ANKI VECTOR

CA GROUP ASSIGNMENT

104.3 COMPUTER ARCHITECTURE

20.3 PLYMOUTH FOC BATCH NATIONAL SCHOOL OF BUSINESS MANAGEMENT

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NATIONAL SCHOOL OF BUSINESS MANAGEMENT

20.3 PLYMOUTH BATCH

FACULTY OF COMPUTING

PREPARED BY

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(1ST YEAR 2ND SEMESTER STUDENTS)

SUPERVISED BY

MR. GAYAN PERERA

PREFACE

This is the effortful work of our group, which was formed specifically for the Computer Architecture module, which was delivered by Mr.Gayan Perera during the 1st year 2nd semester. We are greatly thankful to him for showing us the way, guiding us through the obstacles, to reach the destination that we all yearned.

It was a challenging time amidst the pandemic to form a group among the people who we barely knew since the university was closed and there was no chance for a physical gathering and discuss the proceedings. Nevertheless we strongly endured these circumstances and kept our minds steady and worked as a whole to attain the milestone.

We held online meetings regularly for discussion purposes and made some tough decisions to nip perfection of the report. After many conversations we agreed on studying about a household robot as known as “Anki vector” which is considered as a human-friendly machine. We would give a total background on this device in the upcoming chapters. Through the module concepts learned, we are more than capable of explaining the architecture of the device in a clearer way to the reader.

Last but not least we once again highly appreciate everyone who has given their maximum for us to achieve this task.

ABSTRACT

Learning Computer Architecture will gain the fundamental knowledge of on how a computer is built from the scratch, taking in to consideration things such as the arrangement of the components (RAM, Processor, Registers, Caches etc.) and the way in which these components inter-relate in order to achieve a common task by enabling the relevant functions in each component.

*"**Computer architecture** is a set of rules and methods that describe the functionality, organization, and implementation of computer systems". ~ quoted from Wikipedia*

This project contains the details of a specific device which is currently in use among the human kind, built using the help of computer architecture knowledge. As this progress, the reader shall obtain a thorough on the architecture of the relevant device and functions of each and every component.

The First Chapter will enlighten an overall idea about the product which will be analyzed and discussed in the upcoming chapters. It will explain the design overview of the product and specifically mention the components which help to function the device. Moving forward the Second Chapter will depict the features and specification of the processor and all the essential items mentioned. The Third Chapter will guide through the battery and its specialty to carry out the functions of the device.

The remaining Two Chapters mainly focuses on the external devices and the external technology that is required to function the product properly in order functional the device at full capacity. This would help to gain an overall view on the product and its capability on the basis of its functionalities.

Each Chapter will elaborate on a certain thing to connect with the flow of the details mentioned which would be very helpful indeed to get a better understanding. Also at the latter part a summary is mentioned for a quick reference of the specification.

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CHAPTER 1
1.2 INTRODUCTION

"Anki" was a company which was initiated with the idea of bringing innovative inventions of robotics combined with artificial intelligence. It was private limited company which was founded by three personas by the names of Mark Palatucci, Borris Sofman, and Hanns Tappeirer back in 2010. Their first ever working product was **Anki Drive**, which was a physical racing car game build with intensions of attracting younger generations, introduced during the year of 2013. It was developed as a software which was released to the Apple Corporation, which was launched as an App in the App Store.

Soon another product was introduced, known as **Cozmos** but unfortunately the company went bankrupt and all the assets of the company were bought by the Digitaldream Private Limited company. During that phase the company was upgrading the Cozmos in to a better version with many more features than the initial stage of the product **(i.e. including Wi-Fi facility, voice commands, facial recognition etc.).** It was given the name as **"Vector",** it was an advanced version of cozmos built based on the foundation technology of cozmos. It was released on the 18th of December 2018 for consumer use, which this time was partnered with Amazon's Alexa.

Basically Anki Vector is considered as a human friendly device which can be very helpful at certain times due to the advanced technology used by the company as mentioned above. Due to the awareness of its surrounding it is considered as a product with many utilities. An in-depth analysis is carried out in the upcoming chapters regarding this amazing spin off.

1.2 OVERVIEW OF THE DEVICE

Vector can be recognized as a human-friendly companion, buddy adjusting itself to a playful mode when needed. As of its physical scale (palm sized) people are very fond of this robot.

If we take a look at the externally placed features of this product, it contains a **tilt-able head, a camera to display facial expression, a speaker, arms, sensors and wheels.**

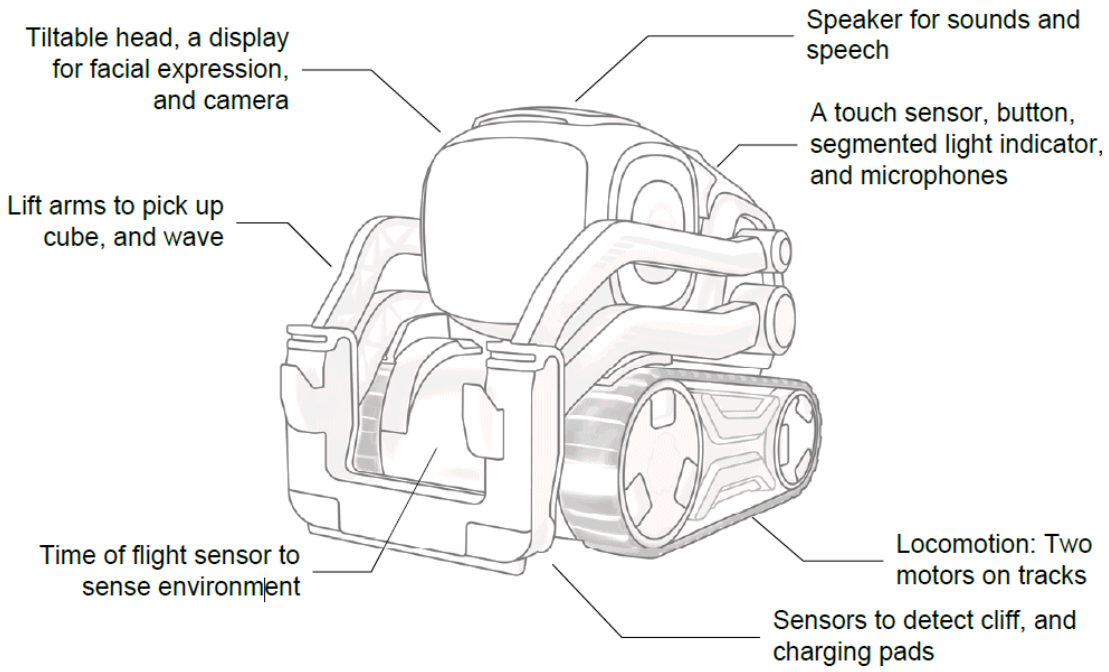

Figure 1

<u>Input sensors hold accountability for the below mentioned processes</u>

- A sensor to detect the tangibility of human contact.
- The inside microphone is used to listen, grasp instructions and derive the ambient level
- On/Off button and to cause it listen or to enable silent mode.
- Head and other compartments are being raised through detection.

Functions performed by the other receivers

- Categorized light on backpack are used to indicate when the device is working, when it is required to charge, when Wi-Fi is not connected properly, for resetting or rebooting processes.
- The LCD display represents the Vector's eyes, and speakers are used to for speech synthesis and to produce different sounds.
    - **Global sensors**
        - Through the vision, by mapping the area, for detection of other tangible things around the Vector and also for facial recognition
        - Functioning of inertial measurement unit
        - Proximity sensors helps in localizing and preventing from collisions.
    - **Local sensors**
        - Volt(voltage) indicator, temperature, charging level
        - IMU for co-ordination and positioning
        - Encoders provide feedback to the motor rotation
    - **Motion Controller**
        - In the bottom level it can manure each of the motor's speeds, cycles of rotation etc. This permits the device to make sudden movements.
        - Being collinear with the local sensing, the device is able to move in with a displacement and make hard turns.
        - Dynamic nature is withheld using a skid-steering kinematic model
        - For all of these activities the motion controller takes in the analyzed information from the motor encoder.

- **Functions of the CUBE**
  - ❖ Sparkling nature
  - ❖ Movement sensing
  - ❖ Links to navigation system for mapping

Figure 2

Figure 3

1.3 DESIGN ANALYSIS

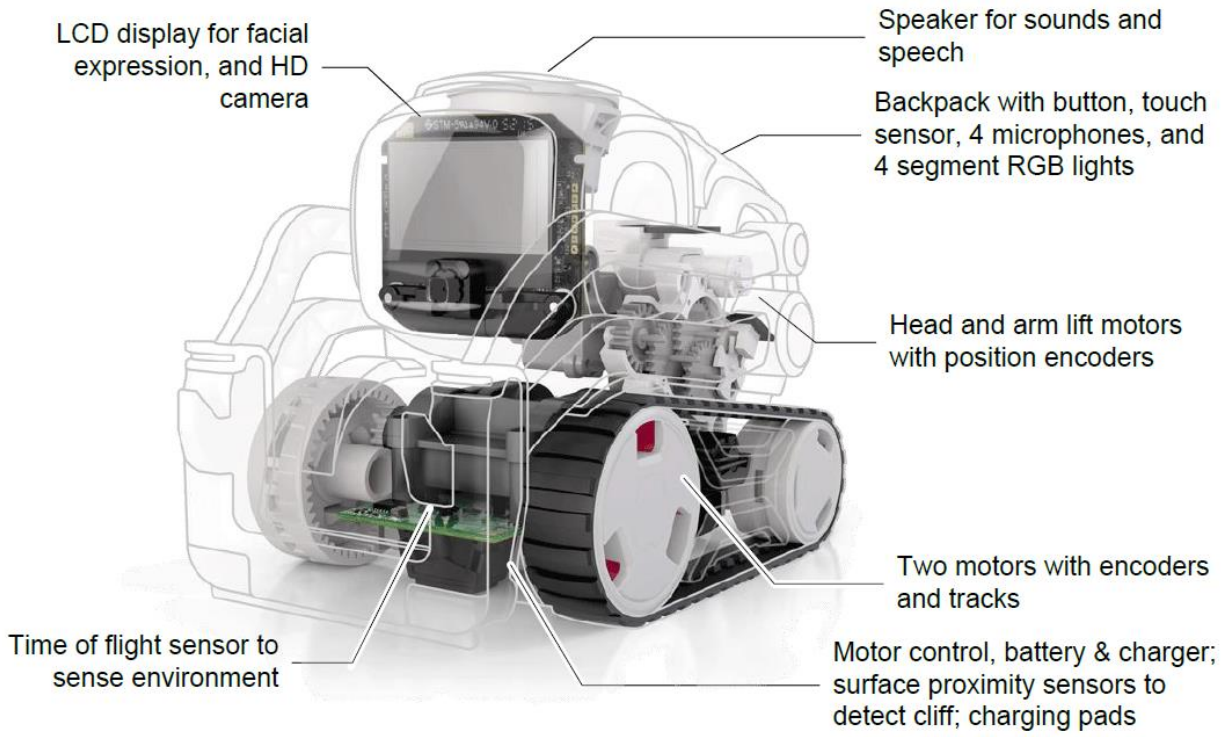

Figure 4

Taking a close look at the structural arrangement of the specific components such as the **Battery, Camera, LCD display, Microphones, LED lights and Speaker**, these components play a major role to function the device efficiently. In the upcoming chapters it is investigated how these components function one by one accordingly when the device is switched on.

➢ Battery	Energy is extracted through a local battery pack
➢ Camera	HD camera to visualize its surrounding, and detect its human contacts.

➢ LCD display	A LCD, with an area of 23.2mm x 12.1mm. It has a resolution of 184 x 96 pixels, with RGB color.
➢ Microphones	There are 4 local in-field microphones to engage to instruction and ambient activity level. It hires beam forming to localize sounds.
➢ Segmented RGB lights	Through the 4 LEDs it would indicate On nature, when required charging, when heard the wake word, when talking to the Cloud, disabled from Wi-Fi, when booting and when resetting (wiping out his robot-specific information).
➢ Speaker	Used for sound exposure and for speech synthesis.

In order to proceed, first it is necessary to understand the heart of the device (circuit board) and how these above mentioned components are inter-connected to the circuit board in order to function. These will be further elaborated in the next few chapters.

CHAPTER 2

2.1 CIRCUIT BOARD

As clearly stated above, to power up every component on the body of Vector, the circuitry of the Anki Vector is quite unique in its own ways. This is because the dual board construction makes all the components of Vector work in unison.

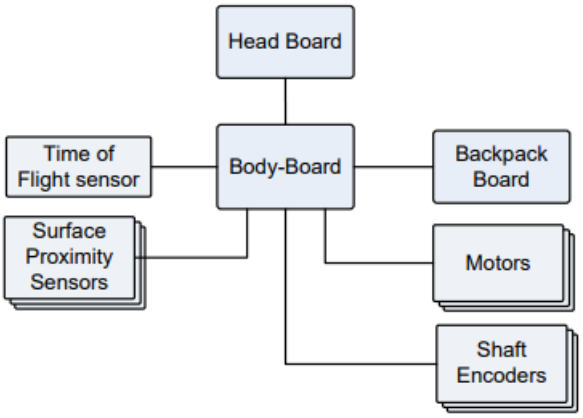

Diagram 1

The head board takes care of the processing part of Vector while the body board is utilized in taking care of the movement of him, which includes various mobility motors and sensors. The connection between the afore mentioned boards will allow Vector to work flawlessly. The main board consists of a couple of parts including the LCD screen which allows Vector to express facial expressions and an HD camera to interact with the outside world and get information. The body board on the other hand has some major components connected to it as well. This includes the motors for motion, proximity sensors for obstacle avoidance and prevention from falling off surfaces (cliffs).

2.2 HEAD BOARD (MAIN PROCESSOR BOARD)

The head board has various components such as the main processor, **RAM**, **IMU** and **PMIC**. The Wi-Fi and the Bluetooth modules are also inbuilt on the board. The IMU stands for Inertial Measurement Unit (This will be further explained). This unit is a 6-axis sensor which measures various properties such as orientation, gravitational forces and velocity by making calculations by taking into account the accelerometer, gyroscope and magnetometer. The PMIC on the other hand is a Power Management Integrated Circuit which controls the flow and direction of the electrical power within the system. The HD camera and the LCD display of the Anki Vector is also attached to this particular board by means of a flex tape. The speaker is also attached onto this board.

2.3 PROCESSOR

- All of Vector's real-time processing is done with the aid of a **Quad-core Arm-A7 Qualcomm APQ8009 microprocessor**. Each core is a **32-bit ARM Cortex A7**. This processor also includes an **Adreno 304 GPU**.

- The Bluetooth and WIFI transmitters are also included into this processor, making it very spacious and power efficient.

- The processor also has a power capping function in order to further save power and for better battery management (which will be further explained in depth ahead).

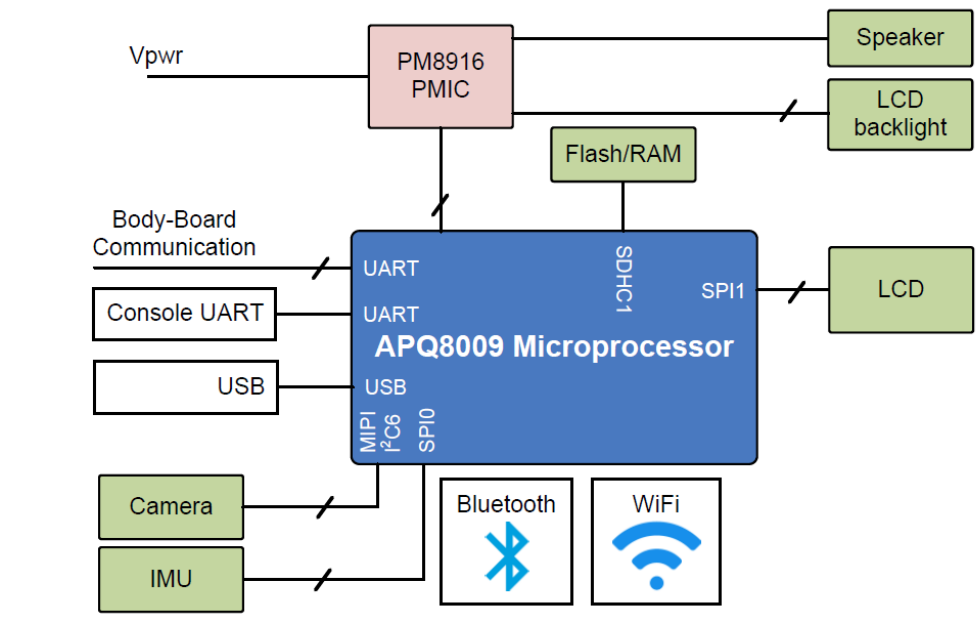

Diagram 2

2.4 BODY BOARD

The body board acts as a secondary processor in order to fulfill another set of tasks different to that of the main processor. The main tasks that the body board control are charging the battery and the actual movement that Vector performs. The body board acts as the junction in order to connect the battery to the rest of the system components. It is also responsible for the battery management and the actual charging of the battery.

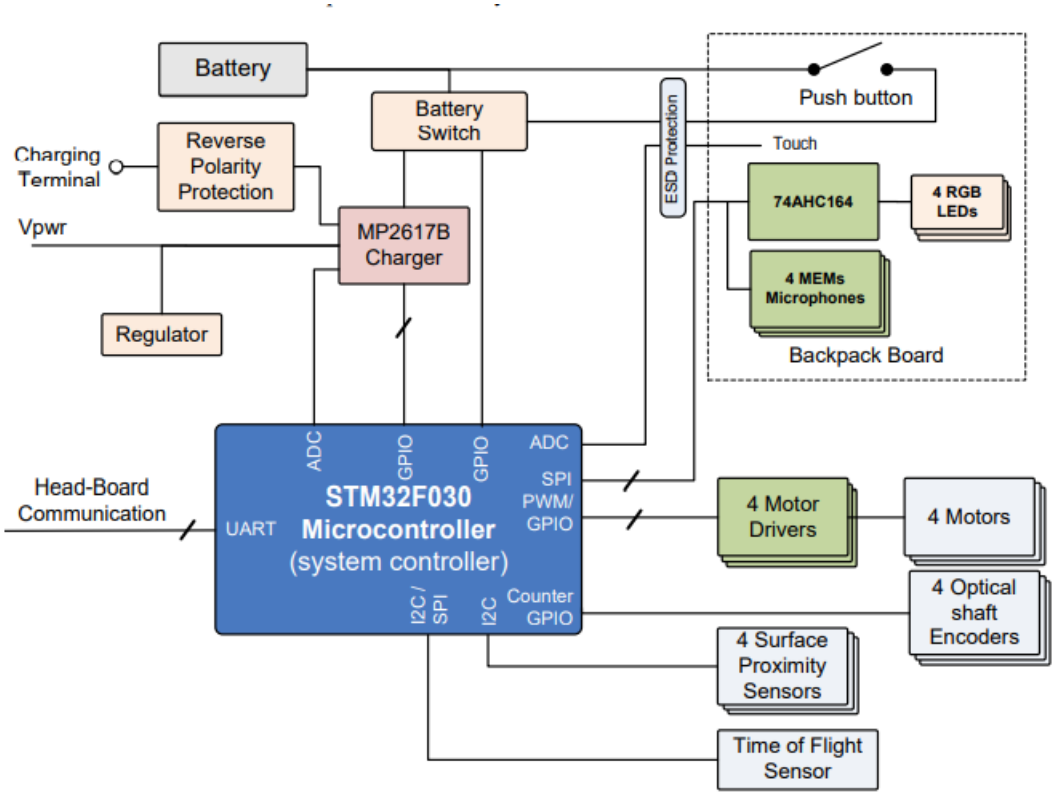

Diagram 3

There are four motors which are connected to the body board of the Vector and they are utilized for various actions that Vector has to perform. One of the motors control the tilting of Vector's head, another controls the motion of Vector lifting his arms while the other two contribute to the actual movement of Vector. The dual motors allow forward and backward motion, allowing Vector to move back and forth while also controlling the speed of the two tracks present on Vector's underside allowing him to take turns quite sharply, even in a tiny environment. Four proximity sensors are also connected to Vector's body board in order to monitor the surrounding and not to fall down from any surface that he may be kept on. A Time of Flight (TOF) sensor is also hardwired on to the body board in order to measure the distance between vector and the objects on its immediate surroundings, allowing him not to bump into anything around him.

2.5 BACKPACK BOARD

The backpack board is a secondary board to the body board, as it contains a lot of the tiny components which make up the whole system of Vector to work flawlessly. Several smart peripherals and extra IO is connected to this backpack board.

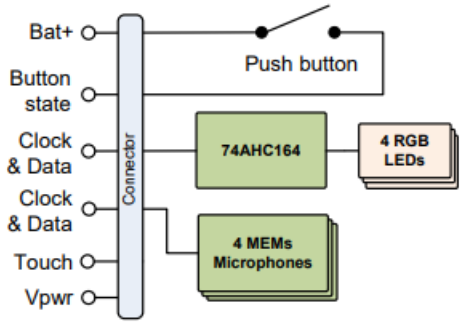

Diagram 4

Components which make up the backup board

- **74AHC164** – This is used to drive the RGB LED's.
- **Microphones** – There are 4 far-field microphones.
- **Push Button** – The push button is connected to the battery.
- **RGB LED's** – There are 4 RGB LED's which can be illuminated individually.
- **Touch Sensor** – A touch sensing wire which is further connected to more complex components.

CHAPTER 3

3.1 BATTERY

Vector do not consist a coulomb counter to recognize the remaining energy for the rest of the work to be done.

Volts (Voltage) - used to predict the battery state.

- The full charge state of the battery is 4.2V (but it will only be considered as fully charged when the voltage is above 3V).
- The LED light indicating the charging requirement will start to blink when the voltage value goes below 1V.

Fuel gauge

- Basically considered as a coulomb counter, is mainly used to prevent any fire or explosion due to overwhelming charging, but in this system it is done using a software.
- Presence of a virtual fuel gauge through a software gives Vector the sense of returning to the starting position, perhaps to take necessary measures to save the battery left.

Calm Power mode

Vector consists of a unique power mode called **"calm power mode."** This mode will be activated normally when Vector is charging. Vector turns off the sensors, minimize the CPU and camera clock rate – or may even disable the camera.

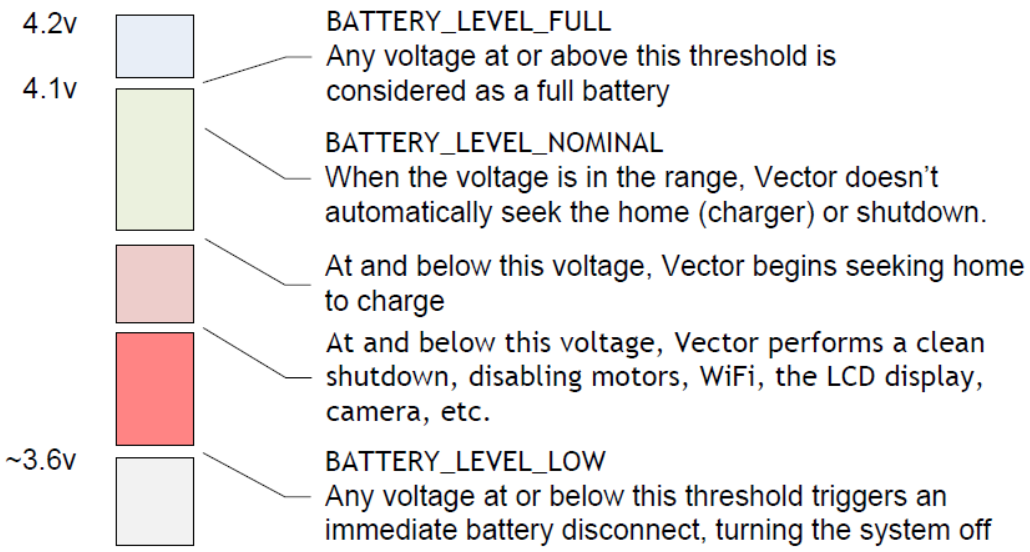

Diagram 5

3.2 LCD DISPLAY

An LCD display is mainly used to depict eyes of a human. Vector's best imagery is his robot eyes. Vector smiles and his eyes reveal a variety of expressions. The LCD is connected to the processor through SPI, and it is illuminated by two LEDs. Previous generation's face and eyes were displayed on an OLED display, however OLEDs are prone to burn-in, uneven dimming, and discoloration of overworked pixels. But the LCD is likewise less prone to burn-in, albeit at the cost of higher power consumption.

LCD ARCHITECTURE

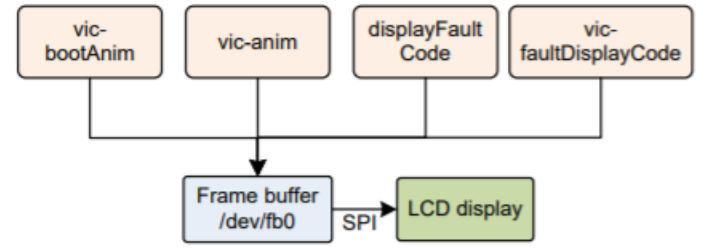

Diagram 6

Basically, when describing the LCD architecture, the display can be accessed by four separate apps, and an SPI interface connects the LCD to the MPU (Main Power Unit). The frame buffer (/dev/fb0) is a buffer that contains information about its breadth, height, pixel format, and alignment. To construct Vector's face (his eyes), animated text jumping and exploding, and mini films like rain or fireworks, vic-anim uses a smart screen compositing technology. When considering about the Vic faulty Display Code and custom care screen has a distinct visual design from the rest of Vector.

SPECIAL SCREENS AND MODES

Vector includes three unique screens and two distinct modes. The unique screens are;

- A Customer Care Info Screen (CCIS) that can show sensor values and other internal data.
- The serial number (ESN) and IP address of Vector are shown on a debug screen.
- When there is an internal failure, the fault code display is used to display a three-digit fault code (this screen is only displayed if there is a defect and cannot be triggered by an operator).

Vector has two unique modes.

- Getting into recovery mode forces Vector to utilize factory software and install replacement firmware. (User data is not deleted in this mode.)
- “Factory reset,” which wipes out all user data as well as Vector's robot name.

3.3 CAMERA

Presence of 720px with a 120º surround view, the camera is calibrated at manufacturing. Its vertical sync (frame sync) is connected to disturb the input on the IMU to synchronize the samples. Vertical synchronization signal is connected to the interrupt line on IMU, making the engagement of the accelerometer and gyroscope sampling inter-connected with the camera frame. Through the vision it would enable to navigate the current location with the aid of the data from the IMU. By the infusion of the above two sources it would accurately determine the current location and the combined movement in a way that could be measured.

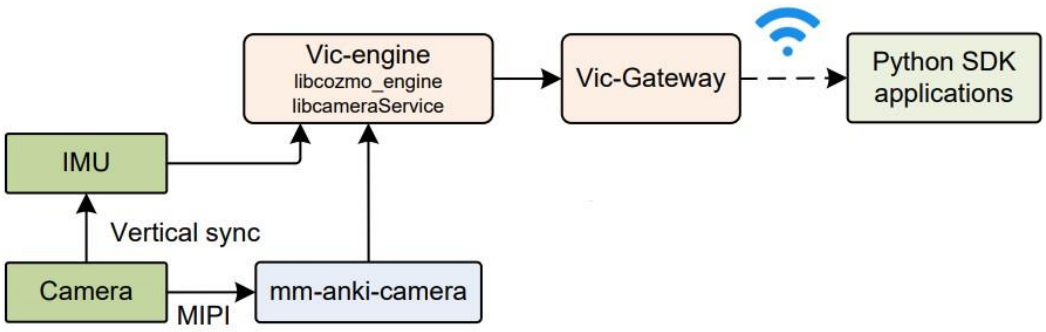

Diagram 7

- Comparison of the image must be carried out with the samples of IMU.

- Even with the transfer (to the processor) it would cause some delays of receiveing the image to the Vic-engine .
- Vertical sync – depicting the image which would be sampled – is used to enable the IMU to take a sample at the same time.
- Involved as a light sensor when Vector is in low power mode (e.g. napping, or sleeping).
- During the minimum power mode, it would suspend the acquiring images.
- But power supply is still carried out.
- The software reads the camera's auto-exposure/gain settings and uses these as an ambient light sensor. (This allows it to detect when there is activity and Vector should wake.)

CAMERA OPERATION

With a camera resolution of 1280x720 it could capture a 360^0 view without turning its head. Connection to the processor done by MIPI interfaces. Data is directly passed to device drivers and eventually passes to Vic-engine for processing

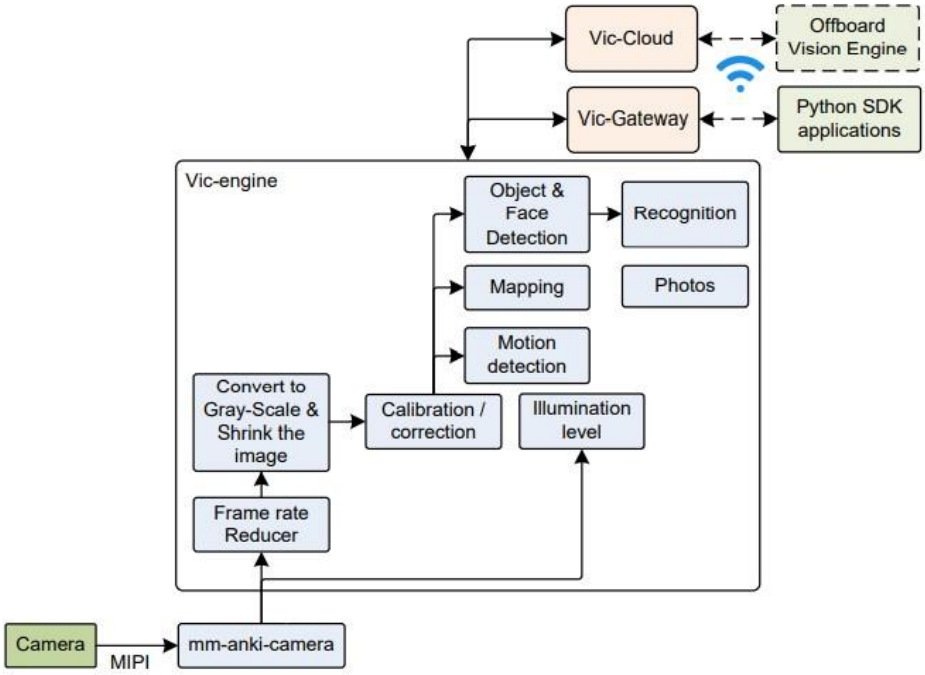

Diagram 4

- Technically Vector could identify the following elements in its environment:
  - Graphic makers (detected objects are considered as movable, while the rest will be ignored or identified as fixed or unmovable)

Graphics:

Heads

Hands

Pets (experimental stage),

Laser pointers,

All tangible objects

3.4 Speaker

Working with 16bits, single channel, inclusive with a sample rate of 8000-16025 samples/sec.

Sound depicts the emotions and perform activities such as responding, and obeying instructions where waves are streamed from SDK applications and Alexa's remote servers.

Sources of sound:

- Inbuilt audio files.
- Audio received and generated through externally parameters.
- Direct transmission from SDK application.
- Text to speech.
- Bulk of waves streamed from Alexa's Voice service.

The Audio Output Structure

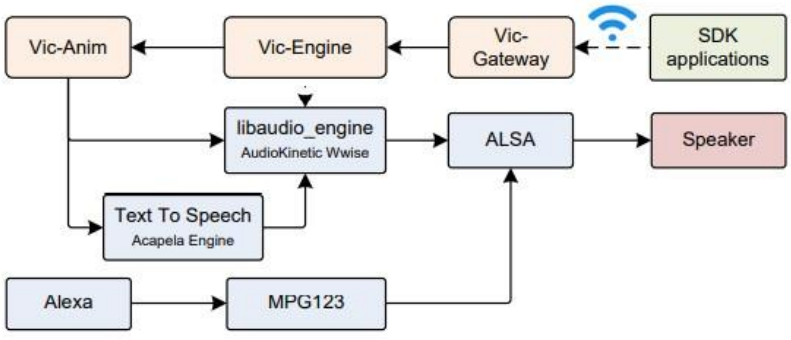

Diagram 10

3.5 MICROPHONE

The microphone of this device is a bit complex part which does many processes in a certain occasion when audio is given as an input.

The below shown diagram will indicate the process of audio being manipulated inside the microphone.

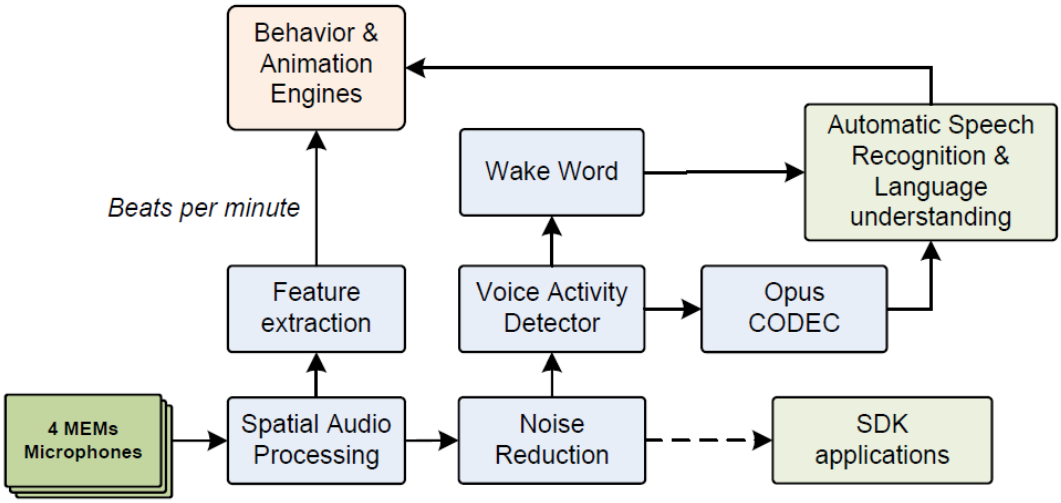

Diagram 11

Features included

- The spatial audio will circumscribe the disruption noises from the background.
- The stimulation activity of the Vector is handled by the feature extraction process.
- Key word which has been embedded will be recognized by the voice activity detector.
- Compression of audio is functioned by CODEC.

CHAPTER 4

4.1 CUBE

Cube is an external device which specializes Vector's certain activities. It comes with a charging dock, and it also consists of different optical identifiers in each side to perform certain functions. It is designed for the engagements with the Vector. The topside of the cube is adorned with colored LED's for Vector to identify the orientation of it.

Figure 5

<u>There are various components which make up the Companion Cube of Vector</u>

1) **Accelerometer** – This sensor is used in order to detect the movement of the cube and is also used for both the user and vector to play various games on the cube itself.

2) **Battery** – There is a 1.5 Volt battery powering on the components including the LED lights and sensors.

3) **Crystal** - The crystal provides a précised frequency reference used by the Bluetooth LE radio.

4) **Dialog DA14580** – This is the Bluetooth LE module which acts as the transmitter and receiver for the necessary protocols to be implemented.

5) **RGB LED's** – There are 4 RGB LED's present on the topside of the cube. Two LED's can have independent coloring and can blink and flash according to the condition.

4.2 INERTIAL MOTION SENSING

Vector's accelerometer and gyroscope ensures the protection of the device by being more vigilant about its environment (prevents falling, bumped in to objects etc.).

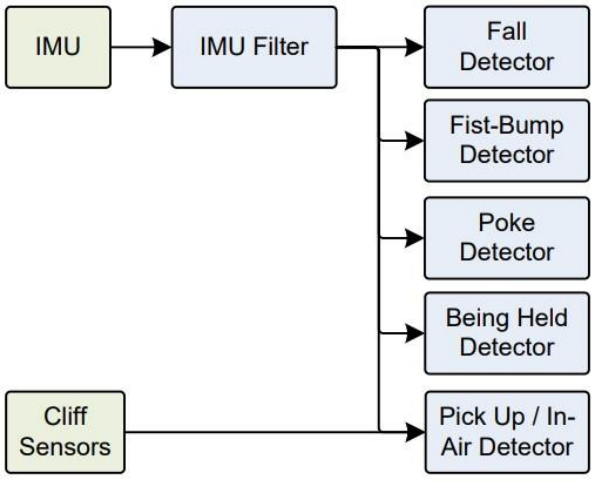

Diagram 12

ACCELEROMETER AND GYROSCOPE

Mainly the function of the accelerometer is to measure the forces along the axes X Y Z of the object, which tend to measure the gravitational force strength as well and provide exact information of the current position of the object when the object's motion is linear. While the gyroscope will measure the rotational motions around the axes. Hence the two would work co-linearly towards a common objective.

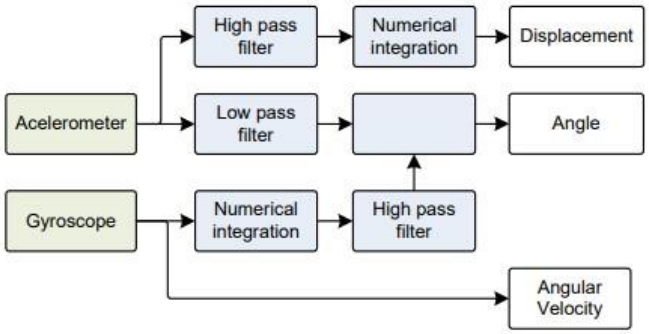

Diagram 13

CHAPTER 5

5.1 LEARNING OUTCOMES

TEMPERATURE LIMITS

The software driven inside the Vector tracks the temperature of the battery and head board in order to take necessary precautions to prevent overheating and to cool down the chipset.

It would indicate a warning sign at 90 degrees Celsius displayed through the overheating icon

Basically Vector would go to a half shut down at this kind of a instance (by disabling the peripherals such Wi-Fi display etc.). The objective of it is to save enough power in the head section to let the chip cool down.

When the processor APQ8009 is heated it would throttle its clock.

MICROPHONE TECHNOLOGY

Type of microphones- PDM (Pulse-density modulation)

- This would transform the weak signal strength/sampling rate to a higher sampling rate.

- **SPI**(Serial Peripherals interface)- Sends data between microcontrollers and peripherals Such as shift registers sensors and SD cards.

  In Vector there are four PDM microphones which are being read by a shared SPI clock and connected to two data lines.

Microphone input= One clock signal driven at one bit per clock

One data line is shared among two microphones

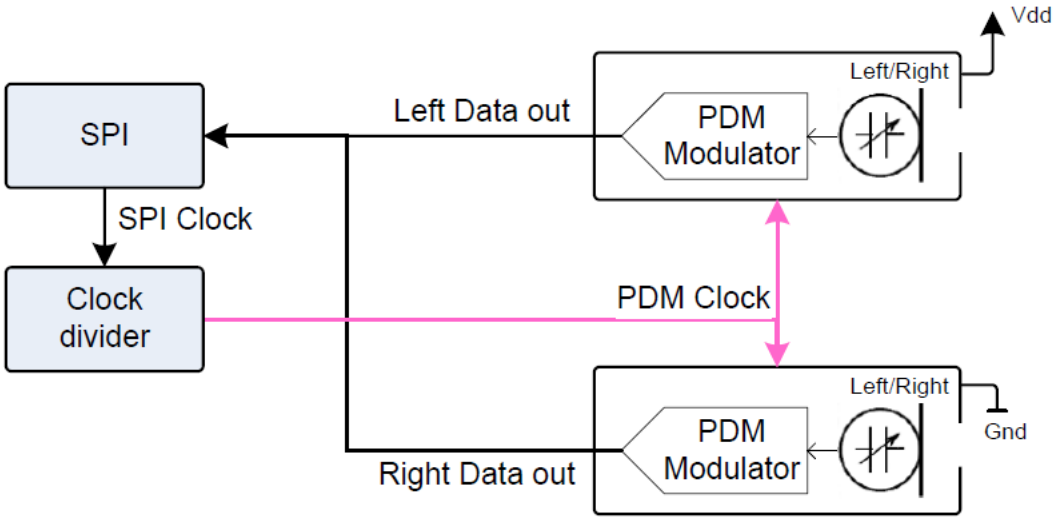

Diagram 14

Left microphone- "left/right" indicator would low-fi the signal and it will configure to produce the data bit maintaining a low PDM clock rate. Vice versa it would be the total opposite when the clock rate is high. While in right microphone-"left/right" the data bit will be transmitted under high PDM clock rate.

SPI will receive data bits, which are being transitioned low through the process and not by the high end. The technic is to function two SPI clock cycles which would enhance the frequency of PDM clock, so that first transition will be low-fi for the left microphone bit, and the second transition low-fi will be for the right microphone. Division of the SPI clock would produce the desired outcome.

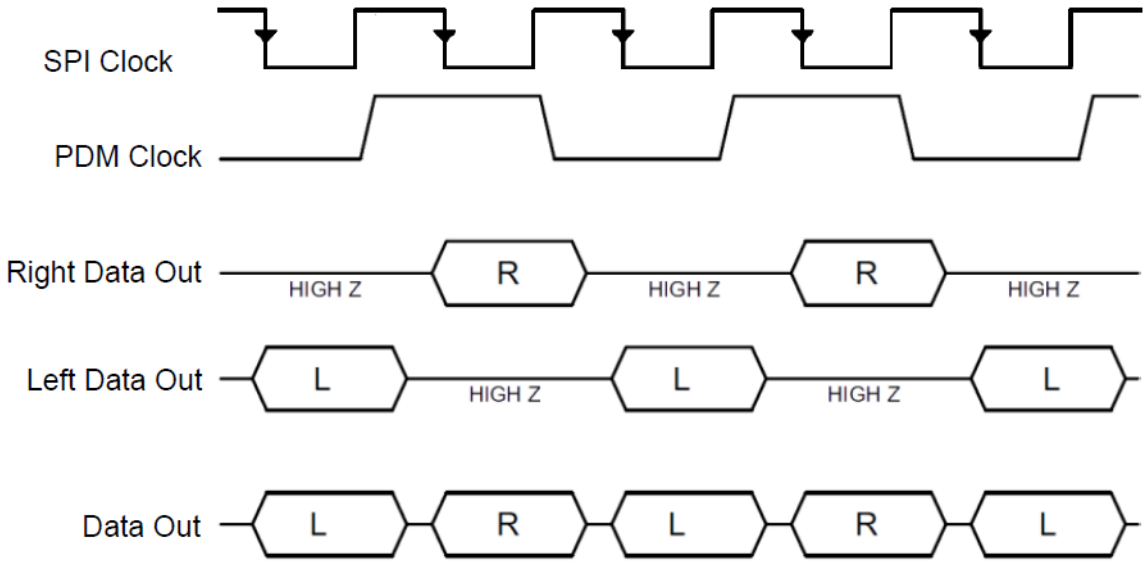
SPI Clock
PDM Clock
Right Data Out
HIGH Z
R
HIGH Z
R
HIGH Z
Left Data Out
L
HIGH Z
L
HIGH Z
L
Data Out
L
R
L
R
L

Diagram 15

5.2 SUMMARY

SPECIFICATIONS

MODEL NUMBER: T7P6

APPEARANCE : 3.9X2.4X2.7inch (HWD)

WEIGHT : 5.7Ounces

COLOR : Black

PROCESSOR : Quad-core Arm-A7 Qualcomm APQ8009 microprocessor

SPEAKERS : 16bit mono audio data.

GRAPHICS : Adreno 304 GPU frame rate between 8000-16025 Hz

LED DISPLAY : IPS color **display** with 184 X 96 resolution

BATTERY : 4.2V (Charging dock available)

ADVANCED

TECHNOLOGY : High-end IPS display- permits to produce wide spectrum of emotions

Reliable Touch receptors- enables to detect the contacts

HD Camera (ultra wide) - sensing the motions and detects unique Recognitions

Cloud connection upon Wi-Fi- operates with new functions

Axial IMU- location identification

5.3 WORK BREAKDOWN STRCUTURE

Group Name- **Digitron**

INDEX NO	NAME	CONTRIBUTION
21505	MPV BANDARANAYAKE	Elaborated on battery, design overview
21893	MN EDIRISINGHE	Elaborated on cube, processor
21268	MDCD CHAMATHKA	Elaborated on head board, body board
21751	WA PERIS	Gathered information and elaborated backpack body, microphone
18830	WMP GUNATHILAKA	Elaborated on speaker, LCD display
21315	KVAB WICKRAMASINGHE	Gathered information and elaborated on IMU
21184	DT WIJESINGHE	Gathered information and elaborated on Learning Outcomes
21259	AHNDN ALDENIYA	Elaborated on camera and summary
21812	VM SAMARASEKARA	Future suggestions and device overview

5.4 FUTURE SUGGESTIONS

Currently the dimensional scale of Anki Vector is very small, according to the details discussed above this would be very helpful indeed to the mankind with more adjustments and developments in the near future. Analysing the product and what the possible improvements which could be quite stretching the capabilities for the betterment would be:

- Increasing the dimensions
- Including Artificial Intelligence
- Increasing the task achievements (such as cleaning and lifting etc.)

.

ABBRIEVIATIONS

WIFI- Wireless Fidelity

LCD-Liquid Crystal Display

IMU-Inertial Measurement Unit

LED-Light Emitting Diode

HD-High Definition

RAM-Random Access Memory

PMIC-Power Management Integrated Circuit

TOF-Time of Flight

CPU-Central Processing Unit

OLEDS-Organic Light Emitting Diode

IO-Input/Output

SPI-Serial Peripherals Interface

MPU-Main Power Unit

CCIS-Customer Care Info Screen

ESN-Electronic Serial Number

IP-Internet Protocol

VIC-Vector

SDK-Software Development Kit

CODEC-Compress/Decompress

PDM-Pulse Density Modulator

MIPI- Mobile Industry Processor Interface