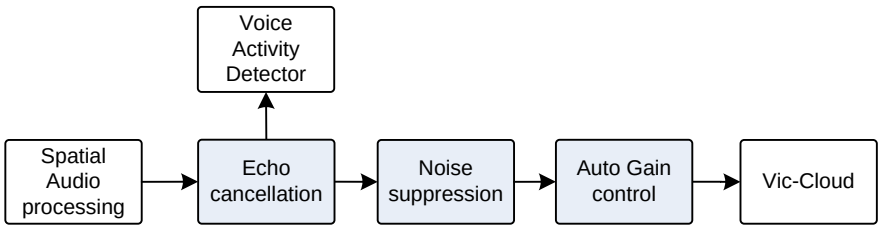

Figure 25: *Typical audio noise reduction*

ACOUSTIC ECHO CANCELLATION cancels slightly delayed repetitions of a signal.

NOISE SUPPRESSION is used to eliminate noise.

The combination of spatial processing and noise reduction gives the cleanest sound (as compared with no noise reduction and/or no spatial processing).

23.4. VOICE ACTIVITY DETECTOR AND WAKE WORD

The voice activity detector is given cleaned up sound from multiple microphones without beam-forming. When it detects voice activity, then the spatial audio processing is fully enabled.[24]

The voice activity detector and the wake word are used so that downstream processing – the search for the wake word, and the automatic speech recognition system – are not engaged all the time. They are both expensive (in terms of power and data usage), and the speech recognition is prone to misunderstanding.

When the voice activity detector triggers – indicating that a person may be talking – the spatial audio processing is engaged (to improve the audio quality) and the audio signals are passed to the Wake Word Detector.

The detector for the "Hey, Vector" is provided by Sensory, Inc. Pryon, Inc provided the detector for "Alexa."[25] The recognition is locale dependent, detecting different wake words for German, etc. It may be possible to create other recognition files for other wake words.

[24] Vector's wake word detection, and speech recognition is pretty hit and miss. Signal Essence's demonstration videos show much better performance. The differences are they used more microphones and the spatial audio filtering in their demos.
[25] This appears to be standard for Alexa device SDKs.

When the “Hey, Vector” wake word is heard,

1. A connection (via Vic-Cloud) is made to the remote speech processing server for automatic speech recognition.
2. A “WakeWordBegin” event message is posted to Vic-Engine and Vic-Gateway. Vic-Gateway may forward the message on to a connected application.

23.5. CLOUD SPEECH RECOGNITION

The audio snippets are sent to a remote server known as “chipper” for processing.

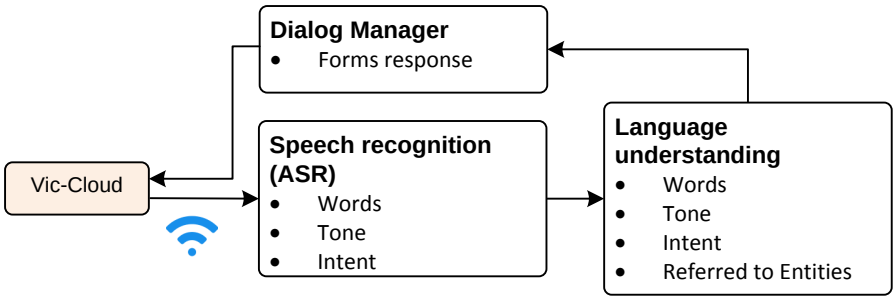

Figure 26: *The speech recognition*

Chipper does speech recognition, and some language understanding. What the user says is mapped to an “user intent” – this may be a command, or a question to be answered. The intent also includes some supporting information – the colour to set the eyes to, for instance. Many of the phrase patterns and the intent they map to can be found in Appendix H. The intent may be further handled by Anki servers; an intent is eventually sent back to Vector.

When the response comes sends a “WakeWordEnd” event message is posted to Vic-Engine and Vic-Gateway. Vic-Gateway may forward the message on to a connected application. This message includes the intent JSON data structure (if any).

23.6. CONNECTIONS WITH VIC-GATEWAY

It is clear that Anki made provisions to connect the audio stream to Vic-Gateway (and potentially Vic-Cloud) but were unable to complete the features before they ceased operation.

The SDK would have been able to

- Enabled and disabled listening to the microphone(s)
- Select whether the audio would have the spatial audio filter and noise reduction processing done on it.
- Include the direction of sound information from the spatial audio processing (see section *23.2 Spatial audio processing*)
- 1600 audio samples; Note: this is 10x the chunk size of the internal processing size

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PART III

Communication

This part provides details of Vector's communication protocols. These chapters describe structure communication, the information that is exchange, its encoding, and the sequences needed to accomplish tasks. Other chapters will delve into the functional design that the communication provides interface to.

- COMMUNICATION. A look at the communication stack in Vector.
- BLUETOOTH LE. The Bluetooth LE protocol that Vector responds to.
- SDK PROTOCOL. The HTTPS protocol that Vector responds to.
- CLOUD. A look at how Vector interacts with remote services

drawing by Jesse Easley

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CHAPTER 9

Communication

This chapter is about the communication system:

- Internal communication with the base-board, and internal peripherals
- Bluetooth LE: with the Cube, and with the application
- WiFi: with the cloud, and with the application
- Internal support

24. OVERVIEW OF VECTOR'S COMMUNICATION INFRASTRUCTURE

A significant part of Vector's software is focused on communication.

- Internal IPC between processes
- Communication with local peripherals and the base-board processor
- Communication with external accessories and applications.

The communication stacks:

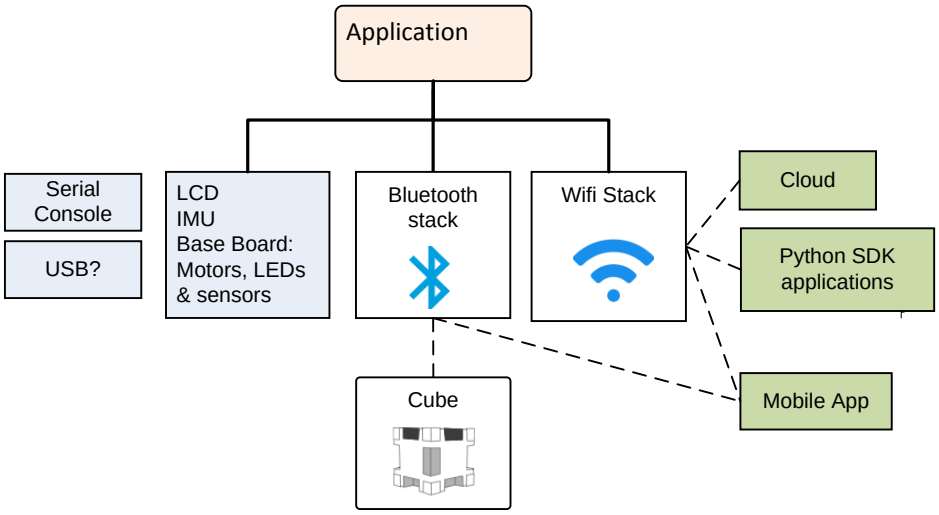


Figure 27: *The overall communication infrastructure*

25. INTERNAL COMMUNICATION WITH PERIPHERALS

Communication stack within the software. One part Linux, one part Qualcomm, and a big heaping dose of Anki's stuff.

25.1. COMMUNICATION WITH THE BASE-BOARD

The head board communicates with the base board using a serial interface. The device file is `/dev/ttyHS0`.

Data rate: 3 Mbits/sec[26]

25.1.1 Messages from the base-board to the head board

The base-board sends packets at regular intervals to the head-board. The frame of the message in

> [Unknown byte] AA_{16} 'B' '2' 'H' [16-bit packet type] [16-bit payload size] [payload bytes] [32-bit CRC]

(All multi-byte values are in little endian order.) The maximum packet size is 1280 bytes.

The packet type implies both the size of the payload, and the contents. If the packet type is not recognized, or the implied size does not match the passed payload size, the packet is considered in error.) The table below gives the different type codes:

Table 14: *JSON structure*

Packet type	Payload Size	Description
6473_{16}	0	
$6b61_{16}$	4	
6466_{16}	768	The size of the message suggests that it holds 120 samples from one or two microphones (2 microphones × 2bytes/sample × 120 samples/microphone == 960 bytes) for the voice activity detection audio processing.
6662_{16}	4	
6675_{16}	1028	The size of the message suggests that it holds 120 samples from the microphones (4 microphones × 2bytes/sample × 120 samples/microphone == 960 bytes) for the spatial audio processing.
$736c_{16}$	16	
$6d64_{16}$	0	
7276_{16}	40	
7374_{16}	0	
7878_{16}	0	

The payload can contain (depending on the type of packet):

- The state of the backpack button
- The touch sensor voltage
- The microphone signals for all 4 microphones. (Most likely as 16 bits)
- The battery voltage
- State of the charger (on dock/etc)
- The temperature of the battery or charger
- The state of 4 motor encoders, possibly as encoder counters, possibly as IO state
- The time of flight reading, probably 16bits in mm

[26] Value from analysis of the RAMPOST program.

- The voltage (or other signal) of each of the 4 cliff proximity sensors

The messages are sent fast enough to support microphone sample rate of 15625 samples/second.

25.1.2 Messages from the head-board to the base-board

The messages from the head board to the base-board have the content:

- The 4 LED RGB states
- Controls for the motors: possible direction and enable; direction and duty cycle; or a target position and speed.
- Power control information: disable power to the system, turn off distance, cliff sensors, etc.

The messages are sent fast enough to support microphone sample rate of 15625 samples/second.

The head-board can update the firmware in the base-board, by putting into DFU (device firmware upgrade) mode and downloading the replacement firmware image.

25.2. SERIAL BOOT CONSOLE

The head-board includes a 115200, 8 data bits no parity, 1 stop bit; the device file is `/dev/ttyHSL0`. Only prints the boot console. (This is passed in the commanded line by the bootloader)

25.3. USB

There are pins for USB on the head board. Asserting "F_USB" pad to VCC enables the port. During power-on, and initial boot it is a Qualcomm QDL port. The USB supports a Qualcomm debugging driver (QDL), but the readout is locked. It appears to be intended to inject firmware during manufacture.

The `/etc/initscriptsusb` file enables the USB and the usual functionfs adb. It lives in `/sbin/usr/composition/9091` (I think, if I understand the part number matching correctly). This launches ADB (DIAG + MODEM + QMI_RMNET + ADB)

Melanie T reports this not working, not enabled.

Vectors log shows the USB being disabled 24 seconds after linux starts.

26. BLUETOOTH LE

Bluetooth LE is used for two purposes:

1. Bluetooth LE is used to initially configure Vector, to reconfigure him when the Wifi changes; to allow him to interact with the cube. Potentially allows some diagnostic and customization.
2. Bluetooth LE is used to communicate with the companion Cube accessory: to detect its movement, taps, and to set the state of its LEDs.

Vector's Bluetooth LE stack looks like:

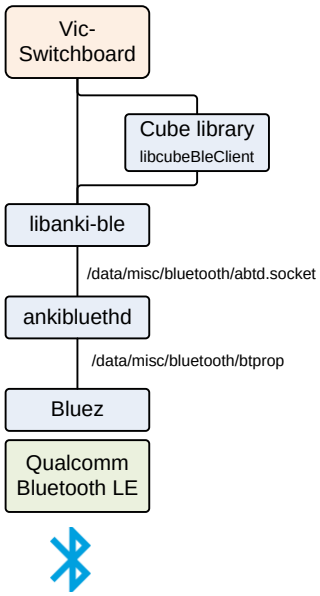


Figure 28: *The Bluetooth LE stack*

The elements of the Bluetooth LE stack include:

Element	Description & Notes
ankibluetoothd	A server daemon. The application layer communicates with it over a socket; `/data/misc/bluetooth/abtd.socket`
BlueZ	Linux's official Bluetooth stack, including Bluetooth LE support. The Anki Bluetooth daemon interacts with it over a socket: `/data/misc/bluetooth/btprop`
bccmd	A Bluetooth core command
btmon	A command-line Bluetooth tool
libanki-ble.so	Communicates with Anki Bluetooth daemon probably serves both the external mobile application interface and communication with the companion cube.
libcubeBleClient.so[27]	A library to communicate with the companion cube, play animations on its LEDs, detect taps and the orientation of the cube.
viccubetool	Probably used to update the firmware in the Cube.

Table 15: *Elements of the Bluetooth LE stack*

27. COMMUNICATING WITH MOBILE APP AND SDK

Vector's *robot name* is something that looks like "Vector-E5S6". This name is used consistently; it will be Vector's:

- advertised Bluetooth LE peripheral name (although spaces are used instead of dashes)
- mDNS network name (dashes are used instead of spaces),
- the name used to sign certificates, and

[27] The library includes a great deal of built in knowledge of the state of application ("game engine"), animations, and other elements

- it will be the name of his WiFi Access Point, when placed into Access Point mode

27.1. CERTIFICATE BASED AUTHENTICATION

A *session token* is always provided by Anki servers.[28] It is passed to Vector to authenticate with him and create a client token. The session token is passed to Vector via the Bluetooth LE RTS protocol or the HTTPS-based SDK protocol; Vector will return a client token. The session token is single use only.

A *client token* is passed to Vector in each of the HTTPS-based SDK commands, and in the Bluetooth LE SDK Proxy commands. It is generated in one of two ways. One method is by the Bluetooth LE command (cloud session); the other is by posting "/v1/user_authentication" SDK request. The client token should be saved indefinitely for future use. It is not clear if the client token can be shared between the two transport mechanisms.

A *certificate* is also generated by Vector in the case of the SDK request. The certificate is intended to be added to the trusted SSL certificates before an HTTPS communication session. The certificate issued by Vector is good for 100 years.

The typical information embedded in a Vector certificate:

Table 16: *Elements of a Vector certificate*

Element	Value
Common Name	*Vector's robot name*
Subject Alternative Names	*Vector's robot name*
Organization	Anki
Locality	SF
State	California
Country	US
Valid From	*the date the certificate was created*
Valid To	*100 years after the date the certificate was created*
Issuer	*Vector's robot name*, Anki
Serial Number	

[28] https://groups.google.com/forum/#!msg/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ
https://groups.google.com/forum/#!msg/anki-vector-rooting/XAaBE6e94ek/OdES50PaBQAJ

CHAPTER 10

Bluetooth LE Communication Protocol

This chapter describes Vector's Bluetooth LE communication protocol.

- The kinds of activities that can be done thru communication channels
- The interaction sequences
- The communication protocol stack, including encryption, fragmentation and reassembly.

Note: communication with the Cube is simple reading and writing a characteristic, and covered in Appendix E.

28. COMMUNICATION PROTOCOL OVERVIEW

Vector advertises services on Bluetooth LE, with the Bluetooth LE peripheral name the same as his robot name (i.e. something that looks like "Vector-E5S6".)

Communication with Vector, once established, is structure as a request-response protocol. The request and responses are referred to as "C-Like Abstract Data structures" (CLAD) which are fields and values in a defined format, and interpretation. Several of these messages are used to maintain the link, setting up an encryption over the channel.

The application layer messages may be arbitrarily large. To support Bluetooth LE 4.1 (the version in Vector, and many mobile devices) the CLAD message must be broken up into small chunks to be sent, and then reassembled on receipt.

Combined with application-level encryption, the communication stack looks like:

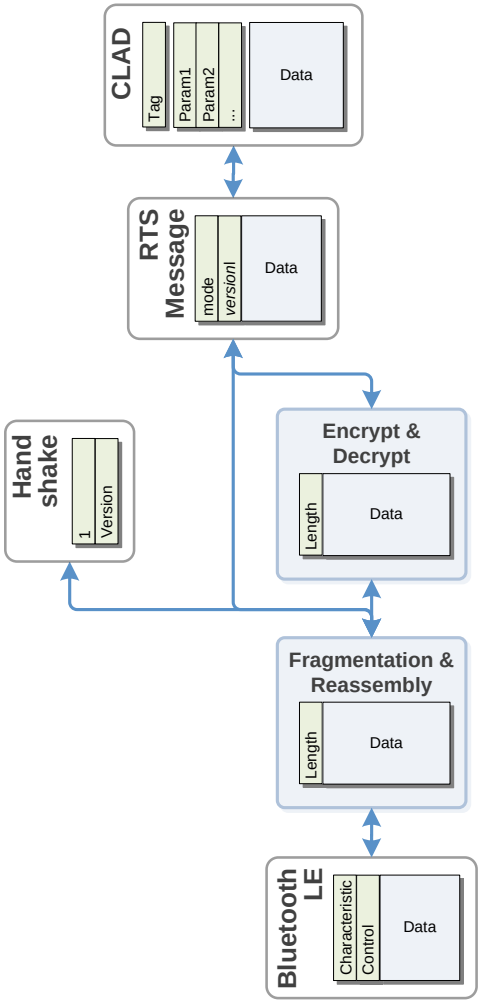


Figure 29: *Overview of encryption and fragmentation stack*

THE BLUETOOTH LE is the link/transport media. It handles the delivery, and low-level error detection of exchanging message frames. The frames are fragments of the overall message. The GUID's for the services and characteristics can be found in Appendix E.

THE FRAGMENTATION & REASSEMBLY is responsible for breaking up a message into multiple frames and reassembling them into a message.

THE ENCRYPTION & DECRYPTION LAYER is used to encrypt and decrypt the messages, after the communication channel has been set up.

THE RTS is extra framing information that identifies the kind of CLAD message, and the version of its format. The format changed with version, so this version code is embedded at this layer.

THE C-LIKE ABSTRACT DATA (CLAD) is the layer that decodes the messages into values for fields, and interprets them,

28.1. SETTING UP THE COMMUNICATION CHANNEL

It sometimes helps to start with the overall process. This section will walk thru the process, referring to later sections where detailed information resides.

If you use "first time" – or wish to re-pair with him – put him on the charger and press the backpack button twice quickly. He'll display a screen indicating he is getting ready to pair.

If you have already paired the application with Vector, the encryption keys can be reused.

The process to set up a Bluetooth LE communication with Vector is complex. The sequence has many steps:

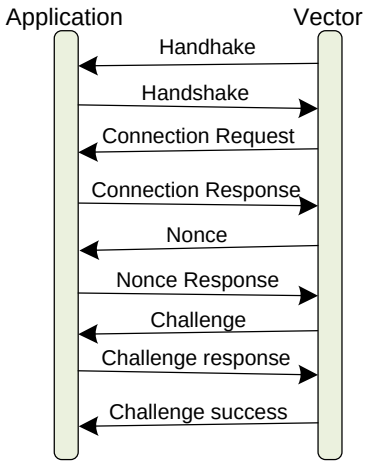


Figure 30: *Sequence for initiating communication with Vector*

1. The application opens Bluetooth LE connection (retrieving the service and characteristics handles) and subscribes to the "read" characteristic (see Appendix E for the UUID).
2. Vector sends *handshake* message; which the application receives. The handshake message structure is given below. The handshake message includes the version of the protocol supported.

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*type*	?
1	4	uint32_t	*version*	The version of the protocol/messages to employ

Table 17: *Parameters for Handshake message*

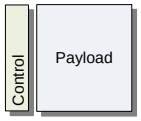
3. The application sends the handshake back
4. Then the Vector will send a *connection request*, consisting of the public key to use for the session. The application's response depends on whether this is a first-time pairing, or a reuse.
    a. First time pairing requires that Vector have already been placed into pairing mode prior to connecting to Vector. The application keys should be created (see section *28.3.1 First time pairing* above).
    b. Reconnection can reuse the public and secret keys, and the encryption and decryption keys from a prior pairing
5. The application should then send the publicKey in the response

6. If this is a first-time pairing, Vector will display a *pin code*. This is used to create the public and secret keys, and the encryption and decryption keys (see section *28.3.1 First time pairing* above). These can be saved for use in future reconnection.
7. Vector will send a *nonce* message. After the application has sent its response, the channel will now be encrypted.
8. Vector will send a *challenge* message. The application should increment the passed value and send it back as a challenge message.
9. Vector will send a *challenge success* message.
10. The application can now send other commands

If the user puts Vector on the charger, and double clicks the backpack button, Vector will usually send a *disconnect* request.

28.2. FRAGMENTATION AND REASSEMBLY

An individual frame sent over Bluetooth LE is limited to 20 bytes. (This preserves compatibility with Bluetooth LE 4.1) A frame looks like:



The control byte is used to tell the receiver how to *reassemble* the message using this frame.

- If the MSB bit (bit 7) is set, this is the start of a new message. The previous message should be discarded.
- If the 2nd MSB (bit 6) is set, this is the end of the message; there are no more frames.
- The 6 LSB bits (bits 0..5) are the number of payload bytes in the frame to use.

The receiver would append the payload onto the end of the message buffer. If there are no more frames to be received it will pass the buffer (and size count) on to the next stage. If encryption has been set up, the message buffer will be decrypted and then passed to the RTS and CLAD. If encryption has not been set up, it is passed directly to the RTS & CLAD.

Fragmenting reverses the process:

1. Set the MSB bit of the control byte, since this is the start of a message.
2. Copy up to 19 bytes to the payload.
3. Set the number of bytes in the 6 LSB bits of the control byte
4. If there are no more bytes remaining, set the 2nd MSB it of the control byte.
5. Send the frame to Vector
6. If there are bytes remaining, repeat from step 2.

28.3. ENCRYPTION SUPPORT

For the security layer, you will need the following:

```
uint8_t Vectors_publicKey[32];
uint8_t publicKey [crypto_kx_PUBLICKEYBYTES];
uint8_t secretKey [crypto_kx_SECRETKEYBYTES];
uint8_t encryptionKey[crypto_kx_SESSIONKEYBYTES];
uint8_t decryptionKey[crypto_kx_SESSIONKEYBYTES];
uint8_t encryptionNonce[24];
uint8_t decryptionNonce[24];
uint8_t pinCode[16];
```

Example 1: *Bluetooth LE encryption structures*

The variables mean:

Variable	Description
decryptionKey	The key used to decrypt each message from to Vector.
decryptionNonce	An extra bit that is added to each message. The initial nonce's to use are provided by Vector.
encryptionKey	The key used to encrypt each message sent to Vector.
encryptionNonce	An extra bit that is added to each message as it is encrypted. The initial nonce's to use are provided by Vector.
pinCode	6 digits that are displayed by Vector during an initial pairing.
Vectors_publicKey	The public key provided by Vector, used to create the encryption and decryption keys.

Table 18: *The encryption variables*

There are two different paths to setting up the encryption keys:

- First time pairing, and
- Reconnection

28.3.1 First time pairing

First time pairing requires that Vector be placed into pairing mode prior to the start of communication. This is done by placing Vector on the charger, and quickly double clicking the backpack button.

The application should generate its own internal *public* and *secret keys* at start.

```
crypto_kx_keypair(publicKey, secretKey);
```

Example 2: *Bluetooth LE key pair*

The application will send a *connection response* with first-time-pairing set, and the public key. After Vector receives the connection response, he will display the *pin code*. (See the steps in the next section for when this will occur.)

The session *encryption* and *decryption keys* can then created:

```
crypto_kx_client_session_keys(decryptionKey, encryptionKey, publicKey, secretKey,
      Vector_publicKey);
size_t pin_length = strlen(pin);

crypto_generichash(encryptionKey, sizeof(encryptionKey), encryptionKey,
      sizeof(encryptionKey), pin, pin_length);
crypto_generichash(decryptionKey, sizeof(decryptionKey), decryptionKey,
      sizeof(decryptionKey), pin, pin_length);
```

Example 3: *Bluetooth LE encryption & decryption keys*

28.3.2 Reconnecting

Reconnecting can reused the public and secret keys, and the encryption and decryption keys. It is not known how long these persist on Vector. {Next pairing? Next reboot? Indefinitely?}

28.3.3 Encrypting and decryption messages

Vector will send a *nonce* message with the *encryption* and *decryption nonces* to employ in encrypting and decrypting message.

Each received enciphered message can be decrypted from cipher text (cipher, and cipherLen) to the message buffer (message and messageLen) for further processing:

```
crypto_aead_xchacha20poly1305_ietf_decrypt(message, &messageLen, NULL, cipher,
      cipherLen,  NULL, 0L, decryptionNonce, decryptionKey);
sodium_increment(decryptionNonce, sizeof decryptionNonce);
```

Example 4: *Decrypting a Bluetooth LE message*

Note: the decryptionNonce is incremented each time a message is decrypted.

Each message to be sent can be encrypted from message buffer (message and messageLen) into cipher text (cipher, and cipherLen) that can be fragmented and sent:

```
crypto_aead_xchacha20poly1305_ietf_encrypt(cipher, &cipherLen, message,
      messageLen, NULL, 0L, NULL, encryptionNonce, encryptionKey);
sodium_increment(encryptionNonce, sizeof encryptionNonce);
```

Example 5: *Encrypting a Bluetooth LE message*

Note: the encryptionNonce is incremented each time a message is encrypted.

28.4. THE RTS LAYER

There is an extra, pragmatic layer before the messages can be interpreted by the application. The message has two to three bytes at the header:

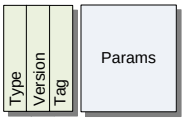


Figure 31: *The format of an RTS frame*

- The type byte is either 1 or 4. If it is 1 the version of the message format is 1.
- If type byte is 4, the version is held in the next byte. (If the type is 1, there is no version byte).
- The next byte is the tag – the value used to interpret the message.

The tag, parameter body, and version are passed to the CLAD layer for interpretation. This is described in the next section.

28.5. FETCHING A LOG

The process to set up a Bluetooth LE communication with Vector is complex. The sequence has many steps:

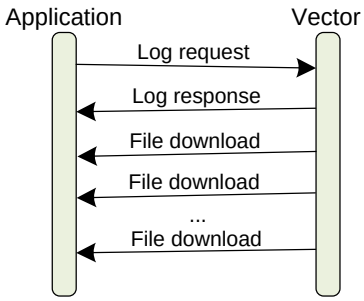


Figure 32: *Sequence for initiating communication with Vector*

The log request is sent to Vector. In principal this includes a list of the kinds of logs (called filter names) to be included. In practice, the "filter name" makes no difference.

Vector response, and if there will be a file sent, includes an affirmative and a 32-bit file identifier used for the file transfer.

Vector zips the log files up (as a tar.bz2 compressed archive) and sends the chunks to the application. Each chunk has this file identifier. (Conceptually there could be several files in transfer at a time.)

The file transfer is complete when the packet number matches the packet total.

29. MESSAGE FORMATS

This section describes the format and interpretation of the CLAD messages that go between the App and Vector. It describes the fields and how they are encoded, etc. Fields that do not have a fixed location, have no value for their offset. Some fields are only present in later versions of the protocol. They are marked with the version that they are present.

Except where otherwise stated:

- Requests are from the mobile application to Vector, and responses are Vector to the application
- All values in little endian order

Table 19: *Summary of the commands*

	Request	Response	Min Version
Application connection id	$1F_{16}$	20_{16}	4
Cancel pairing	10_{16}		0
Challenge	04_{16}	04_{16}	0
Challenge success	05_{16}		0
Connect	01_{16}	02_{16}	0
Cloud session	$1D_{16}$	$1E_{16}$	3
Disconnect	11_{16}		0
File download		$1a_{16}$	2
Log	18_{16}	19_{16}	2
Nonce	03_{16}	12_{16}	
OTA cancel	17_{16}		2
OTA update	$0E_{16}$	$0F_{16}$	0
SDK proxy	22_{16}	23_{16}	5
Response		21_{16}	4
SSH	15_{16}	16_{16}	0
Status	$0A_{16}$	$0B_{16}$	0
WiFi access point	13_{16}	14_{16}	0
WiFi connect	06_{16}	07_{16}	0
WiFi forget	$1B_{16}$	$1C_{16}$	3
WiFi IP	08_{16}	09_{16}	0
WiFi scan	$0C_{16}$	$0D_{16}$	0

29.1. APPLICATION CONNECTION ID

?

29.1.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*name length*	The length of the application connection id; may be 0
2	*varies*	uint8_t[name length]	*name*	The application connection id

Table 20: *Parameters for Application Connection Id request*

29.1.2 Response

There is no response.

29.2. CANCEL PAIRING

Speculation: this is sent by the application to cancel the pairing process

29.2.1 Request

The command has no parameters.

29.2.2 Response

There is no response.

29.3. CHALLENGE

This is sent by Vector if he liked the response to a nonce message.

29.3.1 Request

The parameters of the request body are:

Table 21: Parameters for challenge request

Offset	Size	Type	Parameter	Description
0	4	uint8_t	*value*	The challenge value

The application, when it receives this message, should increment the value and send the response (a challenge message).

29.3.2 Response

The parameters of the response body are:

Table 22: Parameters for challenge response

Offset	Size	Type	Parameter	Description
0	4	uint8_t	*value*	The challenge value; this is 1 + the value that was received.

If Vector accepts the response, he will send a *challenge success.*

29.4. CHALLENGE SUCCESS

This is sent by Vector if the challenge response was accepted.

29.4.1 Request

The command has no parameters.

29.4.2 Response

There is no response.

29.5. CLOUD SESSION

This command is used to request a cloud session.

29.5.1 Command

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*session token length*	The number of bytes in the session token; may be 0
2	varies	uint8_t	*session token*	The session token, as received from the cloud server.[29]
	1	uint8_t	*client name length*	The number of bytes in the client name string; may be 0 version >= 5
	varies	uint8_t[]	*client name*	The client name string. Informational only. The mobile app uses the name of the mobile device. version >= 5
	1	uint8_t	*application id length*	The number of bytes in the application id string; may be 0; version >= 5
	varies	uint8_t[]	*application id*	The application id. Informational only. The mobile uses "companion-app". version >= 5

***Table 23:** Parameters for Cloud Session request*

29.5.2 Response result

The parameters for the connection response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*success*	0 if failed, otherwise successful
1	1	uint8_t	*status*	See *Table 25: Cloud status enumeration*
2	1	uint16_t	*client token GUID length*	The number of bytes in the client token GUID; may be 0
	varies	uint8_t[]	*client token GUID*	The client token GUID. The client token GUID should be saved for future use.

***Table 24:** Parameters for Cloud Session Response*

The cloud status types are:

Index	Meaning
0	unknown error
1	connection error
2	wrong account
3	invalid session token
4	authorized as primary
5	authorized as secondary
6	reauthorization

***Table 25:** Cloud status enumeration*

[29] https://groups.google.com/forum/#!msg/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ
https://groups.google.com/forum/#!msg/anki-vector-rooting/XAaBE6e94ek/OdES50PaBQAJ

29.6. CONNECT

The connect request *comes from Vector* at the start of a connection. The response is from the application.

29.6.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	32	uint8_t[32]	*publicKey*	The public key for the connection

***Table 26:** Parameters for Connection request*

The application, when it receives this message, should use the public key for the session, and send a response back.

29.6.2 Response

The parameters for the connection response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*connectionType*	See *Table 28: Connection types enumeration*
1	32	uint8_t[32]	*publicKey*	The public key to use for the connection

***Table 27:** Parameters for Connection Response*

The connection types are:

Index	Meaning
0	first time pairing (requests pin code to be displayed)
1	reconnection

***Table 28:** Connection types enumeration*

The application sends the response, with its publicKey (see section *28.3 Encryption support*). A "first time pairing" connection type will cause Vector to display a pin code on the screen

If a first time pairing response is sent:

- If Vector is not in pairing mode – was not put on his charger and the backpack button pressed twice, quickly – Vector will respond. Attempting to enter pairing mode now will cause Vector to send a *disconnect* request.
- If Vector is in pairing mode, Vector will display a pin code on the screen, and send a nonce message, triggering the next steps of the conversation.

If a reconnection is sent, the application would employ the public and secret keys, and the encryption and decryption keys from a prior pairing.

29.7. DISCONNECT

This may be sent by Vector if there is an error, and it is ending communication. For instance, if Vector enters pairing mode, it will send a disconnect.

The application may send this to request Vector to close the connection.

29.7.1 Request

The command has no parameters.

29.7.2 Response

There is no response.

29.8. FILE DOWNLOAD

This command is used to pass chunks of a file to Vector. Files are broken up into chunks and sent.

29.8.1 Request

There is no direct request.

29.8.2 Response

The parameters of the response body are:

Table 29: *Parameters for File Download request*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	
1	4	uint32_t	*file id*	
5	4	uint32_t	*packet number*	The chunk within the download
9	4	uint32_t	*packet total*	The total number of packets to be sent for this file download
13	2	uint16_t	*length*	The number of bytes to follow (can be 0)
	varies	uint8_t[length]	*bytes*	The bytes of this file chunk

29.9. LOG

This command is used to request the Vector send a compressed archive of the logs.

29.9.1 Request

The parameters of the request body are:

Table 30: Parameters for Log request

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*mode*	
1	2	uint16_t	*num filters*	The number of filters in the array
3	varies	filter[num filters]	*filters*	The filter names

Each filter entry has the following structure:

Table 31: Log filter

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*filter length*	The length of the filter name; may be 0
2	*varies*	uint8_t[filter length]	*filter name*	The filter name

29.9.2 Response

It can take several seconds for Vector to prepare the log archive file and send a response. The response will be a "log response" (below) and a series of "file download" responses.

The parameters for the response message:

Table 32: Parameters for Log Response

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*exit code*	
1	4	uint32_t	*file id*	A 32-bit identifier that will be used in the file download messages.

29.10. NONCE

A nonce is sent by Vector after he has accepted your key, and the application sends a response

29.10.1 Request

The parameters for the nonce request message:

Offset	Size	Type	Parameter	Description
0	24	uint8_t[24]	*toVectorNonce*	The nonce to use for sending stuff to Vector
24	24	uint8_t[24]	*toAppNonce*	The nonce for receiving stuff from Vector

Table 33: *Parameters for Nonce request*

29.10.2 Response

After receiving a nonce, if the application is in first-time pairing the application should send a response, with a value of 3.

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*connection tag*	This is always 3

Table 34: *Parameters for Nonce response*

After the response has been sent, the channel will now be encrypted. If vector likes the response, he will send a challenge message.

29.11. OTA UPDATE

This command is used to request the Vector download firmware from a given server

29.11.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*length*	The length of the URL; may be 0
1	*varies*	uint8_t[length]	*URL*	The URL string

Table 35: *Parameters for OTA request*

29.11.2 Response

The response will be one or more "OTA response" indicating the status of the update, or errors. Status codes >= 200 indicate that the update process has completed. The update has completed the download when the current number of bytes match the expected number of bytes.

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status*	See *Table 37: OTA status enumeration*
1	8	uint64_t	*current*	The number of bytes downloaded
9	8	uint64_t	*expected*	The number of bytes expected to be downloaded

Table 36: *Parameters for OTA Response*

The OTA status codes are:

Status	Meaning
0	idle
1	unknown
2	in progress
3	complete
4	rebooting
5	error
200...	Status codes from the update-engine. See Appendix C, *Table 104: OTA update-engine status codes*.

Table 37: *OTA status enumeration*

Note: the status codes 200 and above are from the update-engine, and are given in Appendix C.

29.12. RESPONSE

This message will be sent on the event of an error. Primarily if the session is not cloud authorized and the command requires it.

Table 38: *Parameters for Response*

Offset	Size	Type	Parameter	Description
0	1	uint16_t	*code*	0 if not cloud authorized, otherwise authorized
1	1	uint8_t	*length*	The number of bytes in the string that follows.
	varies	uint8_t [length]	*text*	A text error message.

29.13. SDK PROXY

This command is used to pass the gRPC/protobufs messages to Vector over Bluetooth LE. It effectively wraps a HTTP request/response. Note: the HTTPS TLS certificate is not employed with this command.

29.13.1 Request

The parameters of the request body are:

Table 39: *Parameters for the SDK proxy request*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*GUID length*	The number of bytes in the GUID string; may be 0
2	*varies*	uint8_t[GUID length]	*GUID*	The GUID string
	1	uint8_t	*msg length*	The number of bytes in the message id string
	varies	uint8_t[msg id length]	*msg id*	The message id string
	1	uint8_t	*path length*	The number of bytes in the URL path string
	varies	uint8_t[path length]	*path*	The URL path string
	2	uint16_t	*JSON length*	The length of the JSON
	varies	uint8_t[JSON length]	*JSON*	The JSON (string)

29.13.2 Response

The parameters for the response message:

Table 40: *Parameters for the SDK proxy Response*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*msg id length*	The number of bytes in the message id string; may be 0
2	*varies*	uint8_t[msg id length]	*msg id*	The message id string
	2	uint16_t	*status code*	The HTTP-style status code that the SDK may return.
	1	uint8_t	*type length*	The number of bytes in the response type string
	varies	uint8_t[type length]	*type*	The response type string
	2	uint16_t	*body length*	The length of the response body
	varies	uint8_t[body length]	*body*	The response body (string)

29.14. SSH

This command is used to request the Vector allow SSH. It is reported that only the developer releases support SSH; it is not known which versions are applicable. It does not appear that SSH can be enabled in the release firmware.

29.14.1 Request

The parameters for the request message:

Table 41: *Parameters for SSH request*

Offset	Size	Type	Parameter	Description
0	2	uint16_t	*num keys*	The number of SSH authorization keys; may be 0
2	*varies*	keys[num keys]	*keys*	The array of authorization key strings (see below).

Each authorization key has the following structure:

Table 42: *SSH authorization key*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*key length*	The length of the key; may be 0
1	*varies*	uint8_t[key length]	*key*	The SSH authorization key

29.14.2 Response

The response has no parameters.

29.15. STATUS

This command is used to request basic info from Vector.

29.15.1 Request

The request has no parameters.

29.15.2 Response

The parameters for the response message:

Table 43: *Parameters for Status Response*

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string).
	1	uint8_t	*WiFi state*	See *Table 44: WiFi state enumeration*
	1	uint8_t	*access point*	0 not acting as an access point, otherwise acting as an access point
	1	uint8_t	*Bluetooth LE state*	0 if the Bluetooth
	1	uint8_t	*Battery state*	
	1	uint8_t	*version length*	The number of bytes in the version string; may be 0 version >= 2
	varies	uint8_t [version length]	*version*	The version string; version >= 2
	1	uint8_t	*ESN length*	The number of bytes in the ESN string; may be 0 version >= 4
	varies	uint8_t[ESN length]	*ESN*	The *electronic serial number* string; version >= 4
	1	uint8_t	*OTA in progress*	0 over the air update not in progress, otherwise in process of over the air update; version >= 2
	1	uint8_t	*has owner*	0 does not have owner, otherwise has owner; version >= 3
	1	uint8_t	*cloud authorized*	0 is not cloud authorized, otherwise is cloud authorized; version >= 5

Note: a *hex string* is a series of bytes with values 0-15. Every pair of bytes must be converted to a single byte to get the characters. Even bytes are the high nibble, odd bytes are the low nibble.

The WiFi states are:

Table 44: *WiFi state enumeration*

Index	Meaning
0	Unknown
1	Online
2	Connected
3	Disconnected

29.16. WIFI ACCESS POINT

This command is used to request that the Vector act as a WiFi access point. This command requires that a "cloud session" have been successfully started first (see section *29.5 Cloud session*).

If successful, Vector will provide a WiFi Access Point with an SSID that matches his robot name.

29.16.1 Request

The parameters of the request body are:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*enable*	0 to disable the WiFi access point, 1 to enable it

Table 45: *Parameters for WiFi Access Point request*

29.16.2 Response

If the Bluetooth LE session is not cloud authorized a "response" message will be sent with this error. Otherwise the WiFi Access Point response message will be sent.

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*enabled*	0 if the WiFi access point is disabled, otherwise enabled
1	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string)
	1	uint8_t	*password length*	The number of bytes in the password string; may be 0
	varies	uint8_t [password length]	*password*	The WiFi password

Table 46: *Parameters for WiFi Access Point Response*

29.17. WIFI CONNECT

This command is used to request Vector to connect to a given WiFi SSID. Vector will retain this WiFi for future use.

29.17.1 Request

The parameters for the request message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The number of bytes in the SSID string; may be 0
1	*varies*	uint8_t[SSID length]	*SSID*	The WiFi SSID (hex string)
	1	uint8_t	*password length*	The number of bytes in the password string; may be 0
	varies	uint8_t [password length]	*password*	The WiFi password
	1	uint8_t	*timeout*	How long to given the connect attempt to succeed.
	1	uint8_t	*auth type*	The type of authentication to employ; see *Table 48: WiFi authentication types enumeration*
	1	uint8_t	*hidden*	0 the access point is not hidden; 1 it is hidden

***Table 47:** Parameters for WiFi Connect request*

The WiFi authentication types are:

Index	Meaning
0	None, open
1	WEP
2	WEP shared
3	IEEE8021X
4	WPA PSK
5	WPA2 PSK
6	WPA2 EAP

***Table 48:** WiFi authentication types enumeration*

29.17.2 Response

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*SSID length*	The length of the SSID that was deleted; may be 0
1	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) that was deleted
	1	uint8_t	*WiFi state*	See *Table 44: WiFi state enumeration*
	1	uint8_t	*connect result*	version >= 3

***Table 49:** Parameters for WiFi Connect command*

29.18. WIFI FORGET

This command is used to request Vector to forget a WiFi SSID.

29.18.1 Request

The parameters for the request message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*delete all*	0 if Vector should delete only one SSID; otherwise Vector should delete all SSIDs
1	1	uint8_t	*SSID length*	The length of the SSID that to be deleted; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) to be deleted

Table 50: *Parameters for WiFi Forget request*

29.18.2 Response

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*did delete all*	0 if only one; otherwise Vector deleted all SSIDs
1	1	uint8_t	*SSID length*	The length of the SSID that was deleted; may be 0
2	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string) that was deleted

Table 51: *Parameters for WiFi Forget response*

29.19. WIFI IP ADDRESS

This command is used to request Vector's WiFi IP address.

29.19.1 Request

The request has no parameters

29.19.2 Response

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*has IPv4*	0 if Vector doesn't have an IPv4 address; other it does
1	1	uint8_t	*has IPv6*	0 if Vector doesn't have an IPv6 address; other it does
2	4	uint8_t[4]	*IPv4 address*	Vector's IPv4 address
6	32	uint8_t[16]	*IPv6 address*	Vector's IPv6 address

Table 52: *Parameters for WiFi IP Address response*

29.20. WIFI SCAN

This command is used to request Vector to scan for WiFi access points.

29.20.1 Request

The command has no parameters.

29.20.2 Response

The parameters for the response message:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*status code*	
1	1	uint8_t	*num entries*	The number of access points in the array below
2	*varies*	AP[num entries]	*access points*	The array of access points

Table 53: *Parameters for WiFi scan response*

Each access point has the following structure:

Offset	Size	Type	Parameter	Description
0	1	uint8_t	*auth type*	The type of authentication to employ; see *Table 48: WiFi authentication types enumeration*
1	1	uint8_t	*signal strength*	The number of bars, 0..4
2	1	uint8_t	*SSID length*	The length of the SSID string
3	*varies*	uint8_t[SSID length]	*SSID*	The SSID (hex string)
	1	uint8_t	*hidden*	0 not hidden, 1 hidden; version >= 2
	1	uint8_t	*provisioned*	0 not provisioned, 1 provisioned; version>= 3

Table 54: *Parameters access point structure*

CHAPTER 11

The HTTPS based API

This chapter is about the communication with Vector over the local HTTPS. This chapter provides supplemental information not available at:
https://developer.anki.com/vector/docs/proto.html

- JSON document storage interface
- Settings and preferences

The Anki docs include descriptions of the following types:

- ResponseStatus

The descriptions below[30] give the JSON keys, value format. It is implemented as gRPC/protobufs interaction over HTTP. Each command is requested by POST-ing the request structure to the given relative URL (relative to Vector's address or local network name) and interpreting the returned body as the response structure.

The HTTPS header should include

- Bearer *BASE64KEY*
- Content-Type: application/json

(The JSON request is posted in the body)

30. MISC

30.1. ENUMERATIONS

30.1.1 ConnectionCode

The ConnectionCode enumeration has the following named values:

Table 55: *ConnectionCode Enumeration*

Name	Value	Description
AVAILABLE	1	The cloud is connected, and has authenticated successfully
BAD_CONNECTIVITY	2	The internet or servers are down
FAILED_AUTH	4	The cloud connection has failed due to an authentication issue

[30] The protocol was specified in Google Protobufs.

FAILED_TLS	3	The cloud connection has failed due to [TLS certificate?] issue
UNKNOWN	0	There is an error connecting to the cloud, but the reason is unknown

30.2. CHECKCLOUDCONNECTION

Post: "/v1/check_cloud_connection"

30.2.1 Request

The CheckCloudConnectionRequest has no fields.

30.2.2 Response

The CheckCloudConnectionResponse has the following fields:

Field	Type	Description
code	ConnectionCode	Whether the cloud is available, or the relevant connection error
expected_packets	int32	
num_packets	int32	
status	ResponseStatus	
status_message	string	

Table 56: *CheckCloudConnection Response JSON structure*

30.3. DELETECUSTOMOBJECTS

DeleteCustomObjects

Post: "/v1/delete_custom_objects"

30.3.1 Request

30.3.2 Response

30.4. UPLOADDEBUGLOGS

UploadDebugLogs

Post: "/v1/upload_debug_logs"

30.4.1 Request

30.4.2 Response

31. JDOCS

This section discussed the commands for "Jdocs" (short for "JSON Documents"), which are JSON objects that are passed to Vic-Engine and Vic-Cloud. See the next chapter for interactions with a remote Jdocs server, using a sibling protocol.

31.1. ENUMERATIONS

31.1.1 JdocType

The JdocType enumeration has the following named values:

Table 57: *JdocType Enumeration*

Name	Value	Description
ACCOUNT_SETTINGS	2	Refers to the owner's account settings
ROBOT_LIFETIME_STATS	1	Refers to the robot's settings (owner preferences)
ROBOT_SETTINGS	0	Refers to the robot's lifetime stats.
USER_ENTITLEMENTS	3	Refers to the owner's entitlements.

Items of these types are described in more detail in Chapter 15.

31.1.2 ResultCode

The ResultCode enumeration has the following named values:

Table 58: *ResultCode Enumeration*

Name	Value	Description
ERROR_UPDATE_IN_PROGRESS	1	
SETTINGS_ACCEPTED	0	

31.2. STRUCTURES

31.2.1 JDoc

The Jdoc type has the following fields:

Table 59: *JSON Jdoc structure*

Field	Type	Description
client_meta	string	
doc_version	uin64	
fmt_version	uint64	
json_doc	string	

31.2.2 NamedJDoc

The NamedJdoc type has the following fields:

Table 60: *JSON NamedJdoc structure*

Field	Type	Description
doc	Jdoc	The JSON structure and meta-data about the document
jdoc_type	JdocType	The type of document provided in "doc"

31.3. JDOCSCHANGED

The JdocsChanged message has the following fields:

Field	Type	Description
jdoc_types	JdocType repeated	

***Table 61:** JSON JdocsChanged request structure*

31.4. PULLJDOCS

Post: "/v1/pull_jdocs"

31.4.1 Request

The PullJdocsRequest has the following fields:

Field	Type	Description
jdoc_types	JdocType repeated	

***Table 62:** JSON PullJdocsRequest structure*

31.4.2 Response

The PullJdocResponse has the following fields:

Field	Type	Description
named_jdocs	NamedJdoc repeated	
status	ResponseStatus	

***Table 63:** JSON PullJdocsResponse structure*

32. SETTINGS AND PREFERENCES

This section describes the commands and queries related to settings and preferences on Vector. For a description of the settings and what they mean, see Chapter 15 *Settings.* That chapter includes definitions for the following types:

- AccountSettingsConfig
- RobotSettingsConfig

32.1. ENUMERATIONS

32.1.1 UpdateStatus

The UpdateStatus enumeration has the following named values:

Name	Value	Description
IN_PROGRESS_DOWNLOAD	2	
NO_UPDATE	0	
READY_TO_INSTALL	1	

***Table 64:** UpdateStatus Enumeration*

32.2. STRUCTURES

32.2.1 AccountSettingsConfig

The AccountSettingsConfig type has the following fields:

Field	Type	Description
app_locale	string	
data_collection	boolean	

Table 65: *AccountSetting JSON structure*

32.3. UPDATESETTINGS

Post: "/v1/update_settings"

32.3.1 Request

The UpdateSettingsRequest has the following fields:

Field	Type	Description
settings	RobotSettingsConfig	

Table 66: *UpdateSettingsRequest JSON structure*

32.3.2 Response

The UpdateSettingsResponse type has the following fields:

Field	Type	Description
code	ResultCode	
doc	Jdoc	
status	ResponseStatus	

Table 67: *UpdateSettingsResponse JSON structure*

32.4. UPDATEACCOUNTSETTINGS

Post: "/v1/update_account_settings"

32.4.1 Request

The UpdateAccountsSettingsRequest has the following fields:

Field	Type	Description
account_settings	AccountSettingsConfig	

Table 68: *JSON Parameters for UpdateAccountSettings Request*

32.4.2 Response

The UpdateAccountsSettingsResponse type has the following fields:

Field	Type	Description
code	ResultCode	
doc	Jdoc	
status	ResponseStatus	

Table 69: *UpdateAccountSettings Response JSON structure*

32.5. UPDATEUSERENTITLEMENTS

UpdateUserEntitlements

Post: "/v1/update_user_entitlements"

33. FEATURES

Vector has granular features that can be enabled and disabled thru the use of feature flags. This section describes the queries related to list Vector's features flags, and their state. For a description of feature flags, see Chapter 17 *Settings, Preferences, Features, and Statistics.* For a list of the features, and a description of each, see Appendix G.

Note: the API does not include the ability to enable a feature.

33.1. GETFEATUREFLAG

The request the current setting of a feature flag.

post: "/v1/feature_flag"

33.1.1 Request

The FeatureFlagRequest message has the following fields:

Field	Type	Description
feature_name	string	

Table 70: *FeatureFlagRequest JSON structure*

33.1.2 Response

The FeatureFlagResponse type has the following fields:

Field	Type	Description
feature_enabled	bool	
status	ResponseStatus	
valid_feature	bool	

Table 71: *FeatureFlagResponse JSON structure*

33.2. GETFEATUREFLAGLIST

To get a list of the current feature flags.

post: "/v1/feature_flag_list"

33.2.1 Request

The following is streamed… to the robot?

Field	Type	Description
request_list	string	

Table 72: *FeatureFlagListRequest JSON structure*

33.2.2 Response

The FeatureFlagListResponse type has the following fields:

Field	Type	Description
list	string repeated	
status	ResponseStatus	

Table 73: *FeatureFlagListRespons e JSON structure*

34. UPDATES

These commands are siblings to the OTA Update and related commands in Chapter 10 Bluetooth LE protocol. However, they differ: in some cases, less information, in others present the same information in different ways.

34.1. STARTUPDATEENGINE

"StartUpdateEngine cycles the update-engine service (to start a new check for an update) and sets up a stream of UpdateStatusResponse events."

Post: "/v1/start_update_engine"

This command uses the same request and response structures as CheckUpdateStatus

34.2. CHECKUPDATESTATUS

"CheckUpdateStatus tells if the robot is ready to reboot and update."

Post: "/v1/check_update_status"

34.2.1 Request

The CheckUpdateStatusRequest structure has no fields.

34.2.2 Response

This is streamed set of update status

The CheckUpdateStatusResponse type has the following fields:

Field	Type	Description
expected	int64	The number of bytes expected to be downloaded
progress	int64	The number of bytes downloaded
status	ResponseStatus	
update_status	UpdateStatus	
update_version	string	

Table 74: *CheckUpdateStatusResponse JSON structure*

34.3. UPDATEANDRESTART

Post: "/v1/update_and_restart"

34.3.1 Request

The UpdateAndRestartRequest structure has no fields.

34.3.2 Response

The UpdateAndRestartResponse has the following fields:

Field	Type	Description
status	ResponseStatus	

Table 75: *UpdateAndRestartResponse JSON structure*

CHAPTER 12

The Cloud Services

This chapter is about the remote servers that provide functionality for Vector.

- JSON document storage server
- The crash uploader
- The diagnostic logger
- The token/certificate system
- The natural language processing

35. CONFIGURATION

The server URLs are specified in "/anki/data/assets/cozmo_resources/config/server_config.json" (The path to this JSON file is hardcoded in the application binaries.)

Table 76: *The cloud services configuration file*

Element	Description & Notes
appkey	A base64 token used to communicate with servers. "oDoa0quieSeir6goowai7f"
check	The server to use for connection checks
chipper	The natural language processing server
jdocs	The remote JSON storage server
logfiles	The server to upload log files
tms	The token server where Vector gets authentication items like certificates and tokens

The crash upload URL is given in /anki/etc/vic-crashuploader.env

The OTA download URL is given in /anki/etc/update-engine.env

The DAS server to contact is given in /anki/data/assets/cozmo_resources/config/DASConfig.json (This path is hardcoded in vic-DASMgr)

36. JDOCS SERVER

The Vic-Cloud services stores information on a "JDocs" server. This unusual name appears to be short for "JSON Documents."

Vic-Cloud uses the "jdocs" tag in the cloud services configuration file to know which server to contact. It uses the file "anki/config/engine/jdocs_config.json" to adjust how ofteni t contacts the server. (The path to these json files are hardcoded in Vic-Cloud.)

The interactions are basic: store, read, and delete a JSON blob by an identifier. The description below[31] gives the JSON keys, value format. It is implemented as gRPC/protobufs interaction over HTTP.

36.1. JDOCS INTERACTION

The Jdoc message has the following fields

Field	Type	Description
client_meta	string	
doc_version	uin64	
fmt_version	uint64	
json_doc	string	

Table 77: *JSON Parameters for JDoc request*

36.2. DELETE DOCUMENT

36.2.1 Request

DeleteDocReq

- account
- thing – the thing id is a 'vic:' followed by the serial number
- doc_name

36.2.2 Response

DeleteDocResp

36.3. ECHO TEST

36.3.1 Request

EchoReq

- data

36.3.2 Response

EchoResp

- data

36.4. READ DOCUMENTS

36.4.1 Request

ReadDocsReq

- account

[31] The protocol was specified in Google Protobufs. Vic-Cloud and Vic-Gateway were both written in Go. There is enough information in those binaries to reconstruct significant portions of the Protobufs specification in the future.

- thing
- items

36.4.2 Response

ReadDocsResp

- items

36.5. READ DOCUMENT ITEM

36.5.1 Request

ReadDocsReq_Item

- doc_name
- my_doc_version

36.5.2 Response

ReadDocsResp_Item

- status (int)
- doc

36.6. WRITE DOCUMENT

36.6.1 Request

WriteDocReq

- account
- thing
- doc_name
- doc

36.6.2 Response

WriteDocResp

- status (int)
- latest_doc_version

37. NATURAL LANGUAGE PROCESSING

The “knowledge graph” Q&A server is done by Sound Hound.

38. LOG UPLOADER

The logs are uploading by performing a HTTP PUT to the server. The URL is the “logfiles” URL in the server configuration file, with the compressed log file appended. The HTTP headers are:

HTTP header	Description
Anki-App-Key:	The appKey from the server configuration file.

Table 78: *Log upload HTTP header fields*

Usr-RobotESN:	Vector's serial number
Usr-RobotOSRevision:	The OS revision string from /etc/os-version-rev
Usr-RobotOSVersion:	The OS version string from /etc/os-version
Usr-RobotRevision:	The Ank revision string from /anki/etc/revision
Usr-RobotTimestamp:	The time of Vector's internal clock.
Usr-RobotVersion:	The Anki version string from /anki/etc/version
Usr-Username:	

Note: the log uploader does not appear to be enabled in the production firmware.

39. CRASH UPLOADER

Minidumps are uploaded to a backtrace.io server. The URL (including the key) is hard coded in anki-crashuploader. This is done using a POST. The HTTP headers are:

Table 79: *Crash upload form fields*

Form fields	Description
attachment_messages.log	The ".log" file associated with the minimump.. This is optional; only included if /run/das_allow_upload exists
hostname	${hostname}
robot.esn	Vector's serial number
robot.os_version	The OS version string from /etc/os-version
robot.anki_version	The Anki version string from /anki/etc/version
upload_file	The minidump ".dmp" file

40. DAS MANAGER

DAS Manager uploads TBD to an Amazon "Simple Queue Service" (SQS) server. Amazon's API uses the following key/value pairs in a URL encoded form:

Table 80: *DAS Manager SQS key-value pairs*

Keys	Value
Action	SendMessage
MessageAttribute.1.Name	DAS-Transport-Version
MessageAttribute.1.Value.DataType	Number
MessageAttribute.1.Value.StringValue	2
MessageAttribute.2.Name	Content-Encoding
MessageAttribute.2.Value.DataType	String
MessageAttribute.2.Value.StringValue	gzip%2C+base64
MessageAttribute.3.Name	Content-Type
MessageAttribute.3.Value.DataType	String
MessageAttribute.3.Value.StringValue	application%2Fvnd.anki%2Bjson%3B+format%3Dnormal%3B+product%3Dvic
MessageBody	
Version	2012-11-05

Note: there may be a body of compressed JSON data.

41. REFERENCES AND RESOURCES

Davis, Jason; *File Attachments in Backtrace*, Backtrace.io
https://help.backtrace.io/en/articles/1852523-file-attachments-in-backtrace

PART IV

Maintenance

This part describes items that are not Vector's primary function; they are practical items to support Vector's operation.

- SETTINGS, PREFERENCES, FEATURES AND STATISTICS.
- SOFTWARE UPDATES. How Vector's software updates are applied.
- DIAGNOSTICS. The diagnostic support built into Vector

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CHAPTER 17

Settings, Preferences, Statistics

This chapter is about:

- The owner's account settings and entitlements
- The robot's settings (owner preferences)
- The robot's lifetime stats

42. THE ARCHITECTURE

The architecture for setting and storing settings, statistics, account information is:

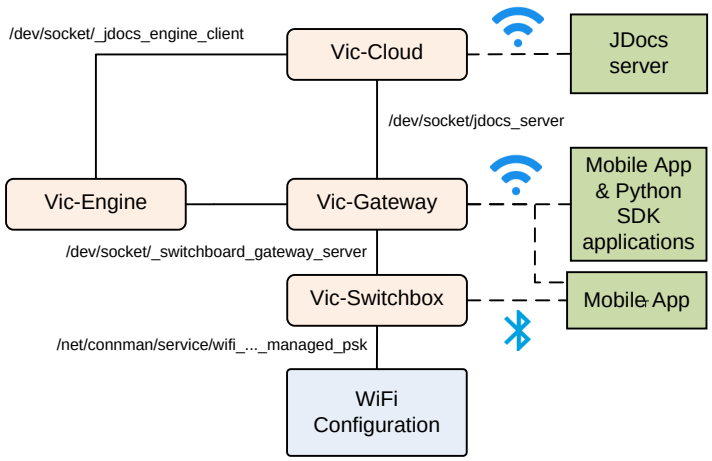

Figure 33: *The architecture for storing preferences, account info, entitlements, and tracking stats*

The Vic-Cloud service accesses information on a remote server.

The Vic-Switchbox interacts with the WiFi subsystem (connman) to allow the mobile App to set the preferred WiFI network to use. The mobile app must use Bluetooth LE to do this.

Vic-Gateway interacts with the mobile App and SDK programs to changes the robot settings.

Vic-Engine receives the preferences from the Vic-Cloud and Vic-Gateway, to carry out an changes in behaviour of Vector.

43. WIFI CONFIGURATION

The WiFi configuration (aka settings or preferences) is entirely local to the Vector robot. The information about the WiFi settings is not stored remotely.

The mobile application can configuration the WiFi settings via Vic-Switchbox commands. The WiFi is managed by connman thru the Vic-Switchbox:

- To provide a list of WiFi SSIDs to the mobile app
- To allow the mobile app to select an SSID and provide a password to
- Tell it forget an SSID
- To place the WiFi into Access Point mode

44. THE OWNER ACCOUNT INFORMATION

The owner account information is sent from the mobile application to Anki servers at time of registration and setting up a Vector. The owner account information includes:[32]

Table 81: *The owners account information*

JSON Key	units	Description & Notes
user_id	base64	A base64 token to identify the user
created_by_app_name	string	The name of the mobile application that register the owner. Example: "chewie"
created_by_app_platform	string	The mobile OS version string when the mobile application created the owners account. Example "ios 12.1.2; iPhone8,1
created_by_app_version	string	The version of the mobile application that register the owner. Example: "1.3.1"
deactivation_reason		
dob	YYYY-MM-DD	The owner's date of birth (the one given at time of registration)
drive_guest_id	GUID	A GUID to identify the owner. This is the same as the "player_id"
email	string	The email address used to register the account; the same as the user name.
email_failure_code		The reason that the email was unable to be verified
email_is_blocked	boolean	
email_is_verified	boolean	True if the email verification has successfully completed. False otherwise.
email_lang	IETF language tag	The IETF language tag of the owners language preference. example: "en-US"
family_name	string	The surname of the owner; null if not set
gender	string	The gender of the owner; null if not set
given_name	string	The given of the owner; null if not set
is_email_account	boolean	
no_autodelete	boolean	
password_is_complex	boolean	
player_id	GUID	A GUID to identify the owner. This is the same as the "drive_guest_id"
purge_reason		
status	string	Example "active"
time_created	string	The time, in ISO8601 format, that the account was created

[32] It is not clear why there is so much information, and why this is sent from JDocs in so many cases.

user_id	base64	A base64 token to identify the owner
username	string	Same as the email address

45. PREFERENCES & ROBOT SETTINGS

The following settings & preferences are stored in (and retrieved from) the JDoc server. They are set by the mobile app or python SDK program using the HTTPS protocol described in chapter 11. They may also be set (in some cases) by the cloud in response to verbal interaction with the owner, via vic-cloud (e.g. "Hey Vector, set your eye color to teal.").

45.1. ENUMERATIONS

45.1.1 ButtonWakeWord

When Vector's backpack button is pressed once for attention, he acts as if someone has said his wake word. The ButtonWakeWord enumeration describes which wake word is treated as having been said:

Table 82: *ButtonWakeWord Enumeration*

Name	Value	Description
BUTTON_WAKEWORD_ALEXA	1	When the button is pressed, act as if "Alexa" was said.
BUTTON_WAKEWORD_HEY_VECTOR	0	When the button is pressed, act is "Hey, Vector" was said.

45.1.2 EyeColor

This is the selectable colour to set Vector's eyes to. The JdocType enumeration maps the playful name to the following value used in the RobotSettingsConfig (and vice-versa) and the colour specification:

Table 83: *EyeClor Enumeration*

Name	Value	Hue	Saturation	Description
CONFUSION_MATRIX_GREEN	6	0.30	1.00	
FALSE_POSITIVE_PURPLE	5	0.83	0.76	
NON_LINEAR_LIME	3	0.21	1.00	
OVERFIT_ORANGE	1	0.05	0.95	
SINGULARITY_SAPHIRE	4	0.57	1.00	
TIP_OVER_TEAL	0	0.42	1.00	
UNCANNY_YELLOW	2	0.11	1.00	

The mapping from to enumeration to color values is held in

```
/anki/assets/cozmo_resources/config/engine/eye_color_config.json
```

This JSON configuration file is a hash that maps the EyeColor *name* (not the numeric value) to a structure with the "Hue" and "Saturation" values suitable for the SetEyeColor API command. The structure has the following fields:

Field	Type	Description & Notes
Hue	float	The hue to use for the color
Saturation	float	The saturation to use for the color.

Table 84: *The eye colour JSON structure*

This structure has the same interpretation as the SetEyeColor request, except the first letter of the keys are capitalized here.

The mapping of the number to the JSON key for the eye colours configuration file is embedded in Vic-Gateway. Adding more named colours would likely require successful complete decompilation and modification. Patching the binary is unlikely to be practical. The colours for the existing names can be modified to give custom, permanent eye colours.

45.1.3 Volume

This is the volume to employ when speaking and for sound effects. Note: the MasterVolume API enumeration is slightly different enumeration.

Name	Value	Description
MUTE	0	
LOW	1	
MEDIUM_LOW	2	
MEDIUM	3	
MEDIUM_HIGH	4	
HIGH	5	

Table 85: *Volume Enumeration*

45.2. ROBOTSETTINGSCONFIG

The RobotSettingsConfig structure has the following fields:

Field	Type	Description & Notes
button_wakeword	ButtonWakeWord	When the button is pressed, act as if this wake word ("Hey Vector" vs "Alexa") was spoken. default: 0 ("*Hey Vector*")
clock_24_hour	boolean	If false, use a clock with AM and PM and hours that run from 1 to 12. If true, use a clock with hours that run from 1 to 24. default: false
default_location	string	default: "San Francisco, California, United States"
dist_is_metric	boolean	If true, use metric units for distance measures; if false, use imperial units. default: false
eye_color	EyeColor	The colour used for the eyes. The colour is referred to by one of an enumerated set. (Within the SDK, the eyes can be set to a colour by hue and saturation, but this is not permanent.) default: 0 (TIP_OVER_TEAL)
locale	strong	The IETF language tag of the owner's language preference – American English, UK English, Australian English, German,

Table 86: *The RobotSettingsConfig JSON structure*

		French, Japanese, etc. default: “en-US”
master_volume	Volume	default: 4 (MEDIUM_HIGH)
temp_is_fahrenheit	boolean	If true, use Fahrenheit for temperature units; otherwise use Celsius.[33] default: true
time_zone	string	The “tz database name” for time zone to use for the time and alarms. default: “America/Los_Angeles”

The default settings are held in

/anki/assets/cozmo_resources/config/engine/settings_config.json

The file is a JSON structure that maps each of the fields of RobotSettingsConfig to a control structure. The control structure has the following fields:

Table 87: *The setting control structure*

Field	Type	Description & Notes
defaultValue		The The value to employ unless one has been given by the operator or other precedent.
updateCloudOnChange	boolean	true if the value is pushed to the colour when it is changed by the operator. False if not. Won’t be restored..?

It is implied that the setting value is to be pulled from the Cloud when the robot is restored after clearing.

46. OWNER ENTITLEMENTS

An entitlement is a family of features or resources that the program or owner is allowed to use. It is represented as set of key-value pairs. This is a concept that Anki provided provision for but was not used in practice.

The only entitlement defined in Vector’s API (and internal configuration files) is “kickstarter eyes” (JSON key “KICKSTARTER_EYES”). Anki decided not to pursue this, and its feature(s) remain unimplemented.

The default entitlement settings are held in

/anki/assets/cozmo_resources/config/engine/userEntitlements_config.json

(This path is hardcoded into libcozmo_engine.so.) The file is a JSON structure that maps each of the entitlement to a control structure. The control structure is the same as *Table 87: The setting control structure*, used in settings in the previous section.

47. VESTIGAL COZMO SETTINGS

There is an “account settings” file held in

/anki/data/assets/cozmo_resources/config/engine/accountSettings_config.json

[33] Anyone else notes that metric requires a true for distance, but a false for temperature? Parity.

These settings are only read by libcozmo (and possibly vic-gateway). The file is a JSON structure that maps each of the settings to a control structure. The control structure is the same as *Table 87: The setting control structure*, used in settings in an earlier section.

The settings include:

***Table 88:** The Cozmo account settings*

Field	Type	Description & Notes
APP_LOCALE	string	The IETF language tag of the owner's language preference – American English, UK English, Australian English, German, French, Japanese, etc. default: "en-US"
DATA_COLLECTION	boolean	default: false

48. FEATURE FLAGS

Vector has granular features that can be enabled and disabled thru the use of feature flags. Feature flags allow the code to be deployed, and selectively enabled. As a software engineering practice, a feature is usually is not enabled because the feature is:

- not yet fully developed, or
- specific to a customer, or
- mostly developed and being tested in some groups, or
- only enabled when there is some error occurs or other functionality is not working intended, or
- a special/premium function sold at a cost or reward (like entitlement).

Many of these possibilities do not apply to Anki. But some do. Many of the disabled features are probably disabled because they are incomplete, do not work, and likely not to work for without further development.

There is a features flag configuration file:

```
/anki/data/assets/cozmo_resources/config/features.json
```

This file is organized as an array of structures with the following fields:

***Table 89:** The feature flag structure*

Field	Type	Description & Notes
enabled	boolean	True if the feature is enabled, false if not
feature	string	The name of the feature

The set of feature flags and their enabled/disabled state can be found in Appendix G. The features are often used as linking mechanisms of the modules. It is likely modules of behavior / functionality. It is not clear how it all ties together.

49. ROBOT LIFETIME STATS

The following lifetime statics are held in the server, updated by the robot (I don't know if the robot has a local copy), and retrievable by the application.

Table 90: *The robot lifetime stats schema*

Key	units	Description & Notes
Alive.seconds	seconds	Vector's age, since he was given preferences (a factory reset restarts this)
Stim.CumlPosDelta		Cumulative stimulation of some kind
BStat.AnimationPlayed	count	The number of animations played
BStat.BehaviorActivated	count	
BStat.AttemptedFistBump	count	The number of fist bumps (attempted)
BStat.FistBumpSuccess	count	
BStat.PettingBlissIncrease		
BStat.PettingReachedMaxBliss		
BStat.ReactedToCliff	count	
BStat.ReactedToEyeContact	count	
BStat.ReactedToMotion	count	
BStat.ReactedToSound	count	
BStat.ReactedToTriggerWord	count	
Feature.AI.DanceToTheBeat		
Feature.AI.Exploring		
Feature.AI.FistBump		
Feature.AI.GoHome		
Feature.AI.InTheAir		
Feature.AI.InteractWithFaces	count	The number of times recognized / interacted with faces
Feature.AI.Keepaway		
Feature.AI.ListeningForBeats		
Feature.AI.LowBattery		
Feature.AI.Observing		
Feature.AI.ObservingOnCharger		
Feature.AI.Onboarding		
Feature.AI.Sleeping		
Feature.AI.Petting		
Feature.AI.ReactToCliff		
Feature.AI.StuckOnEdge		
Feature.AI.UnmatchedVoiceIntent		
Feature.Voice.VC_Greeting		
FeatureType.Autonomous		
FeatureType.Failure		
FeatureType.Sleep		

FeatureType.Social		
FeatureType.Play		
FeatureType.Utility1		
Odom.LWheel		The left wheel odometer
Odom.Rwheel		The right wheel odometer
Odom.Body		
Pet.ms	ms	The number of milliseconds petted?

50. REFERENCES AND RESOURCES

Wikipedia, *List of tz database time zones*, https://en.wikipedia.org/wiki/List_of_tz_database_time_zones

CHAPTER 16

The Software Update process

This chapter is about the software update process

- The software architecture
- The firmware update process
- How to extract official program files

51. THE ARCHITECTURE

The architecture for updating Vector's firmware is:

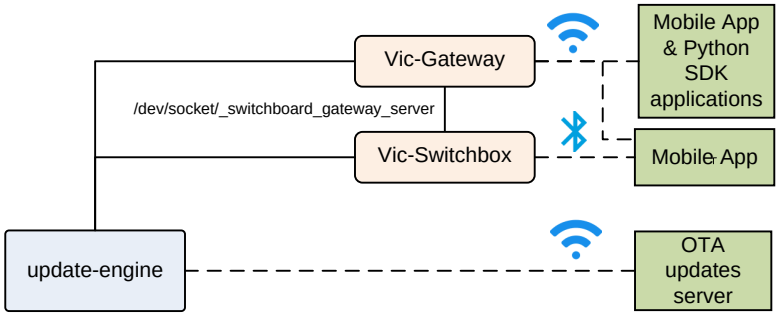

Figure 34: *The architecture for updating Vector's software*

The Vic-Gateway and Vic-Switchbox both may interact with the mobile App and SDK programs to receive software update commands, and to provide update status information.

The update-engine is responsible for downloading the update, validating it, applying it, and providing status information to Vic-Gateway and Vic-switchbox. [It isn't know yet how they kick off the update]. The update-engine provides status information in a set of files with the "`/run/update-engine`" folder

52. THE UPDATE FILE

The update files are TAR files with a suffix "OTA". The TAR file has a fixed structure, with some of the files encrypted. There are 3 kinds of update files

- Factory updates. These modify the `RECOVERY` and `RECOVERYFS` partitions.
- Production updates. These modify the `ABOOT`, `BOOT`, and `SYSTEM` partitions
- Delta updates

The archive contains 3 to 5 files, and they must be in a specific order:

1. manifest.ini
2. manifest.sha256
3. apq8009-robot-delta.bin.gz (optionally encrypted). This is present only in delta updates
4. apq8009-robot-emmc_appsboot.img.gz (optionally encrypted). This is present only in factory updates. It will be applied to the ABOOT partition.
5. apq8009-robot-boot.img.gz (optionally encrypted) . This is not present in delta updates. In factory updates it will be applied to the RECOVERY partition; otherwise it will be applied to the BOOT partition.
6. apq8009-robot-sysfs.img.gz (optionally encrypted). In factory updates it will be applied to the RECOVERYFS partition; otherwise it will be applied to the SYSTEM partition.

52.1. MANIFEST.INI

The manifest.ini is checked by verifying its signature[34] against manifest.sha256 using a secret key (/anki/etc/ota.pub):

Example 6: *Checking the manifest.ini signature*

```
openssl dgst \
   -sha256 \
   -verify /anki/etc/ota.pub \
   -signature /run/update-engine/manifest.sha256 \
   /run/update-engine/manifest.ini
```

Note: the signature check that prevents turning off encryption checks in the manifest below. At this time the signing key is not known.

All forms of update have a [META] section. This section has the following structure:

Table 91: *manifest.ini META section*

Key	Description
ankidev	0 if production release, 1 if development
manifest_version	Acceptable version include 0.9.2, 0.9.3, 0.9.4, 0.9.5, or 1.0.0
num_images	The number of img.gz files in the archive. The number must match that of the type of update file it is. 1, 2, or 3
qsn	The Qualcomm Serial Number; if there are three images (ABOOT, RECOVERY, RECOVERYFS) present, the firmware is treated as a factory update. The QSN must match the robot's. Optional.
reboot_after_install	0 or 1. 1 to reboot after installing.
update_version	The version that the system is being upgrade to, e.g. 1.6.0.3331

After the [META] section, there are 1 to 3 sections, depending on the type of update:

- A delta update has a [DELTA] section
- A regular update has a [BOOT], [SYSTEM] sections; both must be present/
- A factory update has [ABOOT], [RECOVERY], and [RECOVERYFS] sections; all 3 must be present.

[34] I'm using the information originally at: https://github.com/GooeyChickenman/victor/tree/master/firmware

Each of these sections has the same structure:

Table 92: manifest.ini image stream sections

Key	Description
base_version	The version that Vector must be at in order to accept this update. Honored only in delta updates.
bytes	The number of bytes in the uncompressed archive
compression	gz (for gzipped). This is the only supported compression type.
delta	1 if this is a delta update; 0 otherwise
encryption	1 if the archive file is encrypted; 0 if the archive file is not encrypted.
sha256	The digest of the decompressed file must match this
wbits	31. Not used buy update-engine

52.2. HOW TO DECRYPT THE OTA UPDATE ARCHIVE FILES[35]

How to decrypt the OTA update archive files:

Example 7: Decrypting the OTA update archives

```
openssl enc -d -aes-256-ctr -pass file:ota.pas -in apq8009-robot-boot.img.gz -out
apq8009-robot-boot.img.dec.gz
openssl enc -d -aes-256-ctr -pass file:ota.pas -in apq8009-robot-sysfs.img.gz -out
apq8009-robot-sysfs.img.dec.gz
```

To use OpenSSL 1.1.0 or later, add "-md md5" to the command:

Example 8: Decrypting the OTA update archives with Open SSL 1.1.0 and later

```
openssl enc -d -aes-256-ctr -pass file:ota.pas -md md5 -in apq8009-robot-boot.img.gz -
out apq8009-robot-boot.img.dec.gz
openssl enc -d -aes-256-ctr -pass file:ota.pas -md md5 -in apq8009-robot-sysfs.img.gz -
out apq8009-robot-sysfs.img.dec.gz
```

Encrypting the files is a whole other kettle of fish

53. THE UPDATE PROCESS

53.1. STATUS DIRECTORY

The update-engine provides its status thru a set of files in the /run/update-engine folder.

Table 93: update-engine status file

File	Description
done	If this file exists, the update has completed
error	The error code representing why the update failed. See Appendix C, *Table 104: OTA update-engine status codes*
expected-download-size	The expected file size (the given total size of the OTA file) to download.
expected-size	In non-delta updates, the total number of bytes of the unencrypted image files. This is the sum of the "bytes" field in the sections.
progress	Indicates how many of the bytes to download have been completed, or how much of the partitions have been written.

[35] https://groups.google.com/forum/#!searchin/anki-vector-rooting/ota.pas%7Csort:date/anki-vector-rooting/YlYQsX08OD4/fvkAOZ91CgAJ

This folder also holds the unencrypted, uncompressed files from the OTA file:

- manifest.ini
- manifest.sha256
- delta.bin
- aboot.img
- boot.img

53.2. PROCESS

The update process if there is an error at any step, skips the rest, deletes the bin and img files.

1. Remove everything in the status folder
2. Being downloading the OTA file. It does *not* download the TAR then unpack it. The file is unpacked as it is received.
3. Copies the manifest.ini to a file in the status folder
4. Copies the manifest.sha256 to a file
5. Verifies the signature of the manifest file
6. Validates that the update to the OTA version is allowed. This includes a check that it is to a newer version number, and the developer vs production firmware type matches whether this Vector is a developer or production.
7. If this is factory update, it checks that the QSN in the manifest matches Vector's QSN.
8. It marks the target partition slots as unbootable
9. Checks the img and bin contents
    a) delta
    b) boot & system
    c) If this is a factory update, it aboot, recovery, recoveryfs
10. If this is a factory update:
    a) Sets /run/wipe-data. This will trigger erasing all of the user data on the next startup
    b) Makes both a and b slots for BOOT and SYSTEM partitions as unbootable
11. If this is not factory update
    a) Sets the new target slot as active
12. Deletes any error file
13. Sets the done file
14. Posts a DAS event robot.ota_download_end to success + next version
15. If the reboot_after_install option was set, reboots the system

54. RESOURCES

https://source.android.com/devices/bootloader/flashing-updating
Describes the a/b process as it applies to android

CHAPTER 20

Diagnostics

This chapter is about the diagnostic support built into Vector

- The customer care information screen
- Fault code display
- The logging of regular use
- Crash logs
- Gathering performance data

Logging and diagnostic messages are typically not presented to the owner, neither in use with Vector or thru the mobile application... nor even in the SDK.

The exception is gross failures that displays a 3-digit error code. This is intended to be very exceptional.

Diagnostic and logging information is available thru undocumented interfaces. (The lack of documentation indicates that this was not intended to be supported and employed by the public... at least not until other areas had been resolved.

Diagnostic and logging information is available thru undocumented interfaces.[36]

55. CUSTOMER CARE INFORMATION SCREEN

56. FAULT CODE DISPLAY

This is triggered by systemd if any of the main services fail.

57. LOGS

Acquiring Logs

- Logs can be downloaded to a PC or mobile application using the Bluetooth LE API
- The Logs can be used to the server using the SDK command X

Pushing Logs to the server

57.1. GATHERING LOGS, ON DEMAND

The logs can be requested by issuing a log fetch command via Bluetooth LE. Vic-switchboard handles the request, delegating the preparation of the log files to diagnostics-logger. This utility gathers the following tars and compresses them:

[36] The lack of documentation indicates that this was not intended to be supported and employed by the public... at least not until other areas had been resolved.

File	Description
connman-services.txt	connmanctl services
dmesg.txt	dmesg
ifconfig.txt	ifconfig wlan0
iwconfig.txt	iwconfig wlan0
log.txt	Concenates /var/log/messages.1.gz (uncompressed) and /var/log/messages
netstat-ptlnu.txt	netstat -ptlnu
ping-anki.txt	Ping's anki.com for connectivity and latency.
ping-gateway.txt	Looks up the IP address (using netstat) of the gateway that Vector is using and pings it for connectivity and latency.
ps.txt	Process stats (ps) of Anki's "Vic" processes
top.txt	top -n 1

Table 94: *Files in the log archive*

This utility is triggered by vic-switchboard when issued a log fetch command (via Bluetooth LE).

57.2. GATHERING LOGS, REGULARLY

57.3. SENDING THEM TO THE SERVER

58. CRASHES

Crash logs are sent on system start (reboot). They are primarily minidump files produced by Google breakpad, and are sent to backtrace.io for analysis.

59. CONSOLE FILTER

The logging by functional blocks (primarily in Vic-engine) can be configured. The logging configuration file is located at:

`/anki/data/assets/cozmo_resources/config/engine/console_filter_config.json`

This file is organized as dictionary whose key is the operating system. The "vicos" key is the one relevant for Vector.[37] It dereferences to a structure with the following fields:

Field	Type	Description & Notes
channels	array	An array of the channel logging enable structures
levels	array	An array of logging level enable structures

Table 95: *The console filter channel structure*

This "channels" is as an array of structures with the following fields:

Field	Type	Description & Notes
channel	string	The name of the channel
enabled	boolean	True if should log information from the channel, false if not.

Table 96: *The channel logging enable structure*

[37] The other OS key is "osx" which suggests that Vector's software was development on an OS X platform.

This “levels” is an array of structures with the following fields:

Table 97: *The logging level enable structure*

Field	Type	Description & Notes
enabled	boolean	True if should log information at that level, false if not.
level	string	“event” or “debug”

Table 98: *The channels*

Chanel	enabled	Description & Notes
Actions	false	
AIWhiteboard	false	
Alexa	false	
Audio	false	
Behaviors	false	
BlockPool	false	
BlockWorld	false	
CpuProfiler	true	
FaceRecognizer	false	
FaceWorld	false	
JdocsManager	true	
MessageProfiler	true	
Microphones	false	
NeuralNets	false	
PerfMetric	true	
SpeechRecognizer	false	
VisionComponent	false	
VisionSystem	false	
*	false	

60. PERFORMANCE AND USAGE PROFILING

61. REFERENCES AND RESOURCES

os-release — Operating system identification
https://www.freedesktop.org/software/systemd/man/os-release.html
Describes the `/etc/os-version` and `/etc/os-version-rev` files

References & Resources

Note: most references appear in the margins, significant references will appear at the end of their respective chapter.

62. CREDITS

Credit and thanks to Anki, C0RE, Melanie T for access to the flash partitions, file-systems, decode keys, and board shots. Fictiv for board shots. The board shots that help identify parts on the board and inter-connection on the board. HSReina for Bluetooth LE protocol information.

63. REFERENCE DOCUMENTATION AND RESOURCES

63.1. ANKI

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https://www.slideshare.net/embeddedvision/making-cozmo-see-a-presentation-from-anki
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63.2. OTHER

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https://fccid.io/2AAIC00010

FCC *ID 2AAIC00011 internal photos*
https://fccid.io/2AAIC00011

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https://www.fictiv.com/blog/anki-vector-robot-teardown

Kinvert, *Anki Vector Customer Care Info Screen (CCIS)*
https://www.kinvert.com/anki-vector-customer-care-info-screen-ccis/

cozmopedia.org

PyCozmo
https://github.com/zayfod/pycozmo/tree/master/pycozmo

63.3. QUALCOMM

Although detailed documentation isn't available for the Qualcomm APQ8009, there is documentation available for the sibling APQ8016 processor.

Qualcomm, *APQ8016E Application Processor Tools & Resources*, https://developer.qualcomm.com/hardware/apq-8016e/tools

Qualcomm, *DragonBoard™ 410c based on Qualcomm® Snapdragon™ 410E processor ADB Debugging Commands Guide*, LM80-P0436-11, Rev C, 2016 Sep lm80-p0436-11_adb_commands.pdf

Qualcomm, *DragonBoard™ 410c based on Qualcomm® Snapdragon™ 410E processor Software Build and Installation Guide, Linux Android*, LM80-P0436-2, Rev J, 2016 Dec lm80-p0436-2_sw-build-and-install_gd_linux_android_dec2016.pdf

Appendices

These appendices provide extra material supplemental to the main narrative. These include tables of information, numbers and keys.

- ABBREVIATIONS, ACRONYMS, & GLOSSARY. This appendix provides a gloss of terms, abbreviations, and acronyms.
- TOOL CHAIN. This appendix lists the tools known or suspected to have been used by Anki to create, and customize the Vector, and for the servers. Tools that can be used to analyze Vector
- FAULT AND STATUS CODES. This appendix provides describes the system fault codes, and update status codes.
- FILE SYSTEM. This appendix lists the key files that are baked into the system.
- BLUETOOTH LE PROTOCOLS. This appendix provides information on the Bluetooth LE interfaces to the companion Cube, and to Anki Vector
- SERVERS. This appendix provides the servers that the Anki Vector and App contacts
- PHRASES. This appendix reproduces the phrases that the Vector keys off of.
- FEATURES. This appendix enumerates the Vector OS "features" that can be enabled and disabled.
- PLEO. This appendix gives a brief overview of the Pleo animatronic dinosaur, an antecedent with many similarities.

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APPENDIX A

Abbreviations, Acronyms, Glossary

Abbreviation / Acronym	Phrase
ADC	analog to digital converter
AG	animation group
AVS	Alexa Voice Service
BIN	binary file
CCIS	customer care information screen
CLAD	C-like abstract data structures
CRC	cyclic redundancy check
CSI	Camera serial interface
DAS	*unknown (diagnostic/data analytics service?)*
DFU	device firmware upgrade
EEPROM	electrical-erasable programmable read-only memory
EMR	*unknown (emergency mode recovery?)*
ESD	electro-static discharge
ESN	electronic serial number
FBS	flat buffers
FDE	full disc encryption
GPIO	general purpose IO
GUID	globally unique identifier (effectively same as UUID)
I2C	inter-IC communication
IMU	inertial measurement unit
IR	infrared
JDocs	JSON Documents
JSON	javascript object notion
JTAG	Joint Test Action Group
LCD	liquid crystal display
LED	light emitting diode
LUKS	linux unified key setup
MCU	microcontroller

Table 99: *Common acronyms and abbreviations*

mDNS	multicast domain name service (DNS)
MEMS	micro-electromechanical systems
MIPI	mobile industry processor interface
MISO	master-in, slave-out
MOSI	master-out, slave-in
MPU	microprocessor
MSRP	manufacturer's suggest retail price
OLED	organic light-emitting diode display
OTA	over the air updates
PCB	printed circuit board
PCBA	printed circuit board assembly (PCB with the components attached)
PMIC	power management IC
PWM	pulse width modulation
QSN	Qualcomm serial number
RPM	resource power management
RRT	rapidly-expanding random tree
SCLK	(I2C) serial clock
SDA	(I2C) serial data
SDK	software development kit
SLAM	simultaneous localization and mapping
SPI	serial-peripheral interface
SSH	secure shell
SSID	service set identifier (the name of the Wifi network)
STM32	A microcontroller family from ST Microelectronics
SWD	single wire debug
TAR	tape archive file
TTS	text to speech
UART	universal asynchronous receiver/transmitter
USB	universal serial bus
UUID	universally unique identifier (effectively same as GUID)
vic	short Victor (Vector's working name)

Phrase	**Description**
A*	A path finding algorithm
aboot	The Android boot-loader used to launch Vector's linux system.
attitude	orientation
beam forming	A technique using multiple microphones to listen to a single speaker by selectively paying attention to sound only coming from that direction.
boot loader	A piece of software used to load and launch the application firmware.

Table 100: *Glossary of common terms and phrases*

C-like abstract data structure	Anki's phrase for when information is packed into fields and values with a defined binary format, and interpretation. (Protobufs are often used for the same purpose.)
capacitive touch	
certificate	Vector generates an SSL certificate that can be used for the secure communications.
characteristic (Bluetooth LE)	A key (or slot) that holds a value in the services key-value table. A characteristic is uniquely identified by its UUID.
client token	A string token provided by Vector that is passed with each SDK command.
control	Responsible for motors and forces to move where and how it is told to. (smooth arcs)
D*-lite	A path-finding algorithm
device mapper verity (dm-verity)	A feature of the Linux kernel that checks the boot and RAM file systems for alteration, using signed keys
entitlement	An entitlement is a family of features or resources that the program or owner is allowed to use.
feature flags *aka feature toggle*	A setting that enables and disables features, especially those still in development. This allows developing the code and integrating its structure before the module or function is completely ready. Otherwise it is very difficult to keep the different branches of development in sync and merge them when the feature is ready.
flash	A type of persistent (non-volatile) storage media.
guidance	Builds the desired path
navigation	Knowing where it is in the map
nonce	An initially random number, incremented after each use.
path planning	Forms smooth arcs and line segments to move in around an environment to avoid collisions, blocked paths, and TBD.
pose	The position and orientation of an object relative to a coordinate system
power source	Where the electric energy used to power Vector comes from.
rapidly-expanding random tree	A path-finding algorithm
recovery mode	A separate, independent operating system that Vector can boot into for purposes of downloading firmware to replace a damaged partition.
robot name	Vector's robot name looks like "Vector-E5S6". It is "Vector-" followed by a 4 letters and numbers.
session token	A string token provided by the Anki servers that is passed to Vector to authenticate with him and create a *client token.*
simultaneous localization and mapping	A vision-based technique for building a map of the immediate world for purposes of positioning oneself within it and detecting relative movements.
service (Bluetooth LE)	A key-value table grouped together for a common purpose. A service is uniquely identified by its UUID.
syscon	The name of the firmware program running on the base-board.
Trust Zone	A security mode on ARM processor where privileged/special code is run. This includes access to encryption/decryption keys.
universally unique identifier (UUID)	A 128bit number that is unique. (effectively same as GUID)

APPENDIX B

Tool chain

This appendix tries to capture the tools that Anki is known or suspected to have used for the Anki Vector and its cloud server.

Note: Several of these the licenses requiring Anki to post their versions of the GPL tools, and their modification, Anki never did. Qualcomm may have; as the license requirement only to those their customer, they may have provided the changes to them.

***Table 101:** Tools used by Anki*

Tool	Description
Acapela	Vector uses Acapela's text to speech synthesizer, and the Ben voice. https://www.acapela-group.com/
Advanced Linux Sound Architecture (alsa)	The audio system https://www.alsa-project.org
Amazon Alexa	A set of software tools that allows Vector to integrate Alexa voice commands, probably in the AMAZONLITE distribution https://developer.amazon.com/alexa-voice-service/sdk
Amazon Simple Queue Service (SQS)	Vector employs Amazon's SQS for its DAS functions.
Amazon Simple Storage Service (S3)	Vector's cloud interface uses Amazon's AWS go module to interact with Amazon's service: https://docs.aws.amazon.com/sdk-for-go/api/service/s3/ https://docs.aws.amazon.com/AmazonS3/latest/API/API_Operations_Amazon_Simple_Storage_Service.html
Amazon Web services	used on the server https://aws.amazon.com/
android boot-loader	Vector uses the Android Boot-loader;
ARM NN	ARM's neural network support https://github.com/ARM-software/armnn
AudioKinetic Wwise[38]	Used to craft the sounds https://www.audiokinetic.com/products/wwise/
Backtrace.io	A service that receives uploaded minidumps from applications in the field and provides tools to analyze them. https://backtrace.io
clang	A C/C++ compiler, part of the LLVM family https://clang.llvm.org
bluez5	Bluetooth LE support http://www.bluez.org/
busybox	The shell on the Anki Vector linux https://busybox.net
chromium update	?

[38] https://blog.audiokinetic.com/interactive-audio-brings-cozmo-to-life/

civetweb	The embedded webserver that allows Mobile apps and the python SDK to communicate with Vector. https://github.com/civetweb/civetweb
connman	Connection manager for WiFi https://01.org/connman
GNU C Compiler (gcc)	GCC version 4.9.3 was used to compile the kernel
golang	Go is used on the server applications, and (reported) some of Vector's internal software.
Google Breakpad	Google Breakpad is used to generate tracebacks and mini-dump files of programs that crash. Results are sent to htttp://backtrace.io https://chromium.googlesource.com/breakpad/breakpad
Google FlatBuffers	Google FlatBuffers is used to encode the animation data structures https://github.com/google/flatbuffers
Google RPC (gRPC)	A "remote procedure call" standard, that allows mobile apps and the python SDK to communicate with Vector. https://grpc.io/docs/quickstart/cpp/
hdr-histogram	Unknown use https://github.com/HdrHistogram/HdrHistogram
libchromatix	Qualcomm camera support
libsodium	Cryptography library suitable for the small packet size in Bluetooth LE connections. Used to encrypt the mobile applications Bluetooth LE connection with Vector. https://github.com/jedisct1/libsodium
linux, yocto[39]	The family of linux distribution used for the Anki Vector (v3.18.66)
linux	on the server
linux unified key storage (LUKS)	
Maya	A character animation tool set, used to design the look and movements of Cozmo and Vector. The tool emitted the animation scripts.
mpg123	A MPEG audio decoder and player. This is needed by Alexa; other uses are unknown. https://www.mpg123.de/index.shtml
ogg vorbis	Audio codec https://xiph.org/vorbis
OKAO Vision	Vector uses Okao Vision library for face recognition and tracking.
open CV	Used for the first-level image processing – to locate faces, hands, and possibly accessory symbols. https://opencv.org/
openssl	used to validate firmware update signature https://www.openssl.org
opkg	Package manager, from yocto https://git.yoctoproject.org/cgit/cgit.cgi/opkg/
Opus codec	Audio codec; to encode speech sent to servers http://opus-codec.org/
perl	A programming language, on Victor https://www.perl.org
Pretty Fast FFT	Julien Pommier's FFT implementation for single precision, 1D signals

[39] https://www.designnews.com/electronics-test/lessons-after-failure-anki-robotics/140103493460822

pffft	https://bitbucket.org/jpommier/pffft
protobuf	Used to describe the format/encoding of data sent over gRPC to and from Vector. This is used by mobile and python SDK, as well as on the server. https://developers.google.com/protocol-buffers
Pryon, Inc	The recognition for the Alexa keyword at least the file system includes the same model as distributed in AMAZONLITE https://www.pryon.com/company/
python	A programming language and framework used with desktop tools to communicate with Vector. Vector has python installed. Probably used on the server as well. https://www.python.org
Qualcomm TBD	Qualcomm's device drivers and other kit appear to be used.
Segger ICD	A high-end ARM compatible in-circuit debugging probe. Rumoured to have been used by Anki engineers, probably with the STM32F030 https://www.segger.com/products/debug-probes/j-link/
Sensory TrulyHandsFree	Vectors recognition for "Hey Vector" and Alexa wake word is done by Sensory, Inc's TrulyHandsfree SDK 4.4.23 (c 2008) https://www.sensory.com/products/technologies/trulyhandsfree/ https://en.wikipedia.org/wiki/Sensory,_Inc.
Signal Essence	Designed the microphone array, and the low-level signal processing of audio input. https://signalessence.com/
Sound Hound, inc	Vector's Q&A "knowledge graph" is done by Sound Hound https://blog.soundhound.com/hey-vector-i-have-a-question- 3c174ef226fb
SQLite	This is needed by Alexa; other uses are unknown https://www.sqlite.org/index.html
systemd	Used by Vector to launch the internal services https://www.freedesktop.org/software/systemd/
tensor flow lite (TFLite)	Probably used to recognize the object marker symbols, and maybe hands https://www.tensorflow.org/lite/microcontrollers/get_started

Other tools, useful for analyzing and patching Vector:

Table 102: *Tools that can be used to analyze and patch Vector*

Tool	Description
Segger ICD	An education version of the J-Link, suitable for the STM32F030, can be found on ebay for <$60 https://www.segger.com/products/debug-probes/j-link/
ST-Link (v3)	Suitable for debugging STM32F030, extracting and patching firmware; $35 https://www.st.com/en/development-tools/stlink-v3set.html
TI BLE sniffer	$50 http://www.ti.com/tool/CC2540EMK-USB https://www.ti.com/tool/PACKET-SNIFFER
Wireshark	To decode what is said to the servers https://support.citrix.com/article/CTX116557

APPENDIX C

Fault and status codes

The following are system status codes that may be produced during startup:

Table 103: *The system fault codes*

Code	Meaning
1..10	Systemd failed…?
200...	Software update status code, see table below
700-702	Internal sensor out of range or failed. These require vic-robot to tell the base-board to power the system off.
703-705	Internal sensor out of range or failed.
800	Vic-anim was unable to start or crashed.
801	?
898	? "general hardware disconnect"
899	?
913	Vic-switchboard was unable to start or crashed
914	Vic-engine was unable to start or crashed
915	?
916	Vic-robot was unable to start or crashed
917	?
920	Vic-gateway-cert was unable to generate a x509 certificate for vic-gateway
921	Vic-gateway was unable to start or crashed
923	Vic-cloud was unable to start or crashed
980-981	"These codes indicate issues with the camera. These issues are typically caused by mm-anki-camera hanging when we try to stop the camera stream on vic-engine stop. We have to manually kill it and start it again."

The following are the update-engine status codes that may be produced during the update process:

Table 104: *OTA update-engine status codes*

Status	Meaning
200	The TAR contents did not follow the expected order.
201	Unhandled section format for expansion, or The manifest version is not supported, or The OTA has the wrong number of images for the type, or The OTA is missing a BOOT or SYSTEM image, or The manifest configuration is not understood
202	Could not mark target, a, or b slot unbootable, or Could not set target slot as active
203	Unable to construct automatic update URL, or The URL could not be opened
204	The file wasn't a valid TAR file, or is corrupt
205	The compression scheme is not supported, or Decompression failed, the file may be corrupt

207	Delta payload error
208	Couldn't sync OS images to disk, or Disk error while transferring OTA file.
209	The manifest failed signature validation; or the aboot, boot image, system image, or delta.bin hash doesn't match signed manifest
210	The encryption scheme is not supported.
211	Vector’s current version doesn’t match the baseline for a delta update.
212	The decompression engine had an unexpected, undefined error.
213	QSN doesn't match manifest
214	There is a mismatch: development Vectors can’t install release OTA firmware, and release Vectors can’t install development OTA firmware.
215	OTA transfer failed, due to timeout.
216	OS version name in the update file doesn’t follow an acceptable pattern, or it is not allowed to upgrade or downgrade from the current version to the new version.
219	Other unexpected, undefined error while transferring OTA file.

APPENDIX D

File system

This Appendix describes the file systems on Vector's flash. As the Vector uses the Android bootloader, it reuses – or at least reserves – many of the Android partitions[40] and file systems. Many are probably not used. Quotes are from Android documentation.

The file system table tells use where they are stored in the partitions, and whether they are non-volatile.

***Table 105:** The file system mount table*

Mount point	Partition name	Description & Notes
/	BOOT_A	The primary linux kernel and initramfs
/data[41]	USERDATA	The data created for the specific robot (and user) that customizes it. A factory reset wipes out this user data. This portion of the file system is encrypted using "Linux Unified Key Setup" (LUKS).
/firmware	MODEM	The firmware for the WiFi/Bluetooth radio
/factory	OEM	Customizations, such as bootloader property values. … Or the factory recovery?
/persist	PERSIST	Device specific "data which shouldn't be changed after the device is shipped, e.g. DRM related files, sensor reg file (sns.reg) and calibration data of chips; wifi, bluetooth, camera etc."
/media/ram /run /var/volatile /dev/sm		Internal temporary file systems; holds temporary files, interprocess communication

The partition table[42] found on the Vector:

***Table 106:** The partition table*

Partition name	Size	Description & Notes
ABOOT ABOOTBAK	1 MB 1 MB	The primary and backup Android boot loader, which may load the kernel, recovery, or fastboot. This is in the format of a signed, statically linked ELF binary.
BOOT_A BOOT_B	32 MB 32 MB	These are the primary and backup linux kernel and initramfs. Updates modify the non-active partition, and then swap which one is active.
CONFIG	512 KB	This partition is not employed by Vector. It is zero'd out.
DDR	32 KB	Configuration of the DDR RAM.
DEVINFO	1 MB	This partition is not read by Vector. It is zero'd out. In typical aboot implementations this partition is used to hold "device information including: is_unlocked (aboot), is_tampered, is_verified,

[40] https://forum.xda-developers.com/android/general/info-android-device-partitions-basic-t3586565
[41] This is mounted by "mount-data.service' The file has a lot of information on how it unbricks
[42] Much information from: https://source.android.com/devices/bootloader/partitions-images

		charger_screen_enabled, display_panel, bootloader_version, radio_version etc. Contents of this partition are displayed by "fastboot oem device-info" command in human readable format. Before loading boot.img or recovery.img, [the] boot loader verifies the locked state from this partition." Vector's aboot will write to this partition to indicate tampering when it finds that the boot image does not pass integrity checks.
EMR	16 MB	Holds Vector's Model, Serial Number, and such. This appears to be a binary data structure, rather than a file system.
FSC	1KB	"Modem FileSystem Cookies"
FSG	1.5 MB	Golden backup copy of MODEMST1, used to restore it in the event of error
KEYSTORE	512 KB	"Related to [USERDATA] Full Disk Encryption (FDE)"
MISC	1MB	This is "a tiny partition used by recovery to communicate with bootloader store away some information about what it's doing in case the device is restarted while the OTA package is being applied. It is a boot mode selector used to pass data among various stages of the boot chain (boot into recovery mode, fastboot etc.). e.g. if it is empty (all zero), system boots normally. If it contains recovery mode selector, system boots into recovery mode."
MODEM	64 MB	Binary "blob" for the WiFi/Bluetooth radio firmware
MODEMST1 MODEMST2	1.5MB 1.5MB	A FAT filesystem holding executables and binary "blobs" for the WiFi/Bluetooth radio firmware. Several are signed by Anki. Includes a lot of test code, probably for emissions testing.
OEM	16MB	A modifiable ext2/4 file system that holds the logs, robot name, some calibration info, and SDK TLS certificates.
PAD	1MB	"related to OEM"
PERSIST	64MB	This partition is not employed by Vector. It is zero'd out.
RECOVERY	32 MB	An alternate partition holding kernel and initial RAM filesystem that allows the system boot into a mode that can download a new system. Often used to wipe out the updates.
RECOVERYFS	640 MB	An alternate partition holding systems applications and libraries that let the application boot into a mode that can download a new system. Often used to wipe out the updates.
RPM RPMBAK	512KB 512KB	The primary and backup partitions for resource and power management. This is in the format of a signed, statically linked ELF binary.
SBL1 SBL1BAK	512KB 512KB	The primary and back up partitions for the secondary bootloader. Responsible for loading ABOOT; has an "Emergency" download (EDL) mode using Qualcomm's Sahara protocol. This is in the format of a signed, statically linked ELF binary.
SEC	16KB	The secure boot fuse settings, OEM settings, signed-bootloader stuff
SSD	8KB	"Secure software download" for secure storage, encrypted RSA keys, etc
SYSTEM_A SYSTEM_B	896MB 896MB	The primary and backup system applications and libraries with application specific code. Updates modify the non-active partition, and then swap which one is active.
SWITCHBOARD	16 MB	This is a modifiable data area used by Vic-switchboard to hold persistent communication tokens. This appears to be a binary data structure, rather than a file system.
TZ TZBAK	768KB 768KB	The primary and backup TrustZone. This is in the format of a signed, statically linked ELF binary. This code is executed with special privileges to allow encrypting and decrypting key-value pairs without any other modules (or debuggers) having access to the secrets.

USERDATA	768MB	The data created for the specific robot (and user) that customizes it. A factory reset wipes out this user data. This partition is encrypted using "Linux Unified Key Setup" (LUKS).

The files employed in the Vector binaries and scripts:

Table 107: *Files*

File	Description
/anki/etc/revision	Contains the robot revision number
/anki/etc/version	Contains the robot version number
/data/data/com.anki.victor	
/data/data/com.anki.victor/cache/crashDumps	Holds the crash dump files
/data/data/com.anki.victor/cache/outgoing	
/data/data/com.anki.victor/cache/vic-logmgr	A folder used to hold the log files while constructing the compressed archive file that will be uploaded.
/data/diagnostics/	Used to hold the diagnostic logs as the archive is constructed and compressed.
/data/etc	
/data/etc/localtime	The time zone
/data/fault-reports	
/data/lib/connman/	The contents of `/var/lib/connman` are copied here
/data/maintenance_reboot	This is set when the system has rebooted for maintenance reasons (e.g. updates)
/data/misc/bluetooth	A folder to hold communication structures for the Bluetooth LE stack.
/data/misc/bluetooth/abtd.socket	The IPC socket interface to Anki's Bluetooth LE service
/data/misc/bluetooth/btprop	The IPC socket interface to BlueZ Bluetooth LE service.
/data/misc/camera	
/data/panics	
/data/run/connamn	
/data/data/com.anki.victor/persistent/switchboard /sessions	Used by Vic-switchboard to hold persistent session information, e.g. tokens
/data/unbrick	
/data/usb	
/data/vic-gateway	
/dev/block/bootdevice/by-name/emr	Filesystem access to the manufacturing records, including serial number
/dev/block/bootdevice/by-name/switchboard	Filesystem access to switchboards persistent data.
/dev/rampost_error	The status of the rampost checks of the baseboard.
*/dev/socket/_anim_robot_server_*	The IPC socket with Vector's animation controller
*/dev/socket/_engine_gateway_server_*	The IPC socket interface to Vector's Gateway [TBD] server
*/dev/socket/_engine_gateway_proto_server_*	The IPC socket interface to Vector's Gateway [TBD] server
*/dev/socket/_engine_switch_server_*	The IPC socket interface to Vector's Switchbox [TBD] server

/etc/os-version	Contains the OS (linux) version string.
/etc/os-version-rev	Contains the OS (linux) revision string.
/factory/cloud/something.pem	
/proc/sys/kernel/random/boot_id	A random identifier, created each boot
/sys/devices/system/cpu/possible[43] */sys/devices/system/cpu/present*	The number of CPUs and whether they can be used.
/run/after_maintenance_reboot	This is set to indicate to Vectors services that the system was rebooted for maintenance reasons, and they should take appropriate action. This will be set, on boot, if `/data/maintenance_reboot` had been set.
/run/anki-crash-log	
/run/das_allow_upload	If this exists, the crash log files can be uploaded to the backtrace.io servers; if it does not exist, the files are not uploaded. This file probably always exists, but was intended to be a user settable feature.
/run/fake-hwclock-cmd[44]	Sets the fake time to the time file (Vector doesn't have a clock)
/run/fault_code	This is set to the fault code (see Appendix C) if a program is unable to carry out a significant task, or crashes. The fault display program may present this code on the LCD display.
/run/fault_code.pending	The next fault code in queue to be handled
/run/fault_code.showing	The fault code being displayed
/run/fault_restart_count	
/run/fault_restart_uptime	
/tmp/data_cleared	
/tmp/vision/neural_nets	

Key named device files employed in Vector binaries:

Table 108: *Named device and control files*

File	Description
/dev/fb0	The display framebuffer
/dev/spidev0.0	The SPI channel to communicate with the IMU
/dev/spidev1.0	The SPI channel to communicate with the LCD
/dev/ttyHS0	Serial connection with the base-board
/dev/ttyHSL0	Console log
/sys/class/android_usb/android0/iSerial	Set to Vector's serial number
/sys/class/gpio/gpio83	Used to control the camera power
/sys/class/leds/face-backlight-left/brightness	LCD left backlight control
/sys/class/leds/face-backlight-right/brightness	LCD right backlight control
/sys/devices/platform/soc/1000000.pinctrl/gpio/gpiochip0/base	LCD backlight enable (left or right?) GPIO config
/sys/devices/system/cpu/cpu0/cpufreq/scaling_max_freq	The maximum frequency that the CPU can run at. Initially set to 533MHz

[43] https://www.kernel.org/doc/Documentation/ABI/testing/sysfs-devices-system-cpu
[44] https://manpages.debian.org/jessie/fake-hwclock/fake-hwclock.8.en.html

/sys/kernel/debug/msm_otg/bus_voting	Disabled to prevent the USB from pinning RAM to 400MHz.
/sys/kernel/debug/rpm_send_msg/message	Used to control the RAM controller. The RAM is set to a maximum of 400MHz.
/sys/devices/soc/1000000.pinctrl/gpio/gpiochip0/base	LCD backlight enable (left or right?) GPIO config
/sys/devices/soc.0/1000000.pinctrl/gpio/gpiochip911/base	LCD backlight enable (left or right?) GPIO config
/sys/module/spidev/parameters/bufsiz	The buffer size for SPI transfers. This is set to the size of the LCD frame (184 pixels × 96 pixels × 2 bytes/pixel).

APPENDIX E

Bluetooth LE Services & Characteristics

This Appendix describes the configuration of the Bluetooth LE services – and the data access they provide – for the accessory cube and for Vector.

64. CUBE SERVICES

times and other feature parameters:

Service	UUID[45]	Description & Notes
Device Info Service[46]	$180A_{16}$	Provides device and unit specific info –it's manufacturer, model number, hardware and firmware versions
Generic Access Profile[47]	1800_{16}	The device name, and preferred connection parameters
Generic Attribute Transport[48]	1801_{16}	Provides access to the services.
Cube's Service	C6F6C70F-D219-598B-FB4C-308E1F22F830$_{16}$	Service custom to the cube, reporting battery, accelerometer and date of manufacture

Table 109: *The Bluetooth LE services*

Note: It appears that there isn't a battery service on the Cube. When in over-the-air update mode, there may be other services present (i.e. by a bootloader)

Element	Value
Device Name (Default)	"Vector Cube"
Firmware Revision	"v_5.0.4"
Manufacturer Name	"Anki"
Model Number	"Production"
Software Revision	"2.0.0"

Table 110: *The Cube's Device info settings*

[45] All values are a little endian, per the Bluetooth 4.0 GATT specification
[46] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.device_information.xml
[47] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.generic_access.xml
[48] http://developer.bluetooth.org/gatt/services/Pages/ServiceViewer.aspx?u=org.bluetooth.service.generic_attribute.xml

64.1. CUBE'S ACCELEROMETER SERVICE

Values are little-endian, except where otherwise stated.

UUID	Access	Size	Notes
0EA75290-6759-A58D-7948-598C4E02D94A$_{16}$	*Write*	unknown	
450AA175-8D85-16A6-9148-D50E2EB7B79E$_{16}$	Read	The date and time of manufacture (?)	
		char[]	*A date and time string*
43EF14AF-5FB1-7B81-3647-2A9477824CAB$_{16}$	Read, Notify, Indicate	Reads the battery and accelerometer	
		uint16_t	*battery ADC value*
		uint16_t	*accelerometer X ADC value #1*
		uint16_t	*accelerometer Y ADC value #1*
		uint16_t	*accelerometer Z ADC value #1*
		uint16_t	*accelerometer X ADC value #2*
		uint16_t	*accelerometer Y ADC value #2*
		uint16_t	*accelerometer Z ADC value #2*
		uint16_t	*accelerometer X ADC value #3*
		uint16_t	*accelerometer Y ADC value #3*
		uint16_t	*accelerometer Z ADC value #3*
		uint16_t	
9590BA9C-5140-92B5-1844-5F9D681557A4$_{16}$	Write		Unknown

***Table 111:** Cube's accelerometer service characteristics*

Presumably some of these will cause the Cube to go into over the air update (OTAU) mode, allowing its firmware to be updated.

Others turn the RGB on to an RGB color, possibly duty cycle and pulsing duty cycle

65. VECTOR SERVICES SERVICE

times and other feature parameters:

Service	UUID[49]	Description & Notes
Generic Access Profile	1800_{16}	The device name, and preferred connection parameters
Generic Attribute Transport	1801_{16}	Provides access to the services.
Vector's Serial Service	$FEE3_{16}$	The service with which we can talk to Vector.

***Table 112:** Vector's Bluetooth LE services*

It appears that there isn't a battery service on the Vector.

Element	Value
Device Name (Default)	"Vector" followed by his serial number

***Table 113:** The Vector's Device info settings*

[49] All values are a little endian, per the Bluetooth 4.0 GATT specification

65.1. VECTOR'S SERIAL SERVICE

UUID	Access	Format	Notes
30619F2D-0F54-41BD-A65A-7588D8C85B45$_{16}$	Read, Notify,Indicate		
7D2A4BDA-D29B-4152-B725-2491478C5CD7$_{16}$	write		

Table 114: *Vector's serial service characteristics*

APPENDIX F

Servers & Data Schema

This Appendix describes the servers that Vector contacts[50]

Server	Description & Notes
chipper.api.anki.com:443	The speech recognition engine lives here
conncheck.global.anki-services.com/ok	Used to check to see if it can connect to Anki
jdocs.api.anki.com:443	Storage of some sort of data. Name, faces, prefs?
token.api.anki.com:443	Used to get the API certificate.[51]
https://anki.sp.backtrace.io:6098/post?format=minidump&token=6fd2bd053e8dd542ee97c05903b1ea068f090d37c7f6bbfa873c5f3b9c40b1d9	Vector posts crashes (linux minidumps) to this server. This is hard coded in anki-crashuploader
https://sqs.us-west-2.amazonaws.com/792379844846/DasProd-dasprodSqs-1845FTIME3RHN	This is used to synchronize with data analytics services.
https://ota.global.anki-services.com/vic/prod/	Where Vector checks for updates
https://ota.global.anki-dev-services.com/vic/rc/lo8awreh23498sf/	For the Developer branch
amazon.com/code	Where do the images of faces go?

Table 115: *The servers that Vector contacts.*

The Alexa modules contact the following servers:

Server	Description & Notes
https://api.amazon.com/auth/O2/	Used to authenticate the account for the Alexa device.
https://avs-alexa-na.amazon.com	The Alexa Voice Service that accepts the spoken audio and returns a rich intent. Amazon changed preferred URLs on 2019 May 22, and this the is considered legacy.[52]

Table 116: *The Amazon Alexa Voice Service servers that Vector contacts.*

[50] Todo: sync up with info at: https://github.com/anki-community/vector-archive
[51] XYZ had a write up, reference that.
[52] https://developer.amazon.com/docs/alexa-voice-service/api-overview.html

APPENDIX G

Features

The following is the set of features and whether they are enabled:

Table 117: *The features*

Feature	enabled	Description & Notes
ActiveIntentFeedback	true	
Alexa	true	The ability to use Alexa
Alexa_AU	true	The ability to use Alexa, localized for Australia
Alexa_UK	true	The ability to use Alexa, localized for the UK
AttentionTransfer	false	
CubeSpinner	false	
Dancing	true	The ability for Vector to dance to music.
Exploring	true	The ability for Vector to explore his area
EyeColorVC	true	The ability to set Vector's eye color through a voice command
FetchCube	true	The ability for Vector to fetch his cube
FindCube	true	The ability for Vector to find his cube
GazeDirection	false	
GreetAfterLongTime	true	
HandDetection	true	The ability for Vector to spot hands
HeldInPalm	true	
HowOldAreYou	true	The ability for Vector to track how long it has been since he was activated (his age) and use that info to respond to the question "How old are you?"
Invalid	false	
Keepaway	true	
KnowledgeGraph	true	The ability for Vector to answer a question when asked "Hey Vector, I have a question…"
Laser	false	
Messaging	false	
MoveCube	true	

PopAWheelie	true	The ability for Vector pop a wheelie using his cube
PRDemo	false	
ReactToHeldCube	true	
ReactToIllumination	true	
RollCube	true	The ability for Vector to drive up and roll his cube
StayOnChargerUntilCharged	true	
TestFeature	false	
Volume	true	

APPENDIX H

Phrases and their Intent

This Appendix maps the published phrases that Vector responds to and their intent:

Table 118: *The "Hey Vector" phrases*

Intent	Phrase
movement_backward	Back up
imperative_scold	Bad robot
	Be quiet
global_stop	Cancel the timer
	Change/set your eye color to [blue, green, lime, orange, purple, sapphire, teal, yellow].
check_timer	Check the timer
imperative_come	Come here
imperative_dance	Dance.
play_popawheelie	Do a wheelstand
imperative_fetchcube	Fetch your cube
imperative_findcube	Find your cube
play_fistbump	Fist Bump
play_fistbump	Give me a Fist Bump
movement_backward	Go backward
explore_start	Go explore
movement_forward	Go forward.
movement_turnleft	Go left
movement_turnright	Go right
	Go to sleep
	Go to your charger
	Good afternoon
greeting_goodbye	Goodbye
	Good evening
	Good night
greeting_goodmorning	Good morning

imperative_praise	Good robot
seasonal_happyholidays	Happy Holidays
seasonal_happynewyear	Happy New Year
greeting_hello	Hello
	He’s behind you
character_age	How old are you
imperative_abuse	I hate you.
knowledge_question	I have a question …
imperative_love	I love you.
imperative_apology	I’m sorry.
play_blackjack	Let’s play Blackjack
	Listen to music
imperative_lookatme	Look at me
	Look behind you
	My name is [Your Name]
imperative_negative	No
play_anygame	Play a game
play_anytrick	Play a trick
play_blackjack	Play Blackjack
play_pickupcube	Pick up your cube.
play_popawheelie	Pop a wheelie.
play_rollcube	Roll your Cube
	Run
set_timer	Set a timer for [length of time]
explore_start	Start Exploring
	Stop Exploring
global_stop	Stop the timer
take_a_photo	Take a picture of [me/us]
take_a_photo	Take a picture
take_a_photo	Take a selfie
movement_turnaround	Turn around
movement_turnleft	Turn left
{same as quiet down}	Turn off
movement_turnright	Turn right
imperative_volumelevel	Volume [number].
imperative_volumedown	Volume down
imperative_volumeup	Volume up.
	Volume maximum
names_ask	What's my name?

weather_response	What's the weather in [City Name]?
weather_response	What's the weather report?
show_clock	What time is it?
imperative_affirmative	Yes

Note: Vector's NLP server doesn't recognize "home" ..

Questions

Table 119: *The Vector questions phrases*

Subject	**Example Phrase**
Current conversion	What's 1000 Yen in US Dollars?
Flight status	What is the status of American Airlines Flight 100?
Equation solver	What is the square root of 144?
General knowledge	What is the tallest building?
places	What is the distance between London and New York?
People	Who is Jarvis?
Nutrition	How many calories are in an avocado?
Sports	Who won the World Series?
Stock market	How is the stock market?
Time zone	What time is it in Hong Kong?
Unit conversion	How fast is a knot?
Word definition	What is the definition of Artificial Intelligence?

APPENDIX J

Pleo

The Pleo, sold in 2007 –a decade prior to Vector – has many similarities. The Pleo was a software skinned animatronic baby dinosaur created by Caleb Chung, John Sosuka and their team at Ugobe. Ugobe went bankrupt in 2009, and the rights were bought by Innvo Labs which introduced a second generation in 2010. This appendix is mostly adapted from the Wikipedia article and reference manual.

Sensing for interacting with a person

- Two microphones, could do beat detection allowing Pleo to dance to music. The second generation (2010) could localize the sound and turn towards the source.
- 12 touch sensors (head, chin, shoulders, back, feet) to detect when petted,

Environmental sensors

- Camera-based vision system (for light detection and navigation). The first generation treated the image as gray-scale, the second generation could recognize colors and patterns.
- Four ground foot sensors to detect the ground. The second generation could prevent falling by detecting drop-offs
- Fourteen force-feedback sensors, one per joint
- Orientation tilt sensor for body position
- Infrared mouth sensor for object detection into mouth, in the first generation. The second generation could sense accessories with an RFID system.
- Infrared detection of objects
- Two-way infrared communication with other Pleos
- The second generation include a temperature sensor

Annuciators and Actuators

- 2 speakers, to give it sounds
- 14 motors
- Steel wires to move the neck and tail (these tended to break in the first generation)

The processing

- Atmel ARM7 microprocessor was the main processor.
- An NXP ARM7 processor handle the camera system, audio input
- Low-level motor control was handled by four 8-bit processors

A developers kit – originally intended to be released at the same time as the first Pleo – was released ~2010. The design included a virtual machine intended to allow "for user programming of new behaviors."[53]

65.2. SALES

Pleo's original MSRP was $350, "the wholesale cost of Pleo was $195, and the cost to manufacture each one was $140" sold ~100,000 units, ~$20 million in sales[54]

The second generation (Pleo Reborn) had an MSRP of $469

65.3. RESOURCES

Wikipedia article. https://en.wikipedia.org/wiki/Pleo

iFixit's teardown. https://www.ifixit.com/Teardown/Pleo+Teardown/597

Ugobe, *Pleo Monitor*, Rev 1.1, 2008 Aug 18

Ugobe, *Pleo Programming Guide*, Rev 2, 2008 Aug 15

[53] https://news.ycombinator.com/item?id=17755596
[54] https://www.idahostatesman.com/news/business/article59599691.html
https://www.robotshop.com/community/blog/show/the-rise-and-fall-of-pleo-a-fairwell-lecture-by-john-sosoka-former-cto-of-ugobeJohn Sosoka