Implementing it

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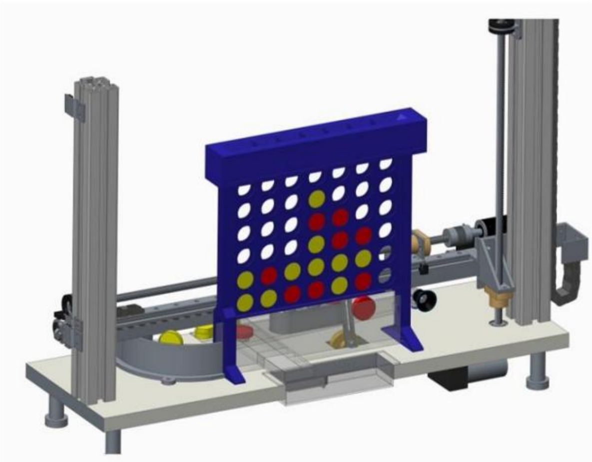

Laurens Verbruggen (3886182)

1/20/2023

Implementing the control system of the 4 in 1 row robot.

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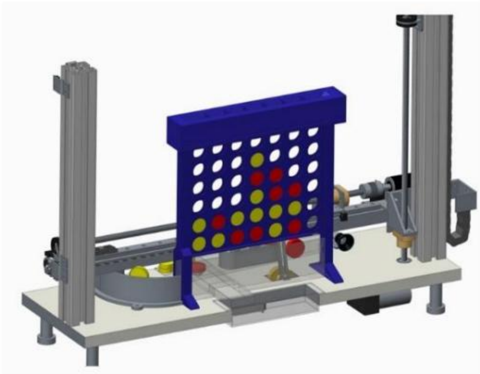

Preface

As a student at Fontys Mechatronics, I didn't get much of a chance to work on a printed circuit board and to really delve into electronics. Fortunately, with a well-formulated assignment and a lot of interest, you can still get those kinds of assignments during an internship. My main interest during my studies was the development of printed circuit boards, and thanks to Alten's help I have spent the past six months working on a printed circuit board in which all facets were present.

Alten had an assignment in which the main control of the 4-in-1-row robot had to be improved. The assignment arose from the demand for better software integration with the hardware in the robot, with a request to use a dual-core STM32. For this, the entire printed circuit board had to be redesigned. This design step was my focus for this project.

During my project I had to deal with the chip shortage that is currently occurring in the electronics world. This chip shortage arose from the shortage of production of electronic components and is felt in every technical field. This added a challenge to the project making component selection significantly more difficult and placing great emphasis on working safely with these costly components.

I would like to thank my supervisor at Alten, Vincent van Hoek, for the regular coaching and mentoring sessions. I owe my connection within the company to a large extent to that.

In addition, I would like to thank my business manager Jos Deelen for the opportunity to carry out this assignment, and the support and feedback during the project. I would also like to thank the rest of the business managers for the practice sessions of the presentation and feedback rounds of this report.

I could not have carried out this project without the help of my colleagues in the Mechatronics department: Jeroen Wilbers and Robert Wijma. Thanks for looking over my shoulder.

Lawrence Verbruggen

Eindhoven, January 2023

Abbreviations

Abbreviation	Meaning
AI	Artificial Intelligence
UART	Universal Asynchronous Receive Transmit
GPIO	General Purpose Input and Output
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
BJT	Bipolar Junction Transistor
PWM	pulse-width modulation

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Summary In order to

improve the hierarchy and structure of the software of the 4-in-1-row robot, Alten asked to replace the microcontroller of the 4-in-1-row robot with a dual-core STM32 microcontroller. To realize this, a new printed circuit board had to be developed to which it could be connected.

This report answers the question: what is needed to implement a dual-core STM32 in the 4-in-1-row robot? This involves looking at what is needed to develop this new printed circuit board.

To make this development on the new printed circuit board, a design cycle according to the V model has been carried out. In this design cycle, the state of the robot has been disregarded and no mechanical adjustments have been made to it. Much attention has been paid to the functionalities of the robot and the desired solution for controlling it. In addition, several problems that occurred in the previous design have been resolved. These design decisions are documented in the System Design Document.

The test phase has shown that the control of the robot works. In addition, the various circuits in the design were tested according to a test plan. The actuators, sensors and switches have been tested and demonstrably functioning by means of a demo. However, there appears to be an error in the control of the actuators, which can be repaired.

It is therefore recommended to make a repair on the printed circuit board. In the meantime, this error should be taken into account when using the PCB. In addition, it is recommended to continue the programming of the control of the robot using this dual-core microcontroller by means of a follow-up project.

1. Project definition

Alten has been working for several years on a robot that is able to play the 4-on-1 game against members of the public during events. This robot is an internal project that has been worked on by several employees. The robot is set up in the company's workshop and is improved and expanded through projects. This chapter describes the robot and the company that builds it. In addition, it describes the assignment with which the improvement to the robot is made and the reason for this project. It provides information about the work that has been done in advance and what the project is building on.

The purpose of this chapter is to provide more context about the operation and background of the assignment. It explains the terms used in the report and provides information about the context of the project.

1.1. Alts

Alten Nederland is a consultancy and engineering organization that supports various (mostly technically oriented) companies in technical developments with its consultants. The company specializes in IT, Technical Software and Mechatronics. These branches each have their own customers and are spread over various branches throughout the Netherlands. Due to the nature of the business, it has few consultants working from its own offices. Most of the employees work on location at the customer. Only a few employees are positioned in the office and working on internal projects for clients or on idle projects.

In order to give these consultants, who do not have a project at the time, the opportunity to continue working on their skills, and also for the production of show models to showcase the company's skills, Alten offers these employees the opportunity to work on research and development projects called idle projects. These projects are developed in collaboration with students and are mainly focused on visually interesting and interactive robots and show models. These projects are then used and showcased at the company's fairs, expositions, and open days.

Because idle consultants work on the projects, it often happens that a project is spontaneously transferred to another idle consultant, because they have received an assignment from a customer. This ensures that there is little documentation and much of the project is not completed. This ensures that the students working on the projects have the added challenge of starting their project with the limited amount of documentation.

1.2. 4-in-1-row game One of
these show models is able to play the 4-in-1-row game. In this game, typically played in a blue rack with red and yellow chips, two players take turns playing a chip into the rack. By playing chips, both players try to fill four squares as quickly as possible that form a connecting horizontal, vertical or diagonal row. Below (Figure 1 The 4-in-1 game) is the rack of the game, with a winning red diagonal row. When a player manages to create the row, the game can be reset by means of a slider at the bottom of the rack that returns the chips to the players.

Alten's robot can replace one of the players. By means of an artificial intelligence, the robot can determine a move and play a chip in the rack. The level of difficulty of the robot can be set, on which it determines a strategy.

Figure 1 The 4-in-1-row game

1.2.1. 4-in-1-row robot

The 4-in-1-row robot plays (by means of motors and a vacuum gripper) chips to the game. In addition, it is able to first sort all chips by means of a color sensor. The robot also resets the game by removing all chips from the rack and returning them to storage when there is a winner. The robot has been developed to be moved by one person and fits completely on a small table. The figure below (Figure 2 The 4-in-1-row robot) shows what this robot looks like from a player's perspective.

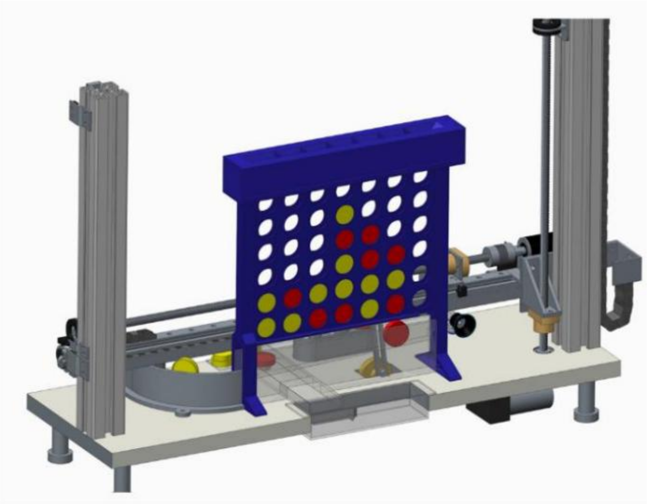

Figure 2 The 4-in-1-row robot

Current state

The 4-in-1-row robot is mechanically constructed. Underneath the robot's mechanical setup is the control system that controls the robot's various actuators and sensors. The operating system of the 4-in-1-row robot consists of two processors: a Raspberry Pi and an STM32 controller. The Raspberry Pi controls the game determination through AI and the control of the robot through a state machine. The STM32 controller controls the execution of these states. This STM32 controller is called the single-core STM32.

In the past, a new structure was devised for the system's software. It uses a dual-core STM32. This STM32 contains two controllers that can work independently of each other. (Figure 3 Function distribution of hardware drivers according to the software architecture.) This new software structure enables the use of the dual-core controller in the software and improves plug-and-play capability, readability and development time by providing a distribution makes functionality based on the two cores. Instead of the STM32 just executing the states, and the Raspberry Pi determining the states, the Raspberry Pi's state machine is moved to the second core on the STM32, leaving the Raspberry Pi just doing the game determination. This creates a clear hierarchy in the operating system. Software blocks can be programmed on the structure of these two cores. This makes it easy to break the software into small chunks, and span these blocks (Figure 7. The software blocks.) across multiple projects.

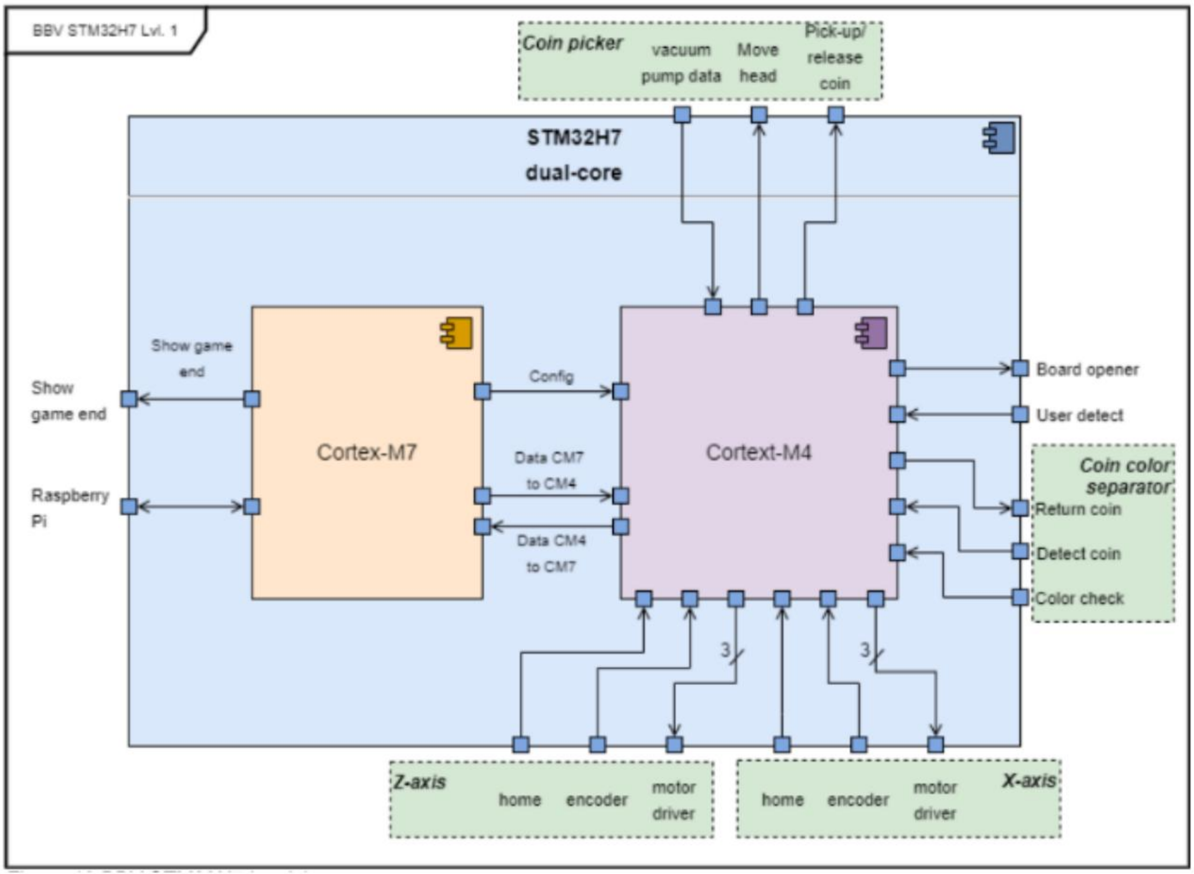

Figure 3 Function distribution of hardware control according to the software architecture.

The control for the motors has been tested through a proof of concept of a dual-core control system with a new software architecture. This proof of concept was part of a previous project to research a dual-core system. This dual-core system uses a new STM32 that has an additional internal core mounted on a small printed circuit board. It is able to control some functions of the robot, but is not usable for the entire robot. This project builds on this dual-core proof of concept, and aims to make a detailed version of this system. (Project goal)

1.2.2. Function tree

The function tree (Figure 4 Function tree) shows the required functionality. This functionality is determined by the supplied setup as described in chapter 1.2.1 (4-in-1-row robot). The system to be delivered will have to comply with this functionality and can be subdivided into three components: control, sensors and 'safety'. These components are further explained in the paragraphs below.

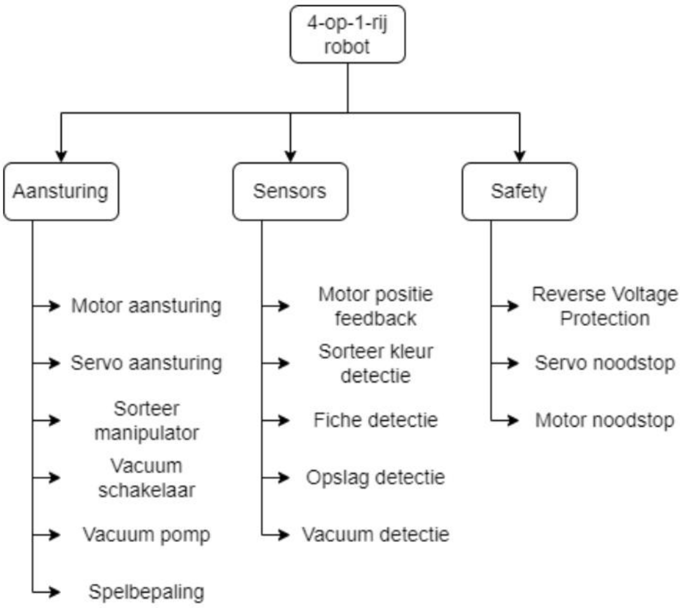

Figure 4 Function tree

Control

The game is played by throwing chips into the rack. The chips are picked up by means of a vacuum gripper. This vacuum gripper uses the negative pressure that is built up by the vacuum pump to suck up the chip. The movement to throw the chips into the rack is controlled by four motors:

• Horizontal axis; a motor with encoder feedback. • Vertical axis; a motor with encoder feedback. • Vacuum pump; a compression engine element.

• Tilt servo; a servo motor on the vacuum gripper.

This movement should be able to move the vacuum gripper horizontally and vertically across the rack and tilt it toward the opening (Figure 5 Degrees of Freedom of Movement). In addition, the pressure of the gripper must be regulated. The pressure is built up by a motor with a vacuum pump and read by a vacuum sensor.

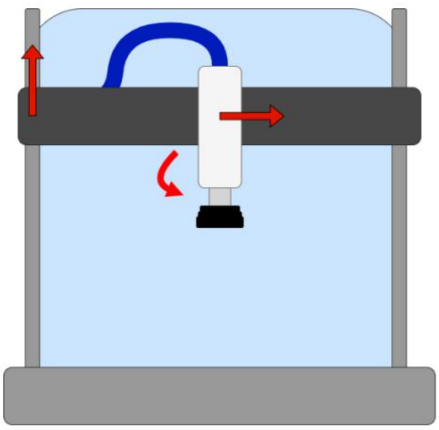

Figure 5 Motion degrees of freedom

Reset

During the game reset, the chips are sorted and played back to the player. The robot prepares the game for a new round. This functionality is performed by first removing all chips from the rack. This is done by an “Opener Servo”. This servo slides the return slide open, causing all chips to roll to an intermediate storage. The vacuum gripper then sorts the chips. You can read more about this under the heading *Control* .

Sensors

The robot contains various sensors that provide feedback to the system. These sensors are there to create the control of the robot or for determining the game

Control The chips are sorted by color during the reset of the robot. The chips are sorted by means of a color sensor. The separated color is played back to the user by tapping it away with a “Pinball Flipper”. The chip moves down a track back to the user's chip tray. During the reset, the contents of the chip storage are also checked by a proximity sensor.

The vacuum gripper has a vacuum sensor that allows it to measure the pressure in the gripper. This feedback allows the system to determine whether it has successfully picked up a chip.

The motors have built-in encoders. These encoders are used to determine the position of the actuators.

Game

determination The artificial intelligence of the robot determines the next move, and gives orders to execute the moves. To determine and execute the robot's moves, the chips must be detected. A "User Detect" sensor registers where a chip is thrown. This User Detect consists of seven color sensors that write their data to an I2C register. The data is communicated via I2C to the control system. The system then communicates with the AI via UART to determine a move.

Safety

To protect the user, there are three major safety systems in the robot:

• Reverse voltage protection; protection against incorrect supply voltage. • Engine emergency stop; a circuit that can cut off the power to the motors. • Servo emergency stop; a circuit that can cut power to the servos.

The reverse voltage protection protects the user from breaking the system by cutting off the voltage if it is connected the wrong way round.

The emergency stop in the setup controls the other two safety systems. These systems cut off the power to the motors and to the servos. This ensures that the power to the motors can be disconnected at all times.

1.3. Project goal The project

focuses on implementing the new dual-core STM32 controller, and answers the question: "What is needed to implement a dual-core STM32 in the 4-in-1-row robot?". For this, a PCB must be designed that can control the motors and sensors with this new dual-core STM32 controller. It is important to monitor changes in requirements arising from the use of the dual-core microcontroller, which may require adjustments.

1.3.1. Tasks To

replace the single-core controller with a dual-core controller, a design for the new circuit board must be developed. This design is developed using the original design and must match the setup of the 4-in-1-row robot. For this, the requirements are first drawn up, then a printed circuit board is developed, and finally software blocks are developed to prove the functionality.

Approach

During the project, a design cycle is carried out by means of the V-model. (Figure 6) In this model, a distinction is made between system and module, with these forming individual steps in the design cycle. The system is validated step by step through design phases and test phases. This report largely maintains the structure of the v-model. Because some system properties could not be filled in during the system design phase (see chapter 3 System design), a system integration phase was added after the module design phase. In addition, the 'modulating' phase has been merged with the testing phases.

The structure of the report is as follows. Chapter 2 analyzes the previous designs, looking at points for improvement and system requirements. In chapter 3 the system is defined and a design is presented. In Chapters 4 and 5, the various blocks in the design are filled in and elaborated. Chapter 6 shows the test results of the system, followed by details of possible points for improvement in chapter 7.

Chapter 8 contains the conclusions of the project. The detailed elaborations of the design can be seen in the appendices.

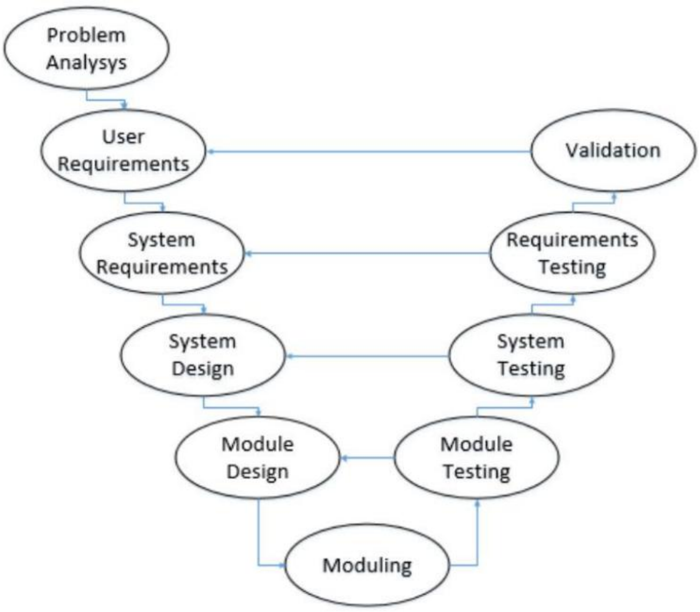

Figure 6 the v-model

Scope project

To be delivered after the project are:

- The design of the final printed circuit board.
- A working operating system product.
- Test software to prove operating system operation.
- Documentation of the design decisions.

User Requirements

The User Requirements have been drawn up together with the customer (Table 1 User Requirements).

Table 1 User Requirements

Number	Requirement	MoSCoW	Test procedure
UR1	The robot plays the 4-in-1 game fully automatically.	Must	Observation
UR2	The robot is easy to take to external locations in a passenger car.	Must	Observation
UR3	The robot is plug and play.	Must	Observation
UR4	The robot is safe to use with the public.	Must	Observation
UR5	The robot is built from industrial components using competencies from Alten.	Must	Observation
UR6	The robot can play continuously for 10 hours.	Must	Observation
UR7	The control system uses the NUCLEO H755ZI-Q controller.	Must	Observation
UR8	The dual-core operating system must retain the same functionality as the single-core operating system.	Must	Observation
UR9	Software blocks retain the structure as shown described in architecture.	Should	Observation
UR10	The software blocks for the initialization protocol are being developed.	Should	Observation
UR11	The delivered products are elaborated with documentation and descriptions.	Should	Observation
UR12	The software blocks for the initialization protocol have been tested on the setup.	Wish	Observation

The software

For this project it was decided to program the initialization procedure with which the system will be tested. This requires the software blocks from Table 2 Start protocol (page 10).
This initialization ensures that the various components of the system are set to their initial state and ready for use. This tests the basic functionality. An extensive structure of the software blocks can be seen in Figure 7 The software blocks.

Part of the initialization procedure is to initialize the cores of the STM32 controller.
Due to the hierarchical structure of the cores, the main core, the M7 core, must be initialized first. This core gives a pulse to the M4 core, the second core, to initialize and start the start protocol. One of the blocks required for this is the task manager. This block handles all tasks sent by the M7 core. This software block is crucial for the co-operation of the two cores, and starts the initialization program. For the test software, it will only be able to process the task of the start protocol.

Table 2 Start protocols

Software block	Start protocol	Inputs and Outputs
Init (M7)	Sends a pulse to the other core to start the start protocol.	Input: Computer start signal Output: Config signal
Init (M4)	Receives the pulse to send the initialization task to the task manager.	Input: Config signal Output: Inittask
Task manager	Sends signals to the motor controller, servo controllers and the sensor blocks to execute the start protocol.	Input: Inittask Output: Motor controller init Output: Coin color separator init Output: User detect init Output: Board opener init Output: Coin picker controller init
engine controller	Moves X-axis motor and Z-axis motor to home position and tests operation of motors and encoders.	Input: Motor controller init Output: Homen completed with status
Coin colour separator	Checks color sensor and proximity sensor. Test the pinball flipper.	Input: Coin color separator init Output: Sensor statuses
User detect	Checks the operation of the I2C io and the gate sensors.	Input: User detect init Output: Sensor statuses
Board opener	Moves servo to home position.	Input: Board opener init Output: Homen completed with status
Coin picker controller	Checks vacuum sensor and test vacuum pump. Moves servo to home position.	Input: Coin picker controller init Output: Homen completed with status Output: Sensor statuses

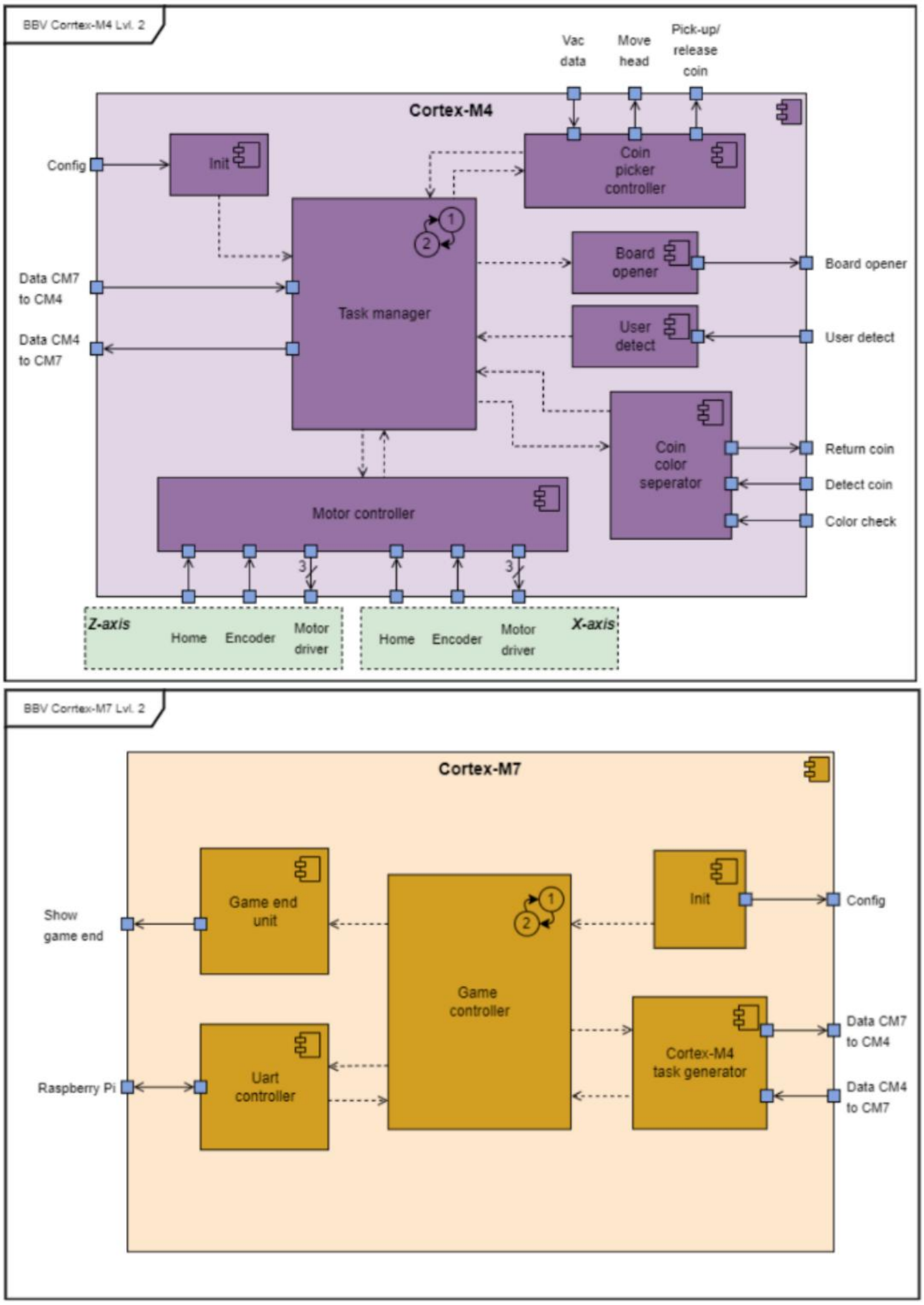

Figure 7 The software blocks. [1]

1.3.2. Project Boundaries

This chapter provides additional demarcation on the topics covered in this report.

Expectation Alten

To complete the 4-in-1-row robot, the dual-core operating system must be implemented. A printed circuit board will have to be produced and tested so that the software can be further developed. The main focus of the project is the printed circuit board and control system implementation. Testing the initialization procedure will serve as proof.

Outside the scope The points below do not fall within the scope.

- Setup: The operating system and associated software will be developed for the existing test setup.
- Software: The software will build on the existing structure, not change on the architecture of the overall project.
- Suppliers: The control system and associated parts will be ordered and produced in Alten's conventional manner. No research is done into suppliers and production techniques. This means that no new chips are ordered, but the development board of the proof of concept is mounted on the printed circuit board.
- Future plans: A next step of this project is moving the robot's state machine from the Raspberry Pi to the extra core on the STM32 controller. However, this is not considered for this project. The operating system continues to use the Raspberry Pi.
- Mechanical adjustments: Making the arrangement in order is not taken into account. No mechanical adjustments will be made.

Completion

The project is completed when the new dual-core control system has been designed and produced and the associated test software and documentation have been submitted.

If the operating system can be implemented in time, and there is time left, additional software blocks will be implemented. However, this is not a must.

If there is not enough time to test the software in the robot, the control of the initialization protocol will be tested in a test setup.

2. Project documentation and architecture

The documentation of the robot is, at the time of start-up, not complete. The single-core system is poorly described, and no longer up-to-date. In order to document the functionality, operation of the single-core design, and the architecture of the desired design, the various schemes have been elaborated in this chapter.

2.1. Previous designs Before this

project started, there were several versions of the control system of the 4-in-1-row robot. Here are the major versions:

- Single-core operating system; the original design on which the dual-core system will be built on.
- Dual core proof of concept; the proof of concept developed during development of the software architecture in a previous project.

The single-core operating system and the dual-core proof of concept are the biggest references on which the new design is made. This previous design forms the basis of the new design. For this purpose, it has been elaborated in a clear architectural documentation.

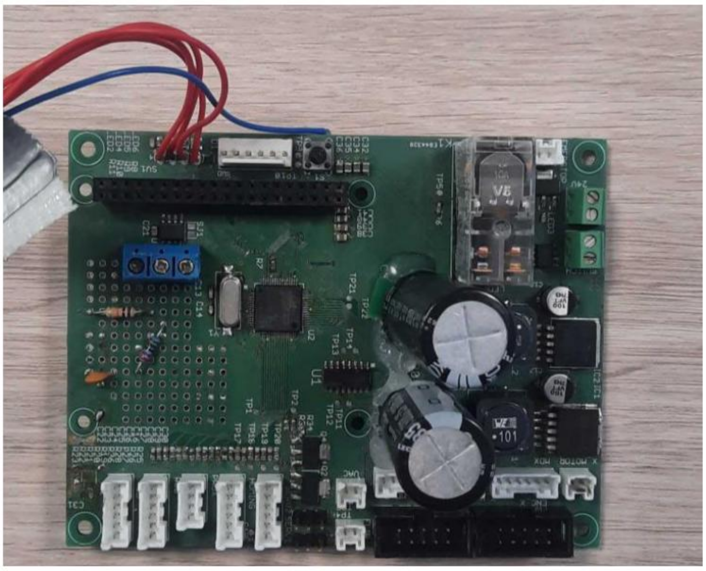

Figure 9 Single-core operating system

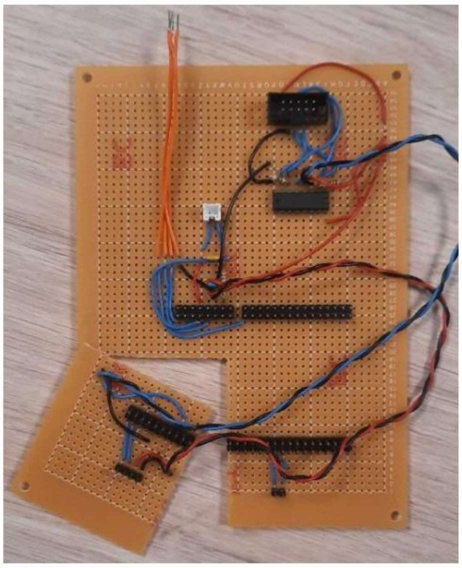

Figure 8 Dual core proof of concept

First design In
addition to the software architecture and the accompanying proof of concept, a start has been made on the design of the printed circuit board of the dual-core operating system. A pinout of the dual-core has been drawn up and a drawing of a wiring diagram of the control system has started, which is not completely finished. These drawings must be checked and further elaborated. Figure 10 shows the architecture of this new dual-core operating system as designed by the client.

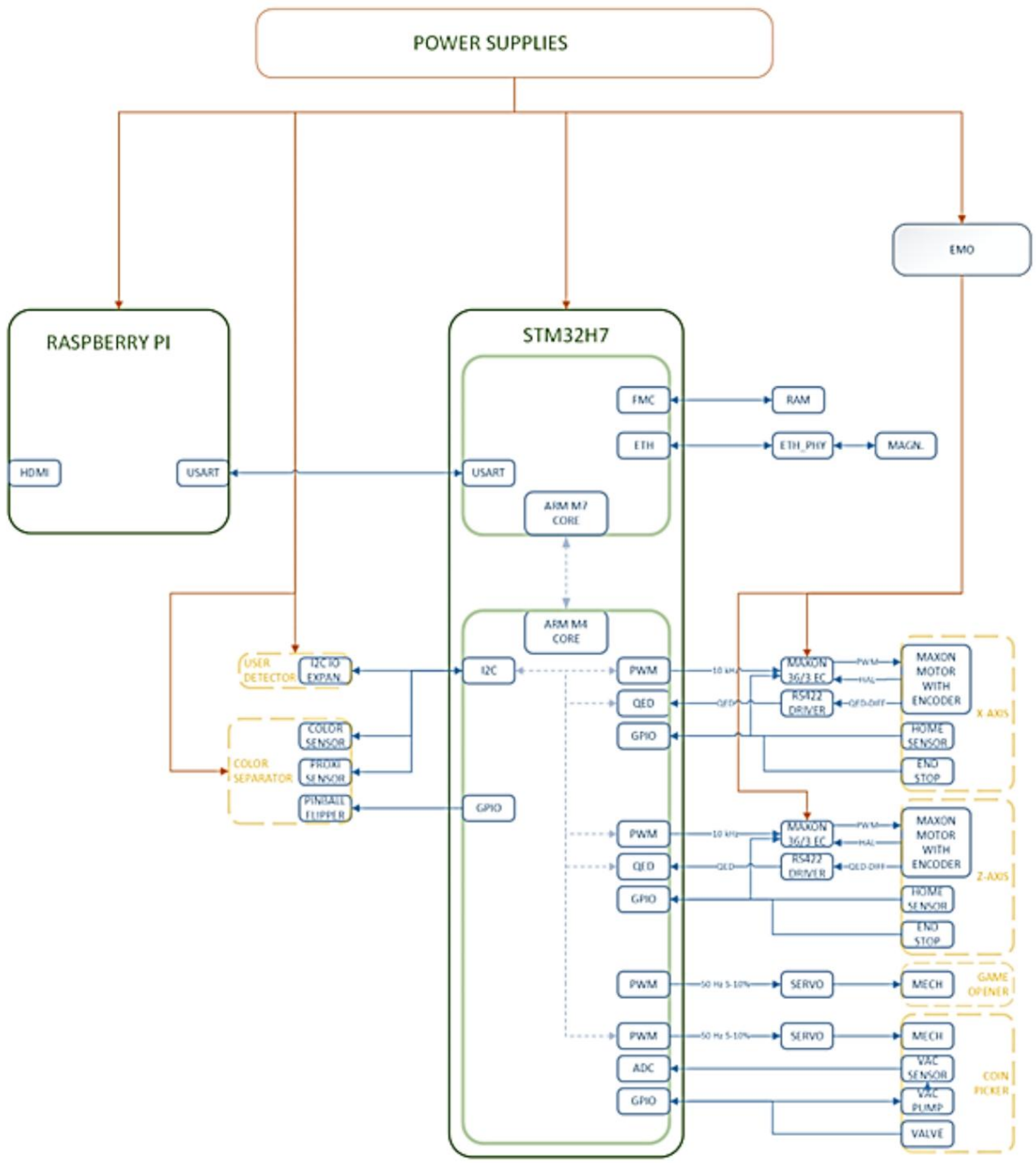

Figure 10 System architecture dual-core

2.2. Electronic architecture

The necessary functionality as described in chapter 1.2.2 (Function tree), and the architecture as described in chapter 2.1 (Previous designs), will have to be implemented in the operating system. For this purpose, the previous single-core operating system has been analyzed and an architecture has been created. This architecture is explained in this chapter.

2.2.1. Distribution of components

In the electronic field, the various functionalities are present in the setup and the previous operating system. The set-up contains all electronics that are mounted on the robot and are fixed for this project. The control system contains all connections for the set-up and the controller of the system. This operating system will be modified. The set-up and operating system are explained in more detail in the following paragraphs. The figure below (Figure 11 Electronic distribution) indicates in gray what is present on the setup, and in red belongs to the control system.

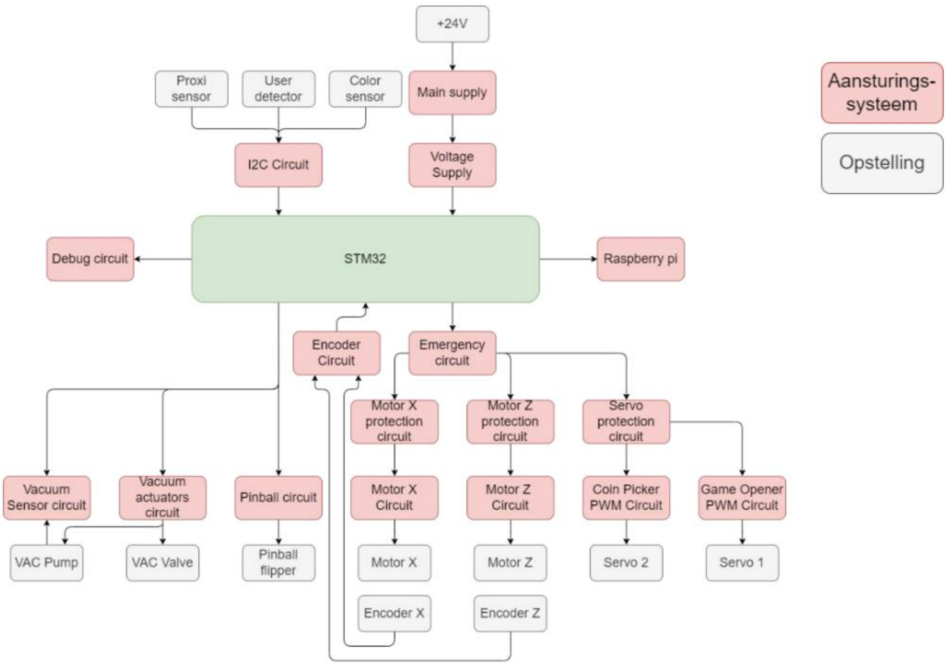

Figure 11 Electronic distribution

The figure below (Figure 12 Previous version with physical location) shows where the previous control system (green printed circuit board) is located in the robot and what the setup looks like. In the middle of the robot, next to the printed circuit board, is a vacuum pump. This pump will have to be moved to make room for the new STM32.

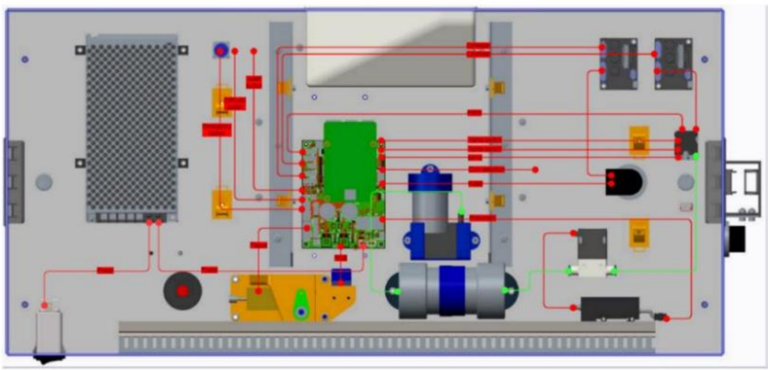

Figure 12 Previous version with physical location

2.3. System requirements

The requirements of the functionality are described in the section Function tree. These requirements are based on the operation of the parts of the 4-in-1-row robot and therefore only describe the functionality. In the appendix (System Requirement Documentation) these requirements are elaborated into system requirements, in which the focus is placed on electrical and mechanical properties that are important in the new control system.

2.3.1. Resulting necessary modifications Some

components of the original single-core control system (Previous designs) are not available for order at the time of the project. These parts must be replaced based on the properties of the system requirements. These system requirements can be found in the SRD (System Requirements).

The analysis of the single-core design shows that the following parts of the robot are not complete or available:

- Vacuum sensor circuit; there is no vacuum sensor in the single-core system. This is due to a design flaw. The vacuum sensor is also not available for order. A new component must be selected and the connection may need to be changed. • Transistors; in the single-core system there are transistors that are not available for order. A new component must be selected.
- Homing switch; the setup contains homing switches that are not suitable for low currents. This will be further examined during the design.
- regulators; coils are not defined in the design for the voltage regulators. A new component must be selected for this.
- Other components; some other components are not available for order (see Adaptions in appendix A.4). However, these components have an alternative option that is almost the same. These components will be tested but are not further explained within this report.

These design choices are elaborated in chapter 3 (System design). In addition, it is discussed how the dual-core microcontroller is added to the system.

2.3.2. Power consumption

The design of the system depends on the power consumption of each component. The most important properties in terms of power consumption are:

- The distance between electrical traces, depending on the voltage difference.
- The width of the electrical tracks, depending on the current strength. • The efficiency and heat coefficient of a component, depending on what is consumed assets.

For each component from the electrical architecture of the existing setup (Electrical architecture), the power consumption of the power supply, the power consumption of the signals and the permitted temperature rise of the component were examined. The final implementation of these system requirements depends on the module design. These are therefore only filled in in chapter 5 (System implementation).

2.4. module requirements

2.4.1. Dual-core controller connection A

number of important requirements are important for the use of the dual-core controller. These requirements are given in the System Requirement Document (Module requirements STM32H755). When designing the connections it is important to pay attention to the pinout functions of the STM32 (Pin list) and the maximum current and voltages on these pins.

Some important requirements are as follows:

- The STM32 has a 3.3 volt signal voltage. This means that outputs cannot supply a voltage higher than 3.3 volts. • The input pins of the GPIO are 5 volt tolerant. That means they are more than 3.3 volts and can therefore be connected to 5 volt signals.
- The analog input pins are not 5 volt tolerant. That means that this must be explicitly stated be taken into account in the design.

2.4.2. Control components The

analysis of the single-core control system has determined how the various components should be controlled. The module requirements for these components are as follows.

The horizontal and vertical motors are controlled by means of two motor controllers. These motor controllers each use three GPIO signals and a PWM signal, and can be terminated by means of a protection circuit. The encoder connections are part of the motor control. The motor controller driver also includes connection points for limit switches and homing switches. These connection points are equipped with switching bounce filters. The servos are controlled by a PWM signal and powered by the 5V regulator, also by means of a protection circuit.

The vacuum gripper is controlled by a vacuum pump and pressure switch. This switch switches the negative pressure generated by the vacuum pump, causing the gripper to draw a vacuum. In addition, the pressure on the vacuum gripper is controlled by an analog vacuum sensor.

The game determination is done by means of a Raspberry Pi. This Raspberry Pi is part of the control system and is communicated with it via UART. The sensors communicate with the controller via an I2C bus.

The control of the vacuum pump, vacuum valve and pinball flipper are controlled by transistor circuits. These switch the power supplies on or off.

The control system is powered by a 24V source. This supply point is protected with a reverse voltage protection circuit (A.6.1 Reverse Voltage Protection). This circuit switches off the power point when the power source is connected the wrong way around. On the printed circuit board, the voltage must be further divided over the different voltage levels. This division goes through different voltage regulators.

3. System design During the

system design phase, the theoretical design of the system was examined. The architecture of the system has been expanded based on the system requirements, and for the software a schematic overview has been made of the course of the initialization process. This chapter looks specifically at the parts that need to be modified and elaborates the design for the total system.

3.1. Electronic Design 3.1.1.

Development boards The operating

system processors are mounted on development boards. These are modules on which all the electronics for the processors are present. These modules can be tested individually. Contrary to previous designs, in addition to the Raspberry Pi, the STM32 will also be mounted on the system as a development board in its entirety. This reduces the cost of the project, is easier to test and shortens the production time. The design must be adapted to this, so that they can be mounted.

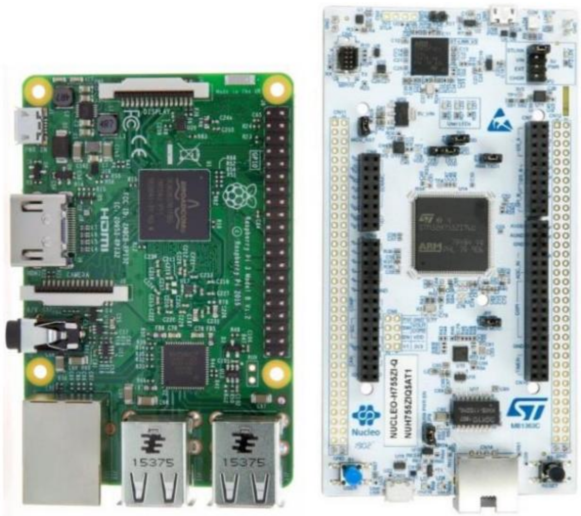

Figure 13 The development boards. [19]

3.1.2. vacuum sensor

Due to a design flaw in the previous control system (Previous Designs), a vacuum sensor was never connected and tested. This vacuum sensor regulates the vacuum gripper, as described in chapter 2.4.2 (Control components). The sensor that was selected at the time is no longer available. This ensures that a completely new sensor has to be chosen.

The most important requirements, as can be read in the SRD (B.3.2 Module requirements VAC Sensor), are the range of pressure that can be applied to the sensor, the signal type and the voltage level of the signal. The optimal sensor would therefore be a pressure sensor that can measure a vacuum level of 0 to 1 bar. A higher pressure than 1 bar does not occur, as there is only vacuum in the system, and later than 0 is not possible. In addition, the sensor should give a maximum output voltage of 3.3V as an analog signal. With this signal, only one input is needed on the STM32, which can only handle 3.6V according to the requirements of the STM32.

3.1.3. End-stop switches The

original design uses end-stop switches (control components), which are currently not present in the setup. The lack of these switches changes little in the robot's functionality, but if used properly, would provide safer operation of the motors. It has therefore been decided not to remove these connections in the new design, and it is recommended to add them in the future.

3.1.4. transistors

Transistors are present in the system for switching the various actuators, as described in chapter 2.4.2 (Control components). The chosen transistors in the single-core design are not available for order and must be chosen again. This component choice depends on the system requirements of the actuators that are controlled.

To make this choice, the system requirements of the actuators (Supplies) were combined to find a suitable transistor. Because the minimum and maximum requirements are combined, a transistor can be selected that meets all requirements. These combined requirements are shown in Table 3 (Combined Transistor Requirements).

Table 3 Combined transistor requirements

No	Requirement	Min value	Max value	Unit
Drain	current (Id) 1.66 Load voltage / Switching voltage (Vgs th) 0 1		3.3	v
2	(Vds)			a
3		24		v

3.1.5. Pin out distribution

Based on the requirements of the STM32 (Dual-core controller connection), a distribution of the connections has been made. These connections are made depending on the functionality and properties of the pins. These are elaborated in the next chapter (Module design).

3.1.6. Complete system overview The
figure below (Figure 14 Complete system) shows the complete system, with the parts covered in this chapter marked. The parts that need to be added to the system are marked in red because they were not yet present or were not available. Points of attention are marked in blue where adjustments have been made that have minimal impact on the design. The blocks marked in green will not be modified.

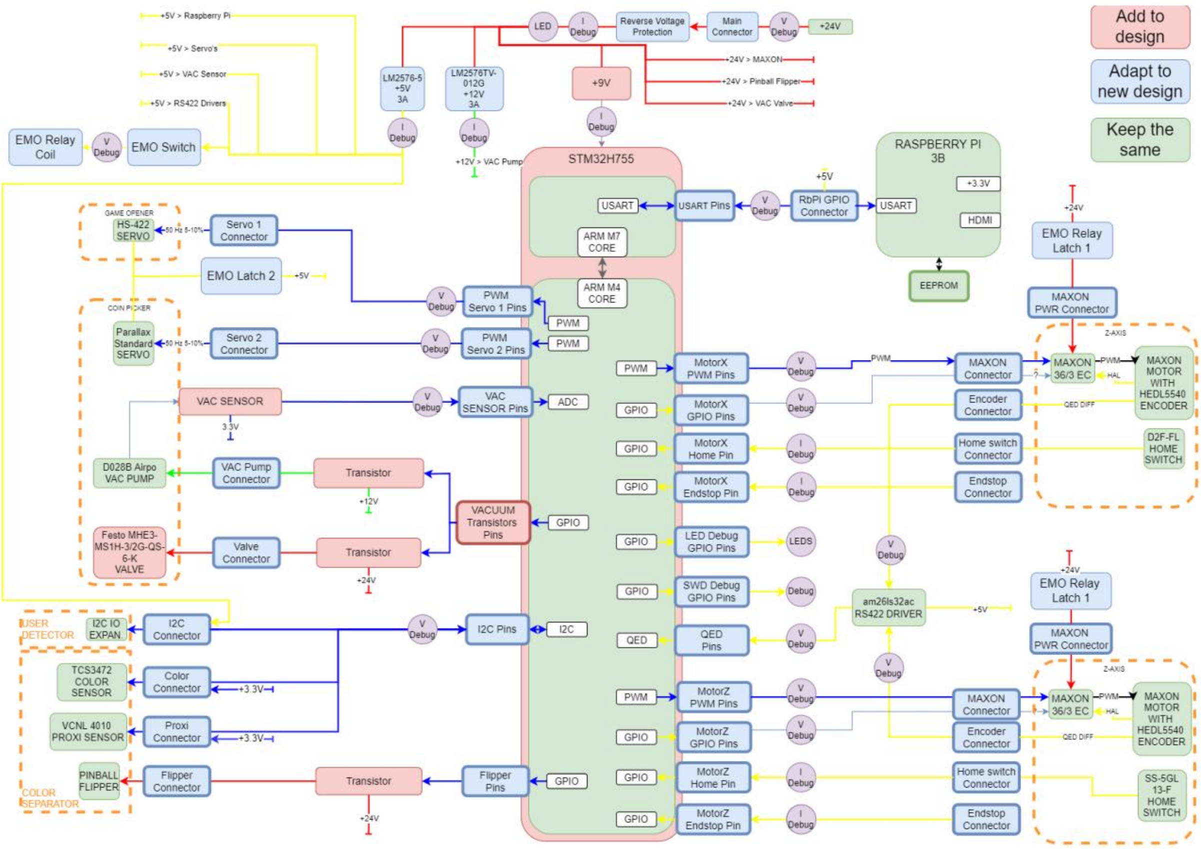

Figure 14 Complete system

3.2. Software Design The software
will perform the initialization of the various functionalities as described
under the heading The software in chapter 0. These functionalities have a clear hierarchy, which is depicted in the appendix (Software). This chapter explains the various components of the architecture.

3.2.1. Actuators

The movement of the motors is controlled by the TIM (timer) class. This timer class outputs all PWM signals. This describes the functions for moving the servos.

The motor_master class uses PWM signals, and sends signals to the motors through the timer class. The motor_master class combines the control of the PWM signals with the reading of the encoders. The main functionality of this class is to control the position of both engines
to guide.

3.2.2. Sensors The
sensors required to run gameplay are received through the I 2C classes, adc class, and timer class.

- The adc class can read the analog pin of the vacuum sensor by means of the GPIO.
  This value can be retrieved from the class.
- In addition to the PWM signals, the timer class also controls the reading of the encoder pulses. This
  pulses are then used to let a counter determine the position of the motors.
- The I 2C classes use the I 2C interface on the STM32 to request information
  from the various I 2C devices.

3.2.3. Game
determination By means of a UART connection, the commands of the AI are requested from the Raspberry Pi. This is done via the usart class. However, this is left out of scope for this project. The AI of the game logic is installed on the Raspberry pi and will not be changed.

4. Module design

The development of the PCB, and the implementation of the system design (Chapter 3 System design), is done in the software 'EAGLE'. This design will have to be worked out in a functional scheme and a layout. The functional diagram is the technical drawing and further details of the system design. The layout is the physical shape of the PCB. This chapter describes the development of the functional diagram, depending on the operation of the components and their typical connection. Based on this, the layout is made in the next chapter.

4.1. vacuum sensor

To use a new vacuum sensor, a circuit must be made that connects to the dual-core microcontroller. Based on the vacuum sensor requirements in Table 4, only a few sensors were available. To be able to add more sensors investigations, the range of the pressure on the sensor had to be extended to also allow differential sensors. Differential sensors use a second connection on which the difference in pressure can be measured. In this open situation, the second port is left open to measure atmospheric pressure. This category of sensors provided more options, allowing a component to be selected that fell within the customer's price range.

Table 4 Vacuum sensor requirements

To demand	Min	Max	
Absolute Operating Pressure	-1.0	1	bar
operating voltage	3.3	24V	
Signal voltage level	0	3.3 V	

The chosen sensor is a 5 volt differential sensor from the Honeywell brand. This sensor was the only one available within an acceptable price range.

However, with this sensor choice, a solution had to be found for a difference in the voltage level of the analog signal and the allowable voltage level of the analog port on the STM32. The analog port may receive a maximum voltage level of 3.6 volts. The following options have been considered for this.

4.1.1. Voltage Divider A

voltage divider uses two resistors that work together to create a ratio in voltage, lowering the voltage across the voltage divider. The combination of resistors determines the output of the output voltage.

Some requirements are important to keep in mind here:

- The voltage of the signal.
- The maximum voltage that can be applied to the ADC.
- The input impedance of the ADC.
- The maximum signal current that the sensor can deliver.
- The power consumption of the ADC.

4.1.2. Voltage divider with buffer By

adding a buffer to the voltage divider, the following requirements can be solved:

- The input impedance of the ADC.

• The power consumption of the ADC.

Because the buffer decouples the circuit of the ADC and the voltage divider from each other, the input impedance of the connection to the ADC is equal to the impedance of the buffer. In addition, it amplifies the current of the signal, so that the power consumption of the ADC no longer matters.

4.1.3. External ADC

A possible solution would be an external, 5 volt tolerant ADC. This would be a separate chip that can be connected to the I2C bus. The problem with this solution is that it adds cost, makes the chip more complex, and makes the code more complicated.
As a result, this option was not further considered.

4.1.4. Design The
vacuum sensor is powered by the +5V source.
This component is recommended to use with a filter. This filter is shown in Figure 15 (Vacuum sensor filter). The sensor has a filter capacitor that must be added to an analog output. [1] This capacitor can be seen in Figure 16 (Schematic) as C2.

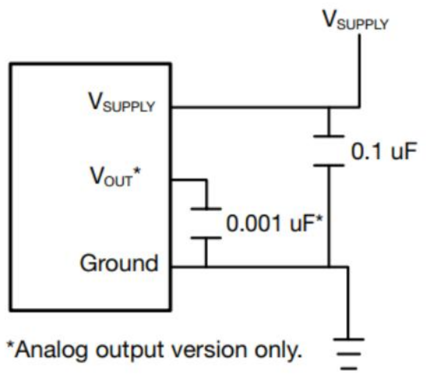

Figure 15 Filter vacuum sensor [2]

An 18K and 33K resistor have been chosen for the resistors of the voltage divider. These resistors form the correct output voltage for the ADC. The resistors will just measure the amperage of it carrying signal. This means that size and power are not crucial.
An opamp is added behind the voltage divider where the output is made to the negative input, making it a buffer.

In the schematic (Schematic) four test pads are connected. These test pads will serve as connection points during the test phase. TP2, the test pad at the output of the vacuum sensor, can be used to measure the voltage of the sensor. TP4, the test pad at the buffer's entrance, shows the resulting voltage from the voltage divider. TP6 is the test pad behind the buffer on which the current to the ADC can be measured.

The resulting functional schematic of the vacuum sensor is shown in Figure 16. The signal behind TP6 connects to the STM32 elsewhere in the schematic.

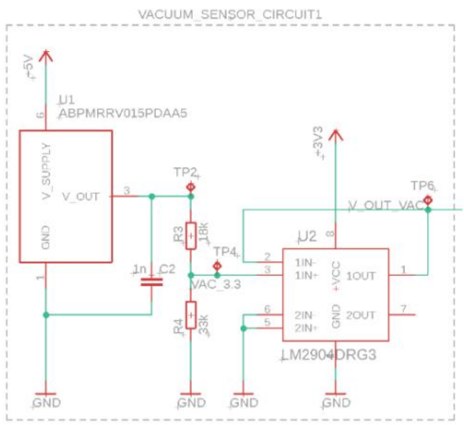

Figure 16 Schematic vacuum sensor

4.2. PWM Connections

The different PWM connections of the control system (Control components) must be configured for clock speed. The components each have their own acceptable clock speed. These must be configured in the STM32.

The internal clock of the STM32 can be set for the PWM signals by means of an Auto Reset Register and Prescaler. These settings must be integers and affect the clock speed and resolution of the signal.

The Auto Reset Register determines the number of the counter to which the counter is reset. This greatly affects the resolution of the signal. By choosing a higher Auto Reset Register, more steps can be counted.

The Prescaler influences the speed at which the counter counts, i.e. the frequency of the counter. Grabbing a lower Prescaler allows a higher Auto Reset Register to be used to achieve the same frequency. In addition, the signals have a maximum resolution, which determines the limit of the Auto Reset Register.

- The servos have a deadband width of 8us. This means that the servo will not respond unless there is a signal change of at least 8us. From this the desired resolution can be determined.
- The motors have a resolution of 0.2us. For this, the desired Auto Reset Register and Prescaler calculates.

As described in the System Design Document (Appendices A.5.2 & A.5.3), the required Auto Reset Register and Prescaler have been calculated. By plotting the formula for the Prescaler, the Auto Reset Register and Prescaler can be calculated.

( ) = ÿ( ) ———

= The needed speed
= The clock speed of the timers of the STM32H755

The minimum ARR for the motor PWM signals, which is an integer and fits within the resolution of the motors, is 10000. This results in a prescaler of 48.

4.3. transistors

For the transistors of the actuators, see 2.4.2 (Control components) a component choice has been made based on the requirements in chapter 3.1.4 (Transistors). After the order it turned out that there was an error in the component selection. After an internal review with colleagues, it appeared that due to the low voltage of the GPIO connections on the STM32, the low gate voltage on the MOSFET would cause a high resistance on the circuit. To prevent this, the gate voltage had to be increased. This is done by means of a pre-switch with a BJT. This ballast can handle only a small amount of current, but has a low threshold voltage. By combining the ballast and the MOSFET, the power is switched to the actuators.

The design of the MOSFET circuits, as explained in Chapter 3 (Transistors), are connected with a ballast. This ballast uses the highest possible potential level that does not fall within the supply voltage category, 12V. This ensures that it it is not necessary to place the ballasts within the plane of the supply voltage, and that the voltage is high enough to fully open the MOSFET.

• In the pre-circuit, a 10K resistor was chosen at the gate of the MOSFET (R56), because it is not dependent on the current strength, and therefore uses less current. • A 1k resistor is placed in front of the base of the transistor to remove the current from the GPIO limit, but allow enough current for the transistor.

• Resistor 53 acts as a pull-down resistor and causes the base to go to ground drawn on a floating input from the GPIO.

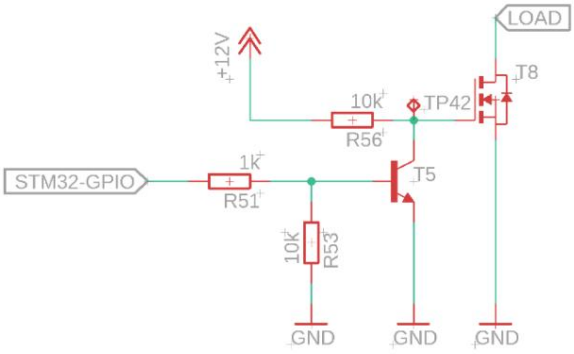

Figure 17 Current ballast

4.4. Homing switch Because
switches have been chosen in the setup for the homing switches of the system (Control components) that do not fall under the category “microload”, the minimum load on the switch is higher than the GPIO of the STM32 can live. This minimum load is necessary to bridge the contact surface. To create this load, a pull-up resistor must be added to allow greater current to flow through the switch.

These microload switches have gold contacts instead of silver contacts, which makes it easier to conduct voltage when they come into contact with each other. This ensures that a low current of 1mA can flow through the switch without the switch failing. However, the switches in the 4-in-1-row robot require a higher current to flow through the switch to ensure that it switches properly. The minimum load of the system is equal to 160mA at 5v. To create this load, an 800mW resistor must be added. This solution has been worked out and discussed with the System Architect.

On the advice of the System Architect, it was decided to purchase microload switches, so that the high power loss in the chosen solution is not necessary. For example, instead of the D2F-FL currently used as a switch in the horizontal movement, a DSF-01 can be used. As a result, less current needs to pass through the switch, and smaller resistors can be selected, so that less power is lost.

The pull-up resistor for the homing switches ensures a minimum load to optimize the switching of the contact.

In Figure 18 (Homing switch circuit), resistor R7 provides the current flow through the switch. A minimum load of 160mA must pass through the switches, for which a pull-up resistor of 30ÿ is used. The calculations and technical substantiation can be found in the SDD (A.5.5 Homing switch). Test path 11 has been added to measure the current through the switch.

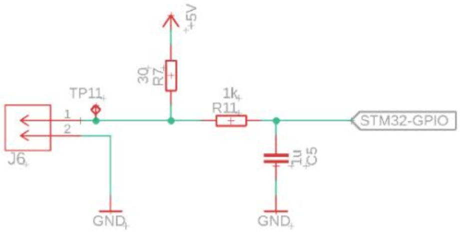

Figure 18 Homing switch circuit

The 30ÿ resistor will consume a power of 800mW. This means choosing a footprint that is large enough to withstand the temperature. This option was discussed with the system architect, after which it was decided to adjust the homing switch so that it uses less power

is consumed.

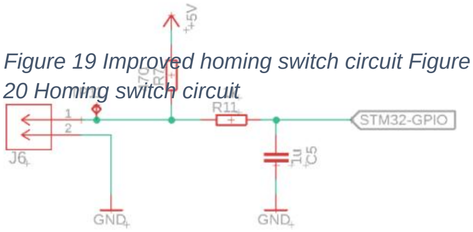

Figure 19 Improved homing switch circuit Figure 20 Homing switch circuit

It is recommended to install a homing switch that is suitable for microload (see chapter 4.4). For the new connection diagram, a load of 10mA has been taken into account. For this R7 has been adjusted to 470ÿ.

Figure 21 Improved homing switch circuit

An RC filter has been added to filter the switching bounce of the switches. This filter adds a slight rise time to the signal and filters out high frequencies.

4.5. Regulators The
control system is powered by an external 24V power supply and three internal power supplies. (see Control components)

The coils in the filters for the 3.3V and 5V supplies turned out to be undefined. To get the right filter, a coil had to be chosen based on the input voltage of the regulator and the maximum current. The System Design Document (Voltage regulator filters) shows how these have been selected. (Figure 22 Elaboration of regulator filter)

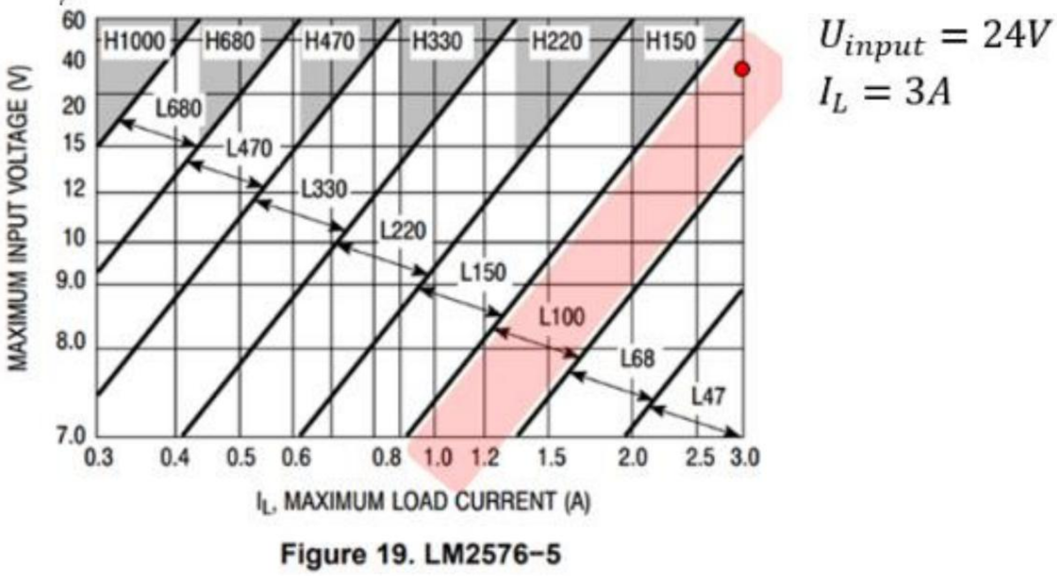

Figure 22 Elaboration of regulator filter

The wrong coil has been selected for the 12V regulator. This error appears not to have been caught by the test plan (Chapter 6) and is not expected to have a major adverse effect on the system. The coil chosen for the 12V regulator is the same as the coil for the 5V regulator.

5. System implementation

The layout of the PCB is the physical connection of the functional diagram to the board. The current strengths and voltage ratios must be considered to determine the thicknesses and spacing of the signal paths. This chapter explains the design decisions within this layout.

5.1. Netclasses The

netclasses of the layout determine the classifications into which the signal paths are divided. The netclass classifications (Table 5 Netclasses) show four netclasses of the 4-in-1-row robot.

Table 5 Net classes

Class	Current	Min tracks clearance	Min tracks width	Min via width	Voltage
Signal	range-0.5A	0.13mm	0.25mm	0.35mm	<16V
Default	0.5A – 1.0A	0.13mm	0.5mm	0.35mm	<16V
Power	1.0A - 3.0A	0.13mm	2.5mm	3x 0.35mm	<16V
Main supply	3.0A - 6.5A	0.53mm	6.75mm	5x 0.35mm	>16V

These ratings automatically determine signal track thickness and spacing in the design. The classifications are determined by voltage level, namely higher or lower than 16V, and by current strength.
The 'Main supply' rating is the only one that uses 24V potential. Other signals use 12V, 9V, 5V or 3.3V. For this, the intermediate distance has been increased to prevent short circuits. The other ratings depend on amperage. The corresponding track thicknesses have been determined for each current strength.

The values for the classifications have been determined by means of Saturn's PCB Toolkit, an application that is used within Alten for the development of PCBs. Based on the amount of amps running through the path and the thickness of the copper, this software calculates the minimum width of the path. The same is also done for the vias, where the same settings are used to calculate the diameter of a via.

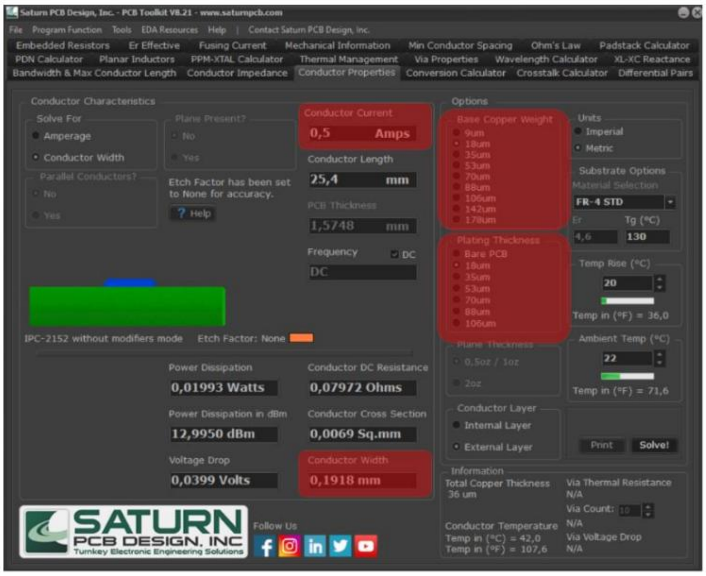

Figure 23 Saturn pad thickness

The minimum distance between to calculate paths it is voltage level and path type is important. The type depends on the location of the path (internal or external), whether an additional coating is present, and whether the path has a hole through the PCB or *not*. Type A6 indicates that the paths lie on the surface of the PCB, no additional coating *components* are used and through-hole connections are used.

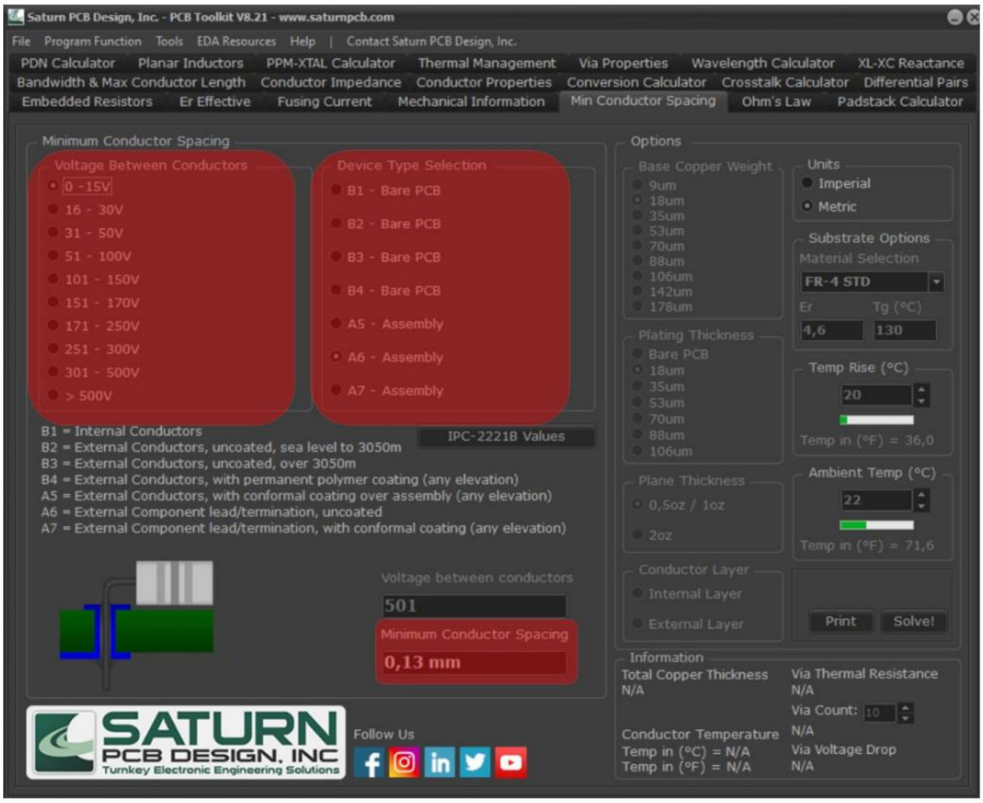

Figure 26 Saturn path clearance

5.2. Component location The

amount of space in the robot for the PCB is determined by the connection points in the setup and the surrounding actuators. To make track lengths as short as possible, components of the same potential level are placed as close together as possible. A division of the space on the board has been made for this purpose. To put the high supply voltages together, the right half of the PCB is reserved. The low voltages are placed on the left side.

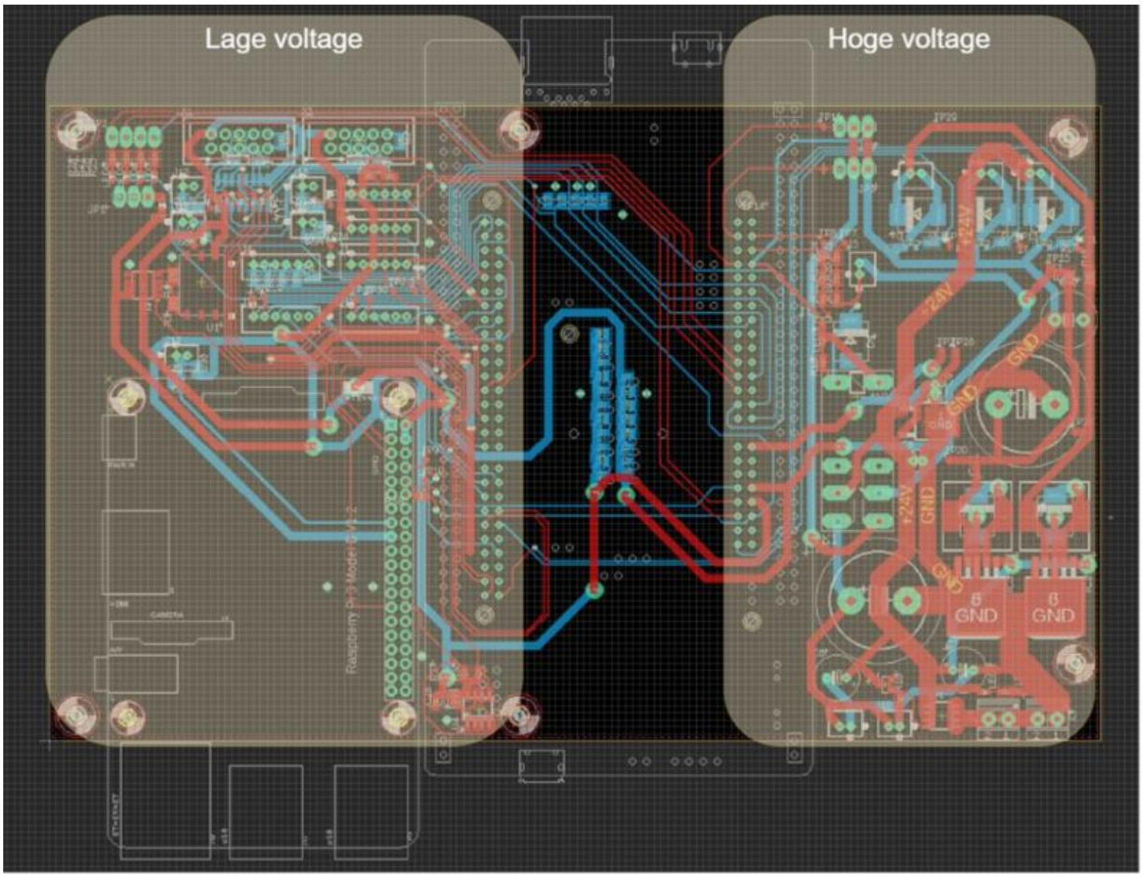

Figure 27 First distribution of components

supplies

Ref	UR.5
Description	The operating requirements of the needed VAC Sensor
Value	Min Mean Max Unit 3.3 24 V
Operating voltage	
Rationale	By using an existing power supply, no new supplies need to be added.

Pneumatics pressures

Ref	UR.5
Description	The operating requirements of the needed VAC Sensor

5.3. Internal layers and polygons To save
space some internal layers have been added. These internal layers have a large plane with a single potential level to power all components in that plane.
In addition, it was decided to connect all nearby components of the same potential by means of a polygon. This surface automatically creates a connection between the connections, so that fewer tracks need to be laid.

By means of these techniques, the PCB can be better designed. Because more space could be saved, thanks to the internal surfaces, parts could be placed closer together. In addition, the distribution has become clearer. This distribution can be seen in Figure 29. A full version of the layout can be seen in the appendix. (Electronic)

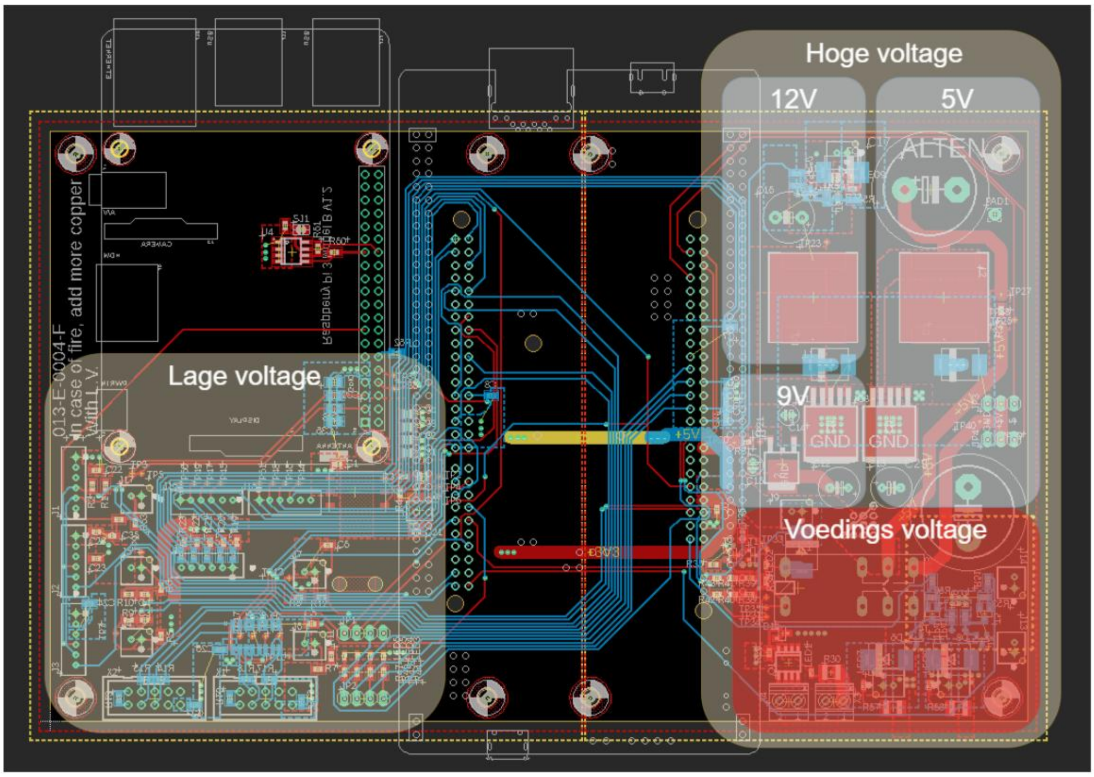

Figure 29 Improved component layout

5.4. Strain relief To
strengthen the connection of the vacuum sensor, some mounting holes have been made at the sensor. This allows the pneumatic hose to be tied to the PCB with tie-wrap, serving as a strain relief.

6. Test Results

By means of the test plan, the PCB is assembled and tested step by step. This is done in different phases where the functionality is tested per phase. In the module testing phase, the functionality is tested at component level, and the PCB is assembled step by step.
In the system testing phase, the various collaborations of the system are tested. An extensive overview of how these tests run can be read in the appendices (Master).

6.1. Module Testing During

module testing, the various components are tested individually. The steps for this are described in the test plan (Master). This phase looks for critical errors in each operating system subsystem. This is done during assembly of the PCB, in order to isolate different parts of the PCB.

6.1.1. Power supply

point In the power supply of the PCB is a reverse voltage protection circuit. This section reacts when a negative voltage is applied to the power supply and should be tested before subsequent parts are placed on the PCB to prevent a short circuit at a later point. This test step is therefore also done first, and is critical for the following test steps.

The reverse voltage protection has been tested by means of a power source and voltage meter. The voltage level on the system supply was less than 0.05V, with a supply voltage of negative 24V. The 24V source provides a stable power supply at a positive voltage.

The LED light at the power point shines just a little too bright. This is not critical to the operation of the PCB, but can be user-unfriendly. The resistance value of the lamp could be higher.

6.1.2. Voltage regulators

The voltage regulators are the most critical parts right after the power point. The potential level must be equal to the expected supply of the components. If this power supply is too high, or short circuited, it can damage other components. This step is also performed in isolation from the other parts. Figure 30 shows a picture of the test setup with the feed point and regulators.

The voltage regulators showed strange behavior with the minimal circuit (only the regulators and the associated coils). The output voltage was too high, not responding to the input voltage level in a consistent manner. After measuring the regulators, in case of a soldering error, the problem turned out to be the lack of the necessary capacitors. This shows that the switching regulators do not function without capacitors. After improving the test plan and connecting the capacitors, the regulators showed the correct behavior. The regulators show a voltage level of 5.015V, 9.16V, 12.13V, which is within the system requirements of the power supply. (Power requirement)

Figure 30 Test setup feed point and regulators

6.1.3. Safety circuit

Before motors are tested, the safety circuit must be operational. This circuit cuts off the power supply to the motors and prevents (further) damage if the motors behave unexpectedly.

The switch and safety relay showed correct behaviour. The relay switched the power supply to the motors on and off through the connector of the switch.

Testing the safety circuit revealed a major fault in the switching of the MOSFET that allows power to the motors. This error was also found in every other MOSFET circuit, namely at the connector of the vacuum pump, vacuum switch and pinball flipper. The fault causes the MOSFET to be normally open, and can be closed by the signal. This is the opposite of the desired behavior, that the MOSFET is normally closed and can be opened. This problem can be solved to a large extent by means of software. You can read more about this in the heading system testing (Inversion).

6.1.4. Further steps

Other functionality will be tested after the previous 3 steps. These test steps are to check the design and are less critical for other functionalities. These steps are further described in the test plan (Master).

vacuum sensor

An interesting test step is the vacuum sensor. This functionality contains by far the most development and can be tested for functionality, accuracy and precision.

The vacuum sensor shows a voltage level of 1.6V at a negative pressure of 0. This is within expectation, as the sensor can measure pressures from +15Pa to -15Pa, and the atmospheric pressure is in the middle of the sensor's measuring range. The output voltage of 1.6V, in relation to the maximum voltage of 3.3V, is therefore acceptable. In addition, the opamp gives the same voltage level as the sensor, and appears to function with it.

An interesting observation here is that in normal circumstances the pressure on the sensor never rises above atmospheric pressure, so that the sensor can never detect a voltage level of more than 1.6V. This effectively sacrifices half the range of the ADC. However, a positive view of this is that, when pressure is placed on the wrong input of the sensor, the sensor does not break. This can lead to an error state, if caught in the code.

PWM signals

With an oscilloscope it has been checked that the PWM signals of both the servos and the motors are correct. These signals were correctly detected by the oscilloscope and considered suitable to connect to the servos.

6.1.5. Inversion encoders

The steps of the motors were illogical compared to the encoder readings. The steps jumped from the highest number back to 0, and seemed inconsistent. However, it turned out that the orientation of the encoders was wrong and had to be reversed.

To reverse this, the second pulse, the B pulse, had to be detected on a falling-edge instead of a rising-edge. This effectively inverts the signal.

6.1.6. Results

This test phase shows that the most important parts of the PCB are functioning.

• The reverse voltage protection shuts off the voltage at a negative voltage. • The LEDs are a bit too bright. • The voltage regulators are functioning. • The safety relay switches when it should.

The MOSFET does not appear to function as expected. More research has been done into this problem in the system testing phase.

6.2. System Testing For the

system testing phase, the entire PCB is assembled and code from the STM32 is used to test various parts of the PCB. In Figure 31 is this test setup to see.

6.2.1. Software integration

Using the GPIO pins, which are individually created in the software of the microcontroller, all outputs of the control system are programmed. This allows all connections of the microcontroller to be switched on and off. By flashing all outputs one by one, they have been checked for functionality.

6.2.2. Inversion MOSFETs

The MOSFETs are wired incorrectly, causing the output voltage to be inverted. This problem has been solved by also inverting the signal pins of the STM32.

Thanks to this solution, the outputs function as needed. However, the outputs of the STM32 cannot switch themselves on immediately upon start-up, so that the outputs of the PCB cannot be switched off immediately. This ensures that the outputs turn on during start-up and during programming of the STM32. If this continues for too long, this can cause the coil in the pinball pinball to heat up and build up pressure in the vacuum tank.

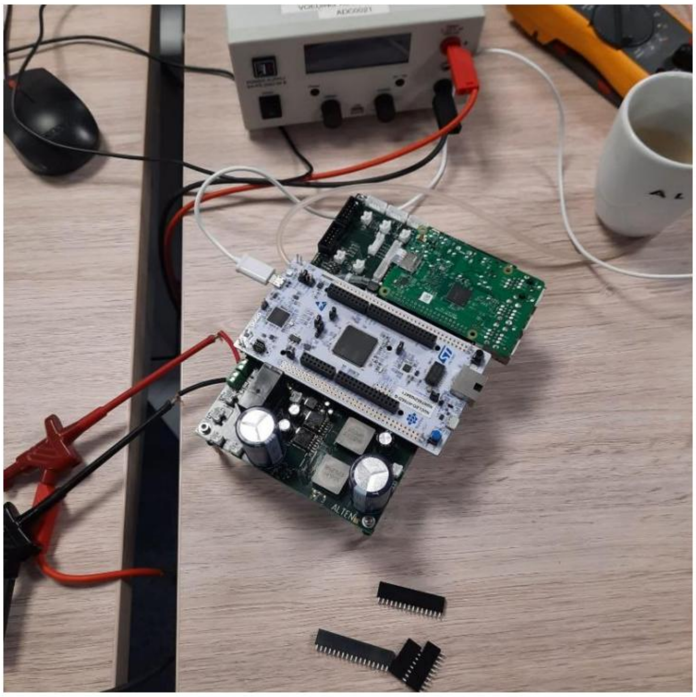

Figure 31 System testing test setup

6.2.3. Vacuum problems

During the testing of the vacuum gripper, the vacuum pump turned out to have great difficulty building up pressure. This is probably due to major leaks in the robot's pneumatics.
As a result, it is currently only possible to pick up the coin without turning off the vacuum pump. This is detrimental to the desired functionality and should be improved. This function has been tested in several ways: manually pressing the chip; positioning the gripper, and lowering automatically, with different compression; and 'feel' the negative pressure with a finger to determine how much force there was.
These all seemed inadequate.

6.2.4. Software demo

In the appendix (Software design) you can see an overview of the software produced.
By calling these functions a short demo has been made. This demo tests and proves the operation of the various parts of the system.

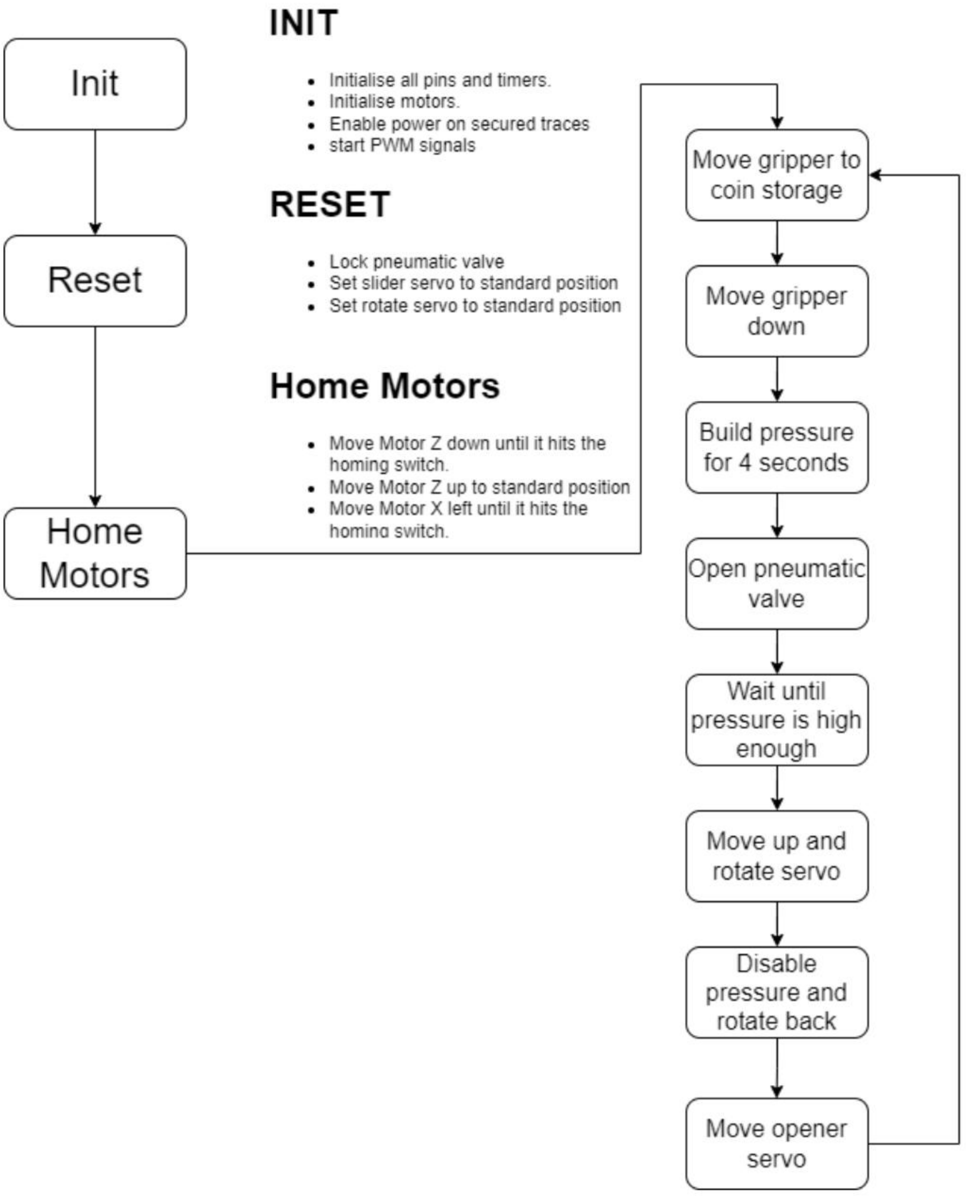

Figure 32 Flow chart of the demo

7. Future possibilities 7.1. Software notes

The software for the STM32 has had several bottlenecks. This has slightly delayed the testing of the system. These points of attention have been important during programming and should be kept in mind for possible follow-up projects. The points of attention of the software are described below.

7.1.1. Code generator

Because the STM32 development software, the program in which the controller is configured and programmed, uses a code generator to prepare large parts of the software, it is very important to work within the structure of the program. The software automatically creates code for the configuration you set in the program, and can override code that was added manually. This structure is indicated by comments in the code.

7.1.2. Dual Core code It

is worth noting that the development software of the STM32 creates a new sub-project for each core of the STM32. This means that the code for a core must be manually uploaded to that core. These two codes are completely independent of each other and will have to communicate with each other through an internal register, as described in the software architecture of the previous project.

7.2. Solution MOSFET inversion During the

test phase (Inversion) it was discovered that the output of the MOSFET circuit is inverted. This is due to an error in the circuit of chapter 4.3 (Transistors). Resistor R53 pulls the base of transistor 5 (T5) to ground when the input is floating. (Table 6 Current Logic MOSFET)

Table 6 Current logic MOSFET

Input	Output	Application
Low	High	Pin set
Float	High	Startup/Reset
High-	Low	Default state

As a result, the transistor is closed by default, and the gate at TP42 is equal to 12V. This causes the output to go high. This inversion causes the output to be open during PCB power-up, which can overload the components if the input remains floating or low for too long.

If this problem were to be solved in the future, R53 should be connected to 3.3V so that the transistor is raised during floating input. (Table 7 Enhanced Logic MOSFET)

Table 7 Enhanced Logic MOSFET

Input	Output	Application
low-	low	Default state
Float	low	Startup/Reset
High	High	Pin set

This would result in the circuit shown in Figure 33. This solution has not yet been implemented, and is recommended to be implemented in the future.

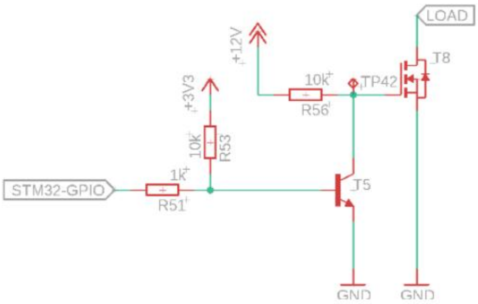

Figure 33 Improved MOSFET circuit

8. Conclusion and recommendations

The circuit board of the 4-in-1 robot has been redesigned to use a dual-core STM32. We looked at the implementation of this new microcontroller and the feedback on the previous design.

In the implementation it was important to pay attention to the voltage levels of the connections on the STM32, because they do not correspond to the single-core STM32. In addition, some tensions had to be strengthened or weakened in order to make the necessary connection.
In addition, it was necessary to properly set the correct settings on the internal clocks of the STM32. This allowed the correct signal frequencies to be selected.

The circuit board is installed in the 4-in-1 row robot and is functioning. To make this circuit board work, several designs had to be replaced and modified. The functionality of these adjustments can be demonstrated by means of a demo.

There is a functional flaw in the design that could cause overheating in the pinball pinball solenoid. The fault is in the MOSFET circuitry of the vacuum valve output, the vacuum pump output, the pinball flipper output, and the safety circuit. A solution has been offered for this error that can be repaired. In the meantime, it is recommended to disconnect the pinball pinball from the system when programming the robot. In addition, it is important not to touch the robot during start-up, because it can cause unexpected movement.

To ensure the operation of the homing switches, they must be changed to “micro-load” switches. These are switches that can be used reliably at low power (5V – 1mA, instead of 5V – 100mA).

In addition, the robot currently has no end stop switches. This makes for unsafe operation of the motors, which should ideally be added to the axes of the robot. These switches must also be “micro-load” switches. A connection to the operating system is available for this improvement.

The software of the robot is far from complete and can be further developed in the future to give the full functionality of the robot. It is important to focus on the operation of the new dual-core STM32. After that, focus can be placed on moving the game control from the Raspberry pi to the STM32.

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Eindhoven
1/20/2023
PUBLIC

Appendix A System Design Document

System Design Documentation -

4 in 1 row - operating system

Version 1.0

Date: 20-1-2023

ALTEN

Lauren Verbrugge

VersionHistory

Version	Date 0.1	State	Author	Remark

Acronyms and Abbreviations

Term	explanation
<ABC>	<First three letters of the alphabet>

Referenced documents

ID	reference	Title	date	Author
01	*SRD*	*System Requirements PCB*		*Lauren Verbruggen*
02	*SAD*	*Software Architecture Documentation – 4-in-1-row robot*	*4/13/2022*	*Pascal Fatz*

A.1 System overview and architecture This section
describes the system architectural design. All system functions and its interfaces will be identified.

A.2 Process flow (Concept of execution)

The process flow shows the requested functionality of the system, and its software flow.

Software block	Start protocol	Inputs and Outputs
Init (M7)	Sends a pulse between the cores to start the initialization process.	Input: Computer start signal Output: Config signal
Init (M4)	Receives the pulse to send the initialization task to the task manager.	Input: Config signal Output: Inittask
Task manager	Sends a signal to the motor controllers and sensors to start their initialization protocol.	Input: Inittask Output: Motor controller init Output: Coin color separator init Output: User detect init Output: Board opener init Output: Coin picker controller init
engine controller	Moves motors X and Z to their home position and tests the functionality of the encoders.	Input: Motor controller init Output: Homing finished with status
Coin colour	Checks the color sensor and proximity sensor. Test the [illegible] separator	Input: Coin color separator init Output: Sensor statuses
User detect	Checks the I2C connection and tests the gate sensors.	Input: User detect init Output: Sensor statuses
Board opener	Moves servo to home position.	Input: Board opener init Output: Homing finished with status
Coin picker controller	Checks vacuum sensor and test vacuum pump. Moves servo to home position.	Input: Coin picker controller init Output: Homing finished with status Output: Sensor statuses

A.3 Disciplinary architecture

8.1.1. mechanical architecture

Mounting connections

Due to static connection bolts in the setup, connector pieces need to be added to mount the PCB correctly to the setup.

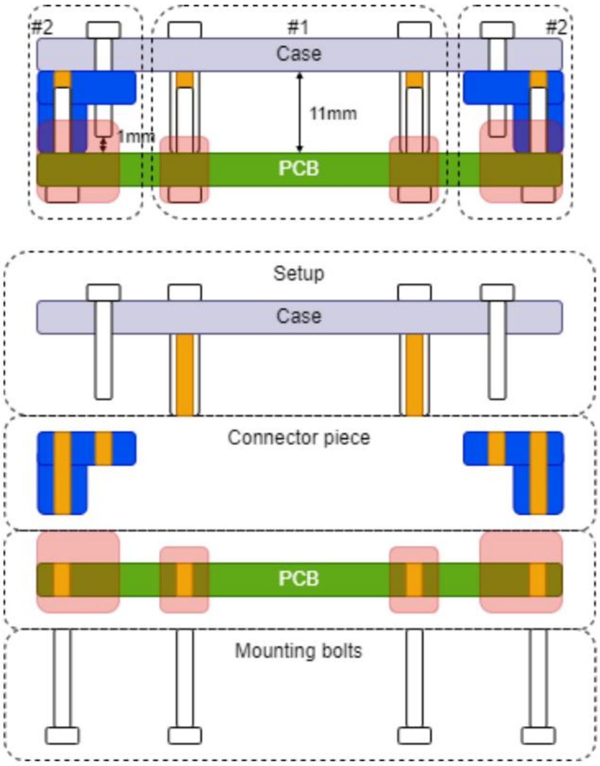


Figure 1 Blue: Connector piece for connection to male bolts

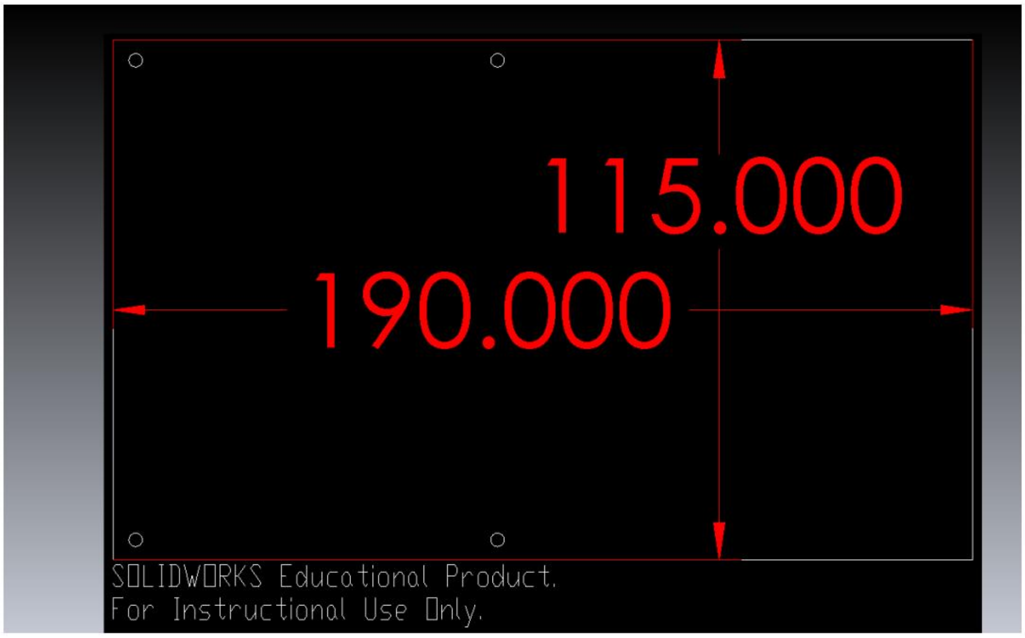
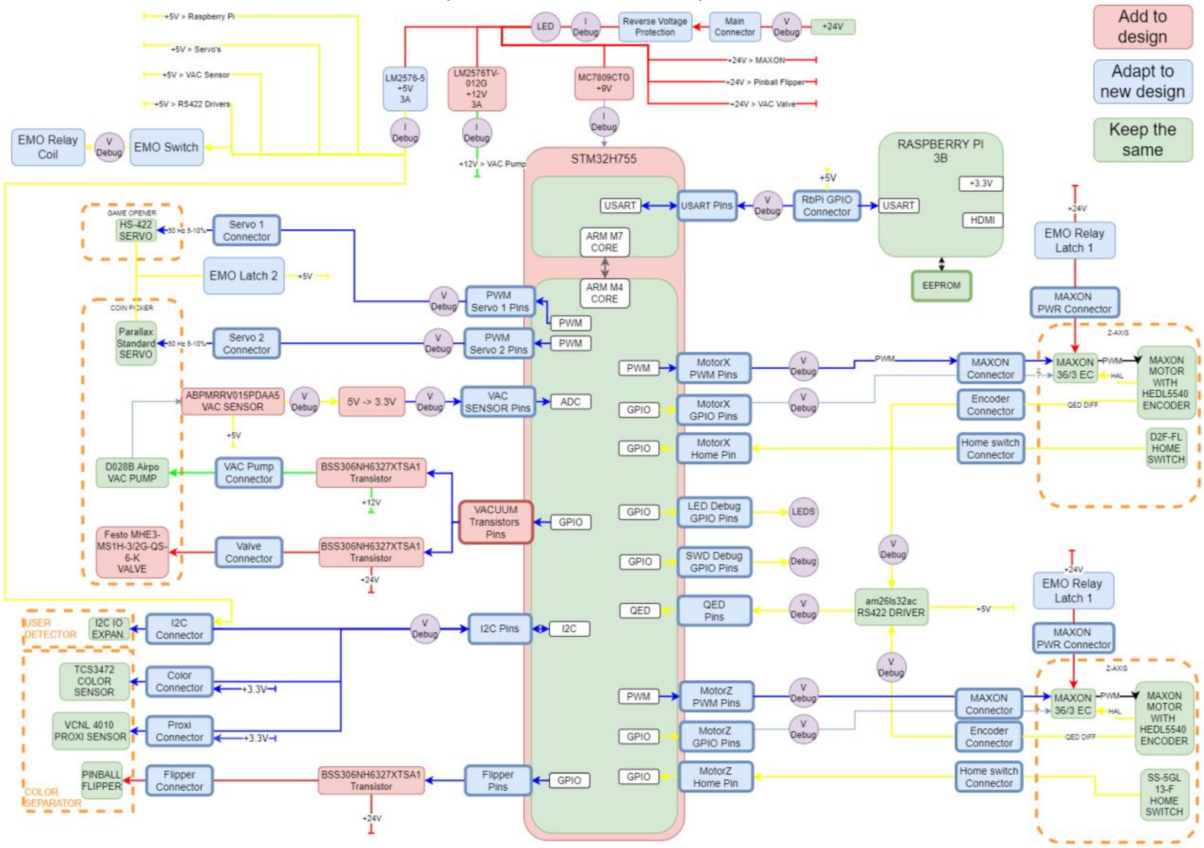
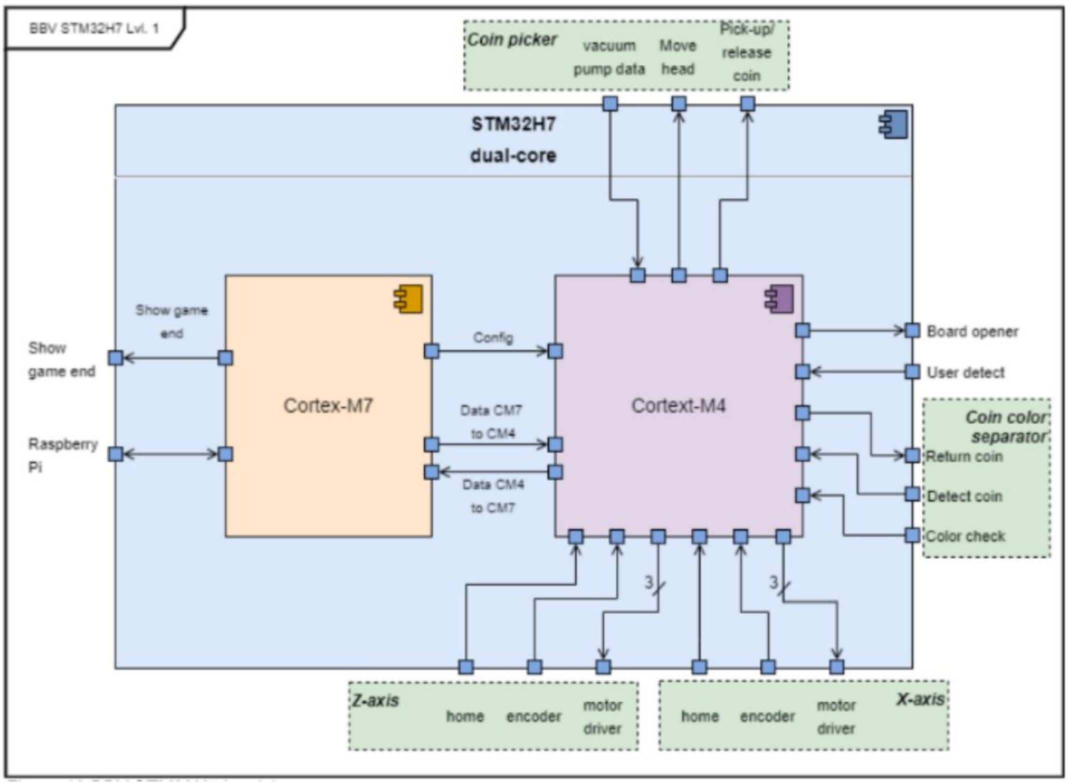


Figure 2 PCB Footprint

8.1.2. Electrical architecture

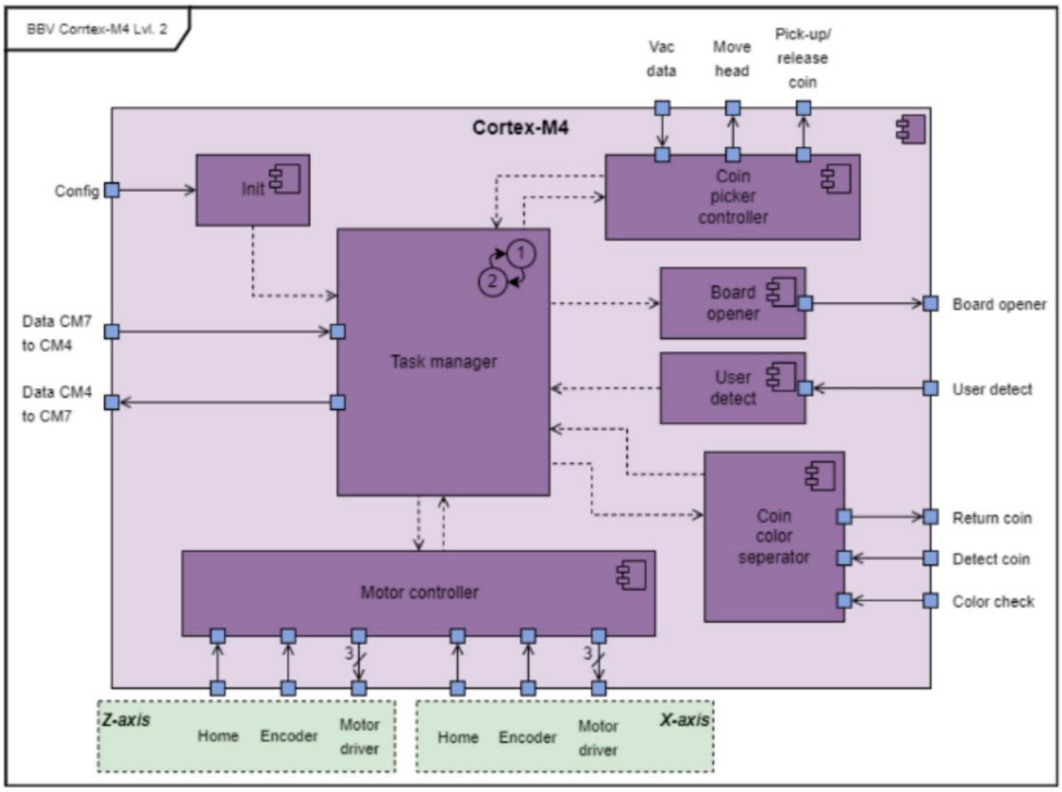
The electrical architecture shows the components and relationships of the PCB.

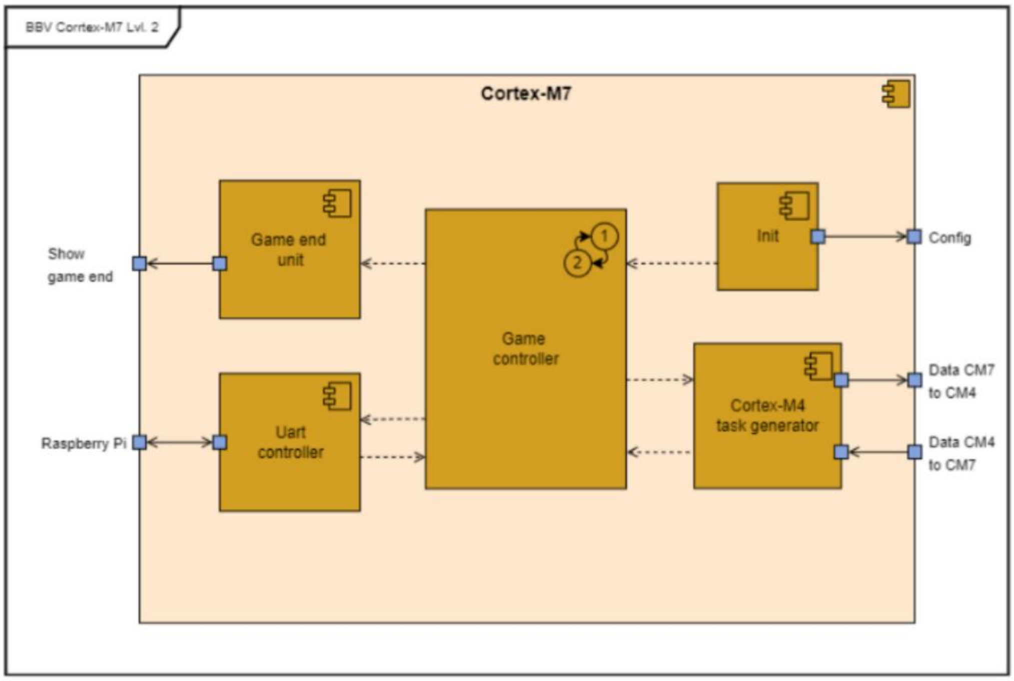




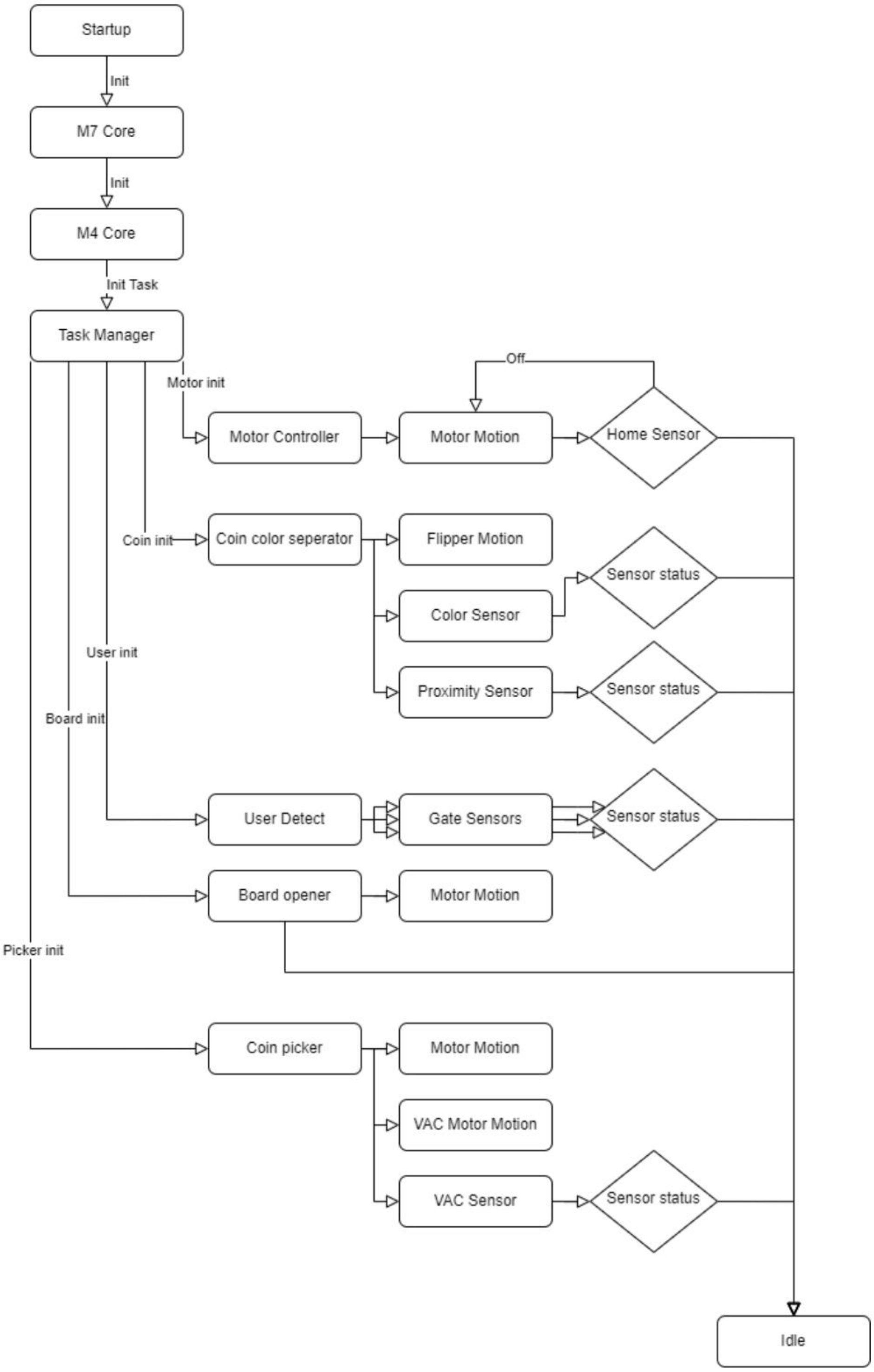
8.1.3. Software architecture

The software architecture contains the software blocks that are designed in the Software Architecture Design[1] .





[1] Reference 01 in referenced documents


Startup
Init
M7 Core
Init
M4 Core
Init Task
Task Manager
Motor init
Off
Motor Controller
Motor Motion
Home Sensor
Coin init
Coin color seperator
Flipper Motion
Sensor status
Color Sensor
User init
Proximity Sensor
Sensor status
Board init
User Detect
Gate Sensors
Sensor status
Board opener
Motor Motion
Picker init
Coin picker
Motor Motion
VAC Motor Motion
VAC Sensor
Sensor status
Idle

A.4 Adaptions The
adaptations show which connections are needed for change. Their requirements are validated, and conclusions are implemented into the new PCB.

Connection	Connection to	Requirement Signal	validation	Conclusion
USART Connection PB6	& PB7	voltage must be 3.3V.	Regular I/O Pin with 3.3V capabilities.	No changes needed
I2C connection	PB8 & PB9	Signal voltage must be 3.3V, with a signal speed of 400kHz at must.	I2C on the STM32 uses 100kHZ speed and regular 3.3v IO.	No changes needed
Flipper Connection PC8		Signal voltage must be higher than 2V and provide 100nA.	PC8 uses regular 3.3v IO. For current calculation see table below.	Check transistor for availability.
VAC transistors Connection	PC7 & PC6	Signal voltage must be higher than 2V and provide 100nA.	PC7 & PC6 uses regular 3.3v IO. For current calculation see table below	Check transistor for availability.
VAC Sensor Connection	PA4	Signal voltage can reach 5v. Connection use 5mA.	ADC uses max 3.6v. For current calculation see table below.	VAC Sensor must be altered for 3.3V.
QED Connection	PD13, PD12, PA6 & PA5	Signal voltage can reach 5v. Connection use 8mA.	QED uses regular 5v IO. For current calculation see table below.	QED Connection must be connected to FT_xx pins
MotorX PWM Connection & MotorZ PWM Connection	PB10 & PB11	Signal voltage uses 3.3V. Connection use 0.07mA. Signal speed must refresh at 10 to 5000Hz.	Motor PWM uses regular 3.3v IO. For current calculation see table below. The refresh rate will be set at 5000Hz	STM32 timer need to have the correct prescaler and AutoReset Register for his frequency.
PWM servo 1 Connection	PD13, PD12, PA6 & PA5	Signal voltage must be atleast 3v. Signal speed must refresh at 50Hz	PWM uses regular 3.3v IO. For current calculation see table below. STM32 timers are 16-bit and provide up to 240MHz.	STM32 timer need to have the correct prescaler and AutoReset Register fort his frequency.
PWM servo 2 Connection	PD13, PD12, PA6 & PA5	Signal voltage must be at minimum 3.3v. signal rate	PWM uses regular 3.3v IO. For current calculation see table below.	STM32 timer need to have the correct prescaler and AutoReset

		must refresh at 50 Hz	STM32 timers are 16-bit and provide up to 240MHz.	Register for this frequency.
MotorZ GPIO Connection & MotorX GPIO Connection	PD14, PE2, PG12, PE0, PD15 & PA0	Signal voltage must be at minimum 3.3v.	GPIO uses regular 3.3v IO. For current calculation see table below.	No changes needed.
MotorZ Home Pin & MotorX Home Pin	PB2 & PE11	Signal voltage must be at least 5v, with 100mA.	GPIO uses regular 5v IO. The maximum amount or ampere on the pin must be 20mA.	Homing Connection must be connected to FT_xx pins. A protection circuit must be made for the current on the GPIO.

A.5 Design options

A.5.1 VAC Sensor Connection

Requirement: Signal voltage can reach 5v. Connection uses 5mA.

Connection to: PA4

Validation: ADC uses max 3.6v. For current calculation see table below.

Conclusion: VAC Sensor must be altered for 3.3V.

Sensor choice

Because the MPXV6115V is not currently available. The ABPMRRV015PDAA5 will be used instead. The functionality is the same.

supplies

SR.3	VAC Sensor Power			
Ref	UR.5			
Description	The operating requirements of the needed VAC Sensor			
Value	Min Mean Max Unit 3.3			
Operating voltage			24	v
Rationale	By using an existing power supply, no new supplies need to be added.			

Pneumatics pressures

SR.4	VAC Sensor			
Ref	UR.5			
Description	The operating requirements of the needed VAC Sensor Min Mean Max			
Value	Unit -1.0			
Definitely Operating Pressure			1	bar
Rationale	The sensor should be able to stand with normal atmosphere pressure and should be able to read over the entire operating range of the pneumatic system.			

connectivity

SR.5	Signal			
Ref	UR.4			
Description	The voltage level of the sensor.			
Value Min Mean Max Unit **Voltage** 0 **level**				
			3.3	v
rationale	The ADC cannot tolerate 5V.			

Environmental

SR.6	Operating Ambient Temperature			
Ref	UR.4			
Description	The ambient temperature allowed for the system.			
Value	Min Mean Max Unit 0			
Operating temperature			+45	° C
rationale	Overheating causes damage to the robot.			

Input impedance

The external resistance of the voltage level shifter needs to be less than the chosen External input impedance value.

Symbol	Parameter	Conditions			Min	Typ	Max	Unit
R_{AIN} (5)	External input impedance	Resolution = 16 bits, T_J = 140 °C	-	-	-	-	50	Ω
		Resolution = 16 bits, T_J = 125 °C	-	-	-	-	170	
		Resolution = 14 bits, T_J = 140 °C	-	-	-	-	200	
		Resolution = 14 bits, T_J = 125 °C	-	-	-	-	435	
		Resolution = 12 bits, T_J = 140 °C	-	-	-	-	700	
		Resolution = 12 bits, T_J =125 °C	-	-	-	-	1150	
		Resolution = 10 bits, T_J = 140 °C	-	-	-	-	3700	
		Resolution = 10 bits, T_J = 125 °C	-	-	-	-	5650	
		Resolution = 8 bits, T_J = 140 °C	-	-	-	-	18000	
		Resolution = 8 bits, T_J = 125 °C	-	-	-	-	26500	

Figure 3 Input Impedance

Voltage divider

For a buffer less divider, we will use the resolution with the highest maximum input impedance possible. With an 8-bit ADC we can allow 18000 ÿ input impedance.

The signal current of the VAC is at most 0.2mA. If the loss of the ADC pin is 400uA, the total current loss is:

$$' \ {}_1 + ÿ (\quad {}_1 + \quad {}_2) =$$

$$0.0004 ÿ 3700 + ÿ 17500 = 5$$

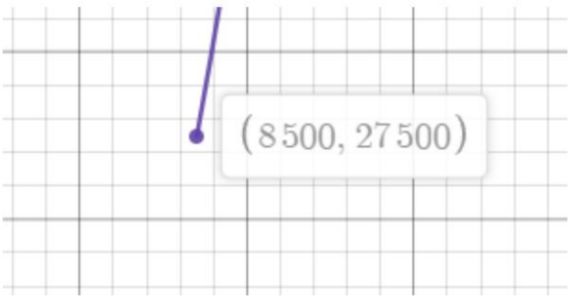
$$= 0.201$$

$$= 0.601$$

is more than 0.2 mA. That means that the resistors of the divider must be made larger, or the ADC pin loss needs to go down. The input impedance of the pin cannot go up, so the frequency of the ADC pin must go down to allow for a lower consumption.

I_{DD} (ADC)	ADC consumption on V_{DD}	f_{ADC}=50 MHz	-	-	-	400	-	
		f_{ADC}=25 MHz	-	-	-	220	-	
		f_{ADC}=12.5 MHz	-	-	-	180	-	
		f_{ADC}=6.25 MHz	-	-	-	120	-	
		f_{ADC}=3.125 MHz	-	-	-	80	-	

Calculating the needed resistors for = 3,125 :



$$= 80 ÿ 10ÿ6$$

$${}_2 = 3.3$$

$${}_1 = \quad {}_2$$

$$(\ {}_1) = \frac{1}{1}$$

$$= (\quad {}_1) ÿ$$

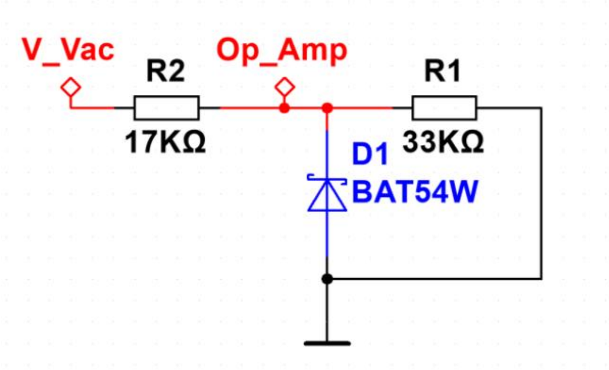
$${}_2 (\ {}_1) = \frac{2}{(\ {}_1)}$$

$$= \quad {}_2 ( ) \{ \quad ( ) < \}\{ > 0\}\{ > 0\}$$

The lowest possible resistor values create an impedance of 36000 ÿ, which the system cannot handle. Another solution has to be found.

Voltage divider with buffer

With a simple voltage divider and an op-amp you can create a division with negligible input impedance. That way the selected voltages of the voltage divider don't matter as long as they produce 3.3V.



However, the correct op-amp (preferably rail to rail) needs to be selected. The op-amp that's currently available at Alten is the LM2904DRG3.

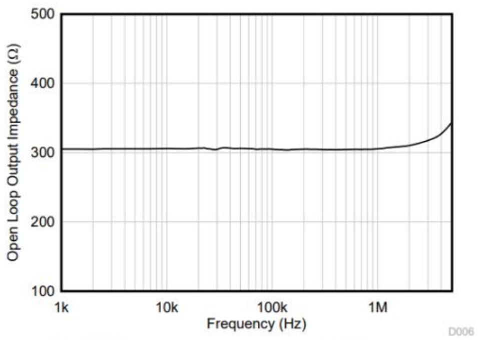
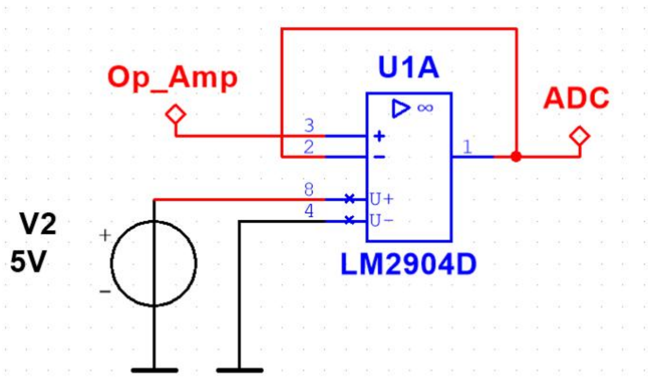


Figure 6-24. Open-Loop Output Impedance vs Frequency .



Using a frequency lower than 1.2MHz, the impedance of the op-amp is about 300ÿ.

According to Figure 3, a 12-bit resolution can sustain 700ÿ at

= 140° .

8.3.1 Unity-Gain Bandwidth

The unity-gain bandwidth is the frequency up to which an amplifier with a unity gain may be operated without greatly distorting the signal. These devices have a 1.2-MHz unity-gain bandwidth (B Version).

To achieve the 1.2MHz resolution, a prescaler must be used for the ADC frequency.

$$= 76000000$$

$$( ) = \frac{}{}$$

$$(64) = 1187500$$

With a prescaler of 64, our frequency is withing the unity-gain bandwidth of the sensor, and lower than the maximum input impedance.

With this resolution, a 12-bit counter, we can count 4096 steps.

This would require making our system unresponsive for a drift of $\frac{4096}{24}$ = 170.667 ÿ 171 count steps.

A.5.2 MotorX PWM Connection & MotorZ PWM Connection

Requirement: Signal voltage uses 3.3V. Connection uses 0.07mA. Signal speed must refresh at 10 to 5000Hz.

Connection to: PB10 & PB11

Validation: Motor PWM uses regular 3.3v IO. For current calculation see table below. The refresh rate will be set at 5000Hz Conclusion: STM32 timer need to have the correct prescaler and AutoReset Register for its frequency.

To calculate the needed prescaler and AutoReset Register, we can use the following

( ) = ÿ (

)

= The needed speed

= The clock speed of the timers of the STM32H755

The smallest step needed is 0.2us, as this is the PWM resolution, expressed in S.

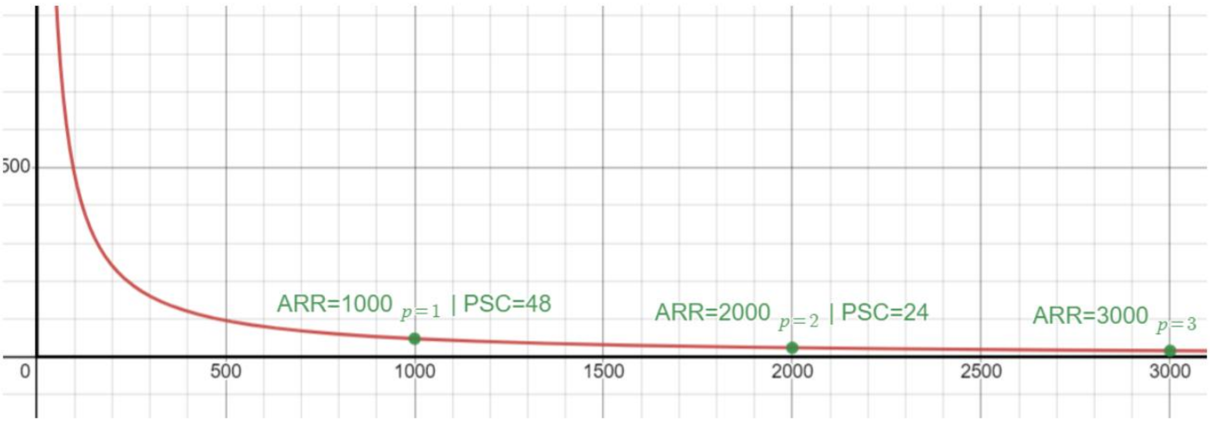
ÿ = 1 /

= 1 /

$$= \frac{1}{5000 \text{ ÿ } 0.0000002}$$

= 1000

Graphing the results of the formula where 0.2us. and are integers, and the smallest step is



To achieve the highest , must be 48.

This results in being 1000.

A.5.3 PWM Servo 1 Connection & PWM Servo 2 Connection

Requirement: Signal voltage must be at least 3v. Signal speed must refresh at 50Hz
Connection to: PD13, PD12, PA6 & PA5 Validation: PWM uses regular 3.3v IO. For current calculation see table below.

STM32 timers are 16-bit and provide up to 240MHz.

Conclusion: STM32 timer need to have the correct prescaler and AutoReset Register for this frequency.

Requirement: Signal voltage must be at least 3.3v. Signal speed must refresh at 50Hz
Connection to: PD13, PD12, PA6 & PA5 Validation: PWM uses regular 3.3v IO. For current calculation see table below.

STM32 timers are 16-bit and provide up to 240MHz.

Conclusion: STM32 timer need to have the correct prescaler and AutoReset Register for this frequency.

To calculate the needed prescaler and AutoReset Register, we can use the following formula.

( ) = ÿ( )

= The needed speed

= The clock speed of the timers of the STM32H755

We want to achieve a resolution that doesn't exceed our servo's deadband.

= 8 The dead band width

= = The width of the signal

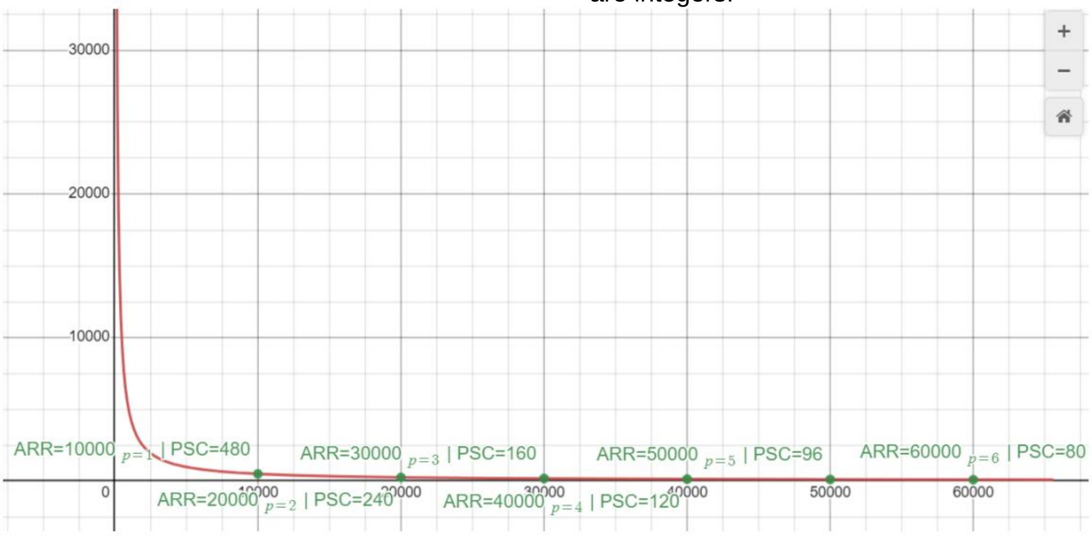
Resolution = 2500

To sit safely in the deadband, we want to use a pulse length of 2us (because with 4us you go over the deadband, with 2us you can stay in the middle)

Resolution = 10000

= 10000

The results of the formula where and are integers.



The minimum prescaler is 480.

We can multiply the resolution by 6 to achieve the highest possible resolution at PSC=80, with an ARR of 60000.

A.5.4 Transistors

- The VAC Valve requires 6.5W at 24V. This means a current of 0.27A will flow through the transistor.
= 0.27
- The VAC Pump requires 12W at 12V. This means a current of 1A will flow through the transistor.
= 1
- The pinball flipper provides 14.5ÿ 24V. This means a current of 1.66A will flow through the transistor.
= 1.66

The chosen transistor in the existing circuit is no longer available for purchase. That's why a new transistor needs to be chosen.

The transistor has the following requirements:

No	Requirement	Min value	Max value	Unit
Drain	current (Id) 1.66 Switching voltage (Vgs(th)) 0 1 Load voltage		3.3	v
2	(Vds)			a
3		24		v

The following transistor is selected:
https://nl.farnell.com/infineon/bss306nh6327xtsa1/mosfet-n-ch-30v-2-3a-sot-23-3/dp/2443468
BSS306NH6327XTSA1

A.5.5 Homing switch

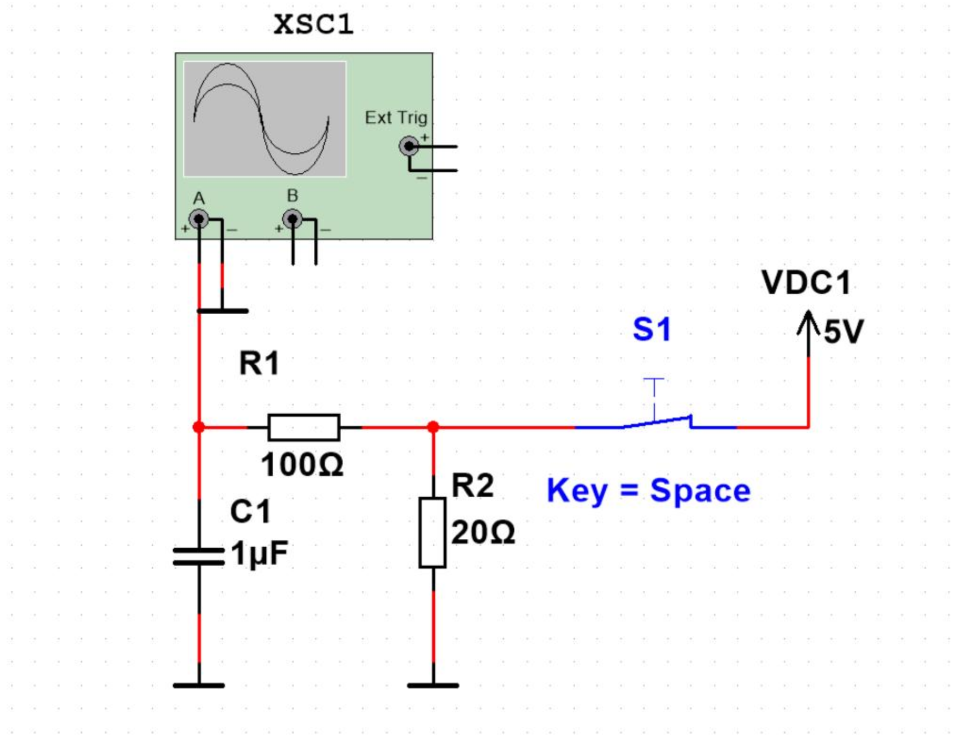
Requirement: Signal voltage must be at least 5v, with 100mA.

Connection to: PB2 & PE11

Validation: GPIO uses regular 5v IO. The maximum amount of ampere on the pin must be 20mA.

Conclusion: Homing Connection must be connected to FT_xx pins. A protection circuit must be made for the current on the GPIO.

To protect the GPIO pin from the current, a resistor to ground must be placed.



A.5.6 LEDs

All leds are red.

Value	Min	Type	max	Unit
VF	1.6	2.0	2.4	v
IF		20		mA
VR (IR = 100uA)	5			v

A led needs to be chosen that operates in combination with a resistor on 24V. The led: ASMT-RR45-AQ902, has been chosen.

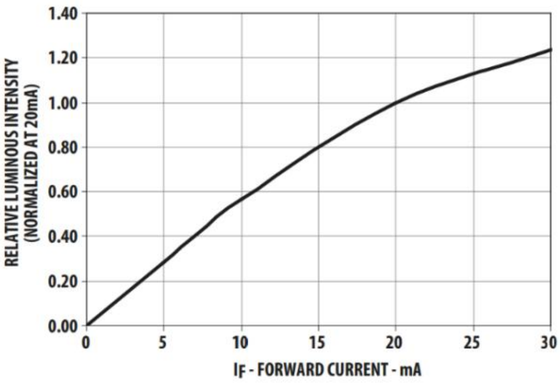


Figure 3. Luminous intensity vs. forward current

The chosen luminous intensity is 30%. This results in a forward current of 5mA.

3V3

The chosen resistor, for 5V, needs to be

+ = 3.3

= ÿ

= (3.3 ÿ)

$= \frac{1.3}{0.005}$ ÿ 260ÿ

5V

The chosen resistor, for 5V, needs to be

+ = 5

= ÿ

= (5 ÿ)

$= \frac{3}{0.005}$ ÿ 600ÿ

For 5V outputs, a value of 680 ohms is chosen.

12V

The chosen resistor, for 12V, needs to be

+ = 12

= ÿ

$$= \frac{(12\ ÿ\ )}{\quad}$$

$$= \frac{10}{0.005}\ ÿ\ 2000ÿ$$

For 12V outputs, a value of 1100 ohms is chosen. This resistor is chosen based on a wrong estimation, and needs to be changed to a resistor with the correct value.

24V

The chosen resistor, for 24V, needs to be

+ = 24

= ÿ

$$= \frac{(24\ ÿ\ )}{\quad}$$

22

R = ÿ 4400ÿ 0.005

A value of 2400 ohms is chosen. This resistor is chosen based on a wrong estimation, and needs to be changed to a resistor with the correct value.

A.6 Original Design A.6.1

Reverse Voltage Protection In the original design, a Reverse Voltage Protection circuit is installed. This circuit will be copied over.

PFET_DRAIN

For the reverse power protection, a PMOS needs to be added. The chosen PMOS in the design is a FDS6679Z. This component is currently outdated, so the FDS6679AZ will be used.

Features

- Max $r_{DS(on)}$ = 9.3mΩ at V_{GS} = -10V, I_D = -13A
- Max $r_{DS(on)}$ = 14.8mΩ at V_{GS} = -4.5V, I_D = -11A
- Extended V_{GS} range (-25V) for battery applications
- HBM ESD protection level of 6kV typical (note 3)
- High performance trench technology for extremely low $r_{DS(on)}$
- High power and current handing capability
- RoHS Compliant

MOSFET Maximum Ratings T_A = 25°C unless otherwise noted

Symbol	Parameter		Ratings	Units
V_{DS}	Drain to Source Voltage		-30	V
V_{GS}	Gate to Source Voltage		±25	V
I_D	Drain Current -Continuous	(Note 1a)	-13	A
	-Pulsed		-65	
P_D	Power Dissipation for Single Operation	(Note 1a)	2.5	W
		(Note 1b)	1.2	
		(Note 1c)	1.0	
T_J, T_{STG}	Operating and Storage Temperature		-55 to +150	°C

Thermal Characteristics

$R_{\theta JA}$	Thermal Resistance , Junction to Ambient (Note 1a)	50	°C/W
$R_{\theta JC}$	Thermal Resistance , Junction to Case (Note 1)	25	°C/W

Package Marking and Ordering Information

Device Marking	Device	Reel Size	Tape Width	Quantity
FDS6679AZ	FDS6679AZ	13"	12mm	2500 units

Figure 4 FDS6679AZ Datasheet

Features

- –13 A, –30 V. $R_{DS(ON)}$ = 9 mΩ @ V_{GS} = –10 V
  $R_{DS(ON)}$ = 13 mΩ @ V_{GS} = – 4.5 V
- Extended V_{GSS} range (–25V) for battery applications
- ESD protection diode (note 3)
- High performance trench technology for extremely low $R_{DS(ON)}$
- High power and current handling capability

Absolute Maximum Ratings T_A=25°C unless otherwise noted

Symbol	Parameter		Ratings	Units
V_{DSS}	Drain-Source Voltage		–30	V
V_{GSS}	Gate-Source Voltage		–25/+20	V
I_D	Drain Current – Continuous	(Note 1a)	–13	A
	– Pulsed		–50	
P_D	Power Dissipation for Single Operation	(Note 1a)	2.5	W
		(Note 1b)	1.2	
		(Note 1c)	1.0	
T_J, T_{STG}	Operating and Storage Junction Temperature Range		–55 to +175	°C

Thermal Characteristics

$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient	(Note 1a)	50	°C/W
$R_{\theta JC}$	Thermal Resistance, Junction-to-Case	(Note 1)	25	°C/W

Package Marking and Ordering Information

Device Marking	Device	Reel Size	Tape width	Quantity
FDS6679Z	FDS6679Z	13"	12mm	2500 units

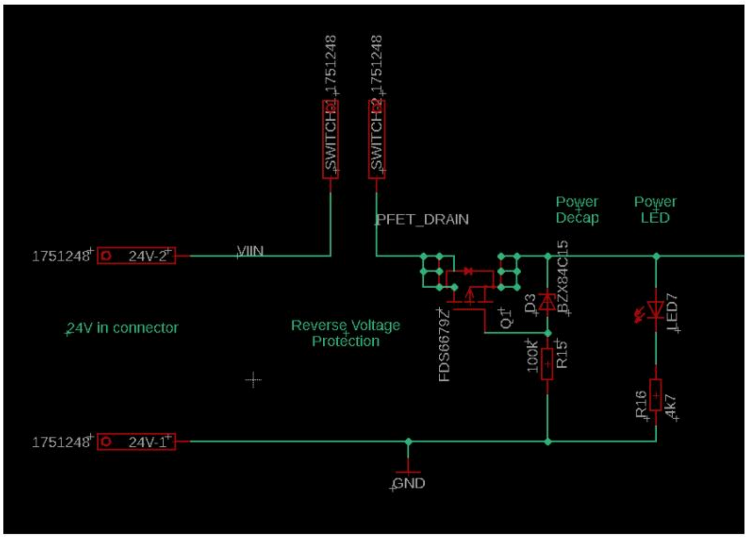
Figure 5 FDS6679Z Datasheet

The characteristics are extremely similar, except for the increased on-resistance, and higher tolerance for drain current.

The FDS6679AZ will be used for the new track.

Power Decap

For the power decap circuit, a Zener diode is used. The chosen component is BZX84C15. This component is currently available. So will be used for this project according to the original circuit.



A.6.2 Emergency Stop The
emergency stop circuit disables the power to the Maxon PWR Connector and the Servo1&2 Connectors.

The relay in the circuit, the G2R-2A DC5, is currently not available for purchase.
However, the G2R-24 DC5 is available. The rating of the new relay is the same as the old relay, with exception of a few differences.

The differences are:

1. The G2R-24 is fully sealed instead of flux protected.
2. The G2R-24 has double contacts instead of being normally open.

The fully sealed option can carry more current, and doesn't have any downsides, thus is suited for this project.

● **Contacts: Fully Protection Type**

Classification	Standard type Quick-connect Terminal (1single-pole type)				High-capacity type		Bifurcated contact type		High-sensitivity type			
Number of poles	1-pole		2-pole		1-pole		2-pole		1-pole		2-pole	
Item / Load	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load	Inductive load (cosϕ = 0.4; L/R = 7 ms)
Contact type	Single				Single		Bifurcated		Single			
Contact material	Ag-alloy (Cd free)											
Rated load	10 A at 250 VAC 10 A at 30 VDC	7.5 A at 250 VAC 5 A at 30 VDC	5 A at 250 VAC 5 A at 30 VDC	2 A at 250 VAC 3 A at 30 VDC	16 A at 250 VAC 16 A at 30 VDC	8 A at 250 VAC 8 A at 30 VDC	5 A at 250 VAC 5 A at 30 VDC	2 A at 250 VAC 3 A at 30 VDC	5 A at 250 VAC 5 A at 30 VDC	2 A at 250 VAC 3 A at 30 VDC	3 A at 250 VAC 3 A at 30 VDC	1 A at 250 VAC 1.5 A at 30 VDC
Rated carry current	10 A		5 A		16 A		5 A		5 A		3 A	
Max. switching voltage	380 VAC, 125 VDC				380 VAC, 125 VDC				380 VAC, 125 VDC			
Max. switching current	10 A		5 A		16 A		5 A		5 A		3 A	
Failure rate (P level) (reference value) *	100 mA at 5 VDC		10 mA at 5 VDC		100 mA at 5 VDC		1 mA at 5 VDC		100 mA at 5 VDC		10 mA at 5 VDC	

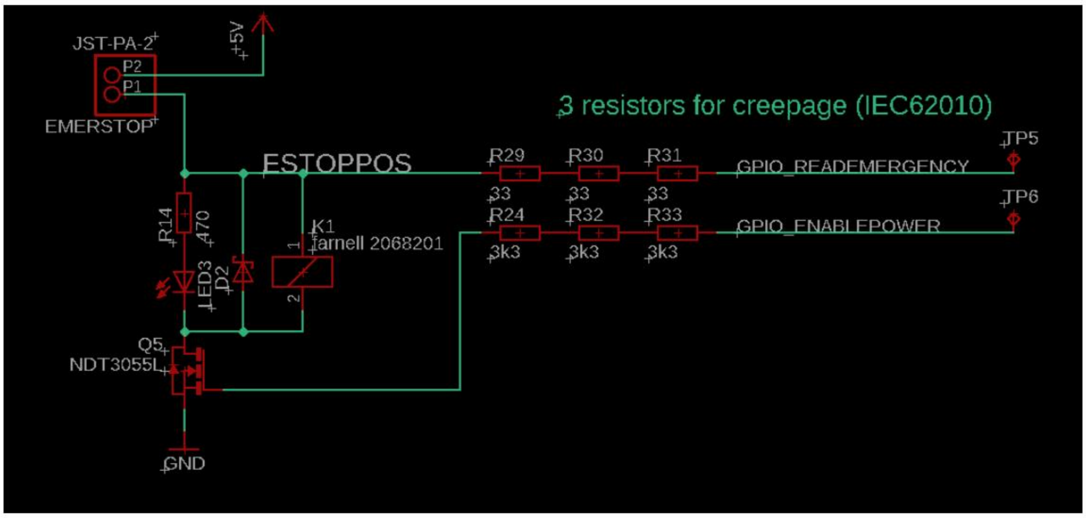
* This value was measured at a switching frequency of 120 operations/min.

● **Contacts: Flux Sealed Type**

Classification	Standard type (Single contact type)				Bifurcated contact type	
Number of poles	1-pole		2-pole		1-pole	
Item / Load	Resistive load (cosϕ = 1)	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load (cosϕ = 1)	Inductive load (cosϕ = 0.4; L/R = 7 ms)	Resistive load (cosϕ = 1)	Inductive load (cosϕ = 0.4; L/R = 7 ms)
Contact type	Single		Single		Bifurcated	
Contact material	Ag-alloy (Cd free)					
Rated load	8 A at 250 VAC 8 A at 30 VDC	6 A at 250 VAC 4 A at 30 VDC	4 A at 250 VAC 4 A at 30 VDC	1.5 A at 250 VAC 2.5 A at 30 VDC	5 A at 250 VAC 5 A at 30 VDC	2 A at 250 VAC 3 A at 30 VDC
Rated carry current	8 A		4 A		5 A	
Max. switching voltage	380 VAC, 125 VDC		380 VAC, 125 VDC		380 VAC, 125 VDC	
Max. switching current	8 A		4 A		5 A	
Failure rate (P level) (reference value) *	100 mA at 5 VDC		10 mA at 5 VDC		1 mA at 5 VDC	

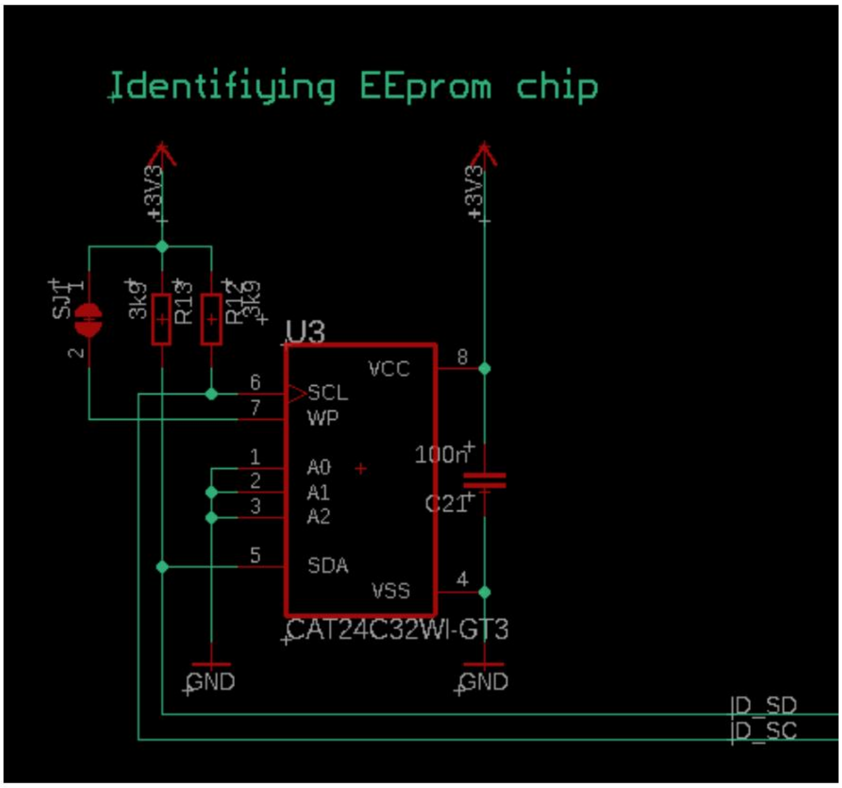
* This value was measured at a switching frequency of 120 operations/min.

G2R



A.6.3 Raspberry Pi EEPROM

The CAT23C43WI-GT3 is available for purchasing and will be added into the circuit.



A.6.4 Voltage regulator filters For
the voltage regulator filters, spools needed to be selected. These are based on their input voltage and load current.

5V

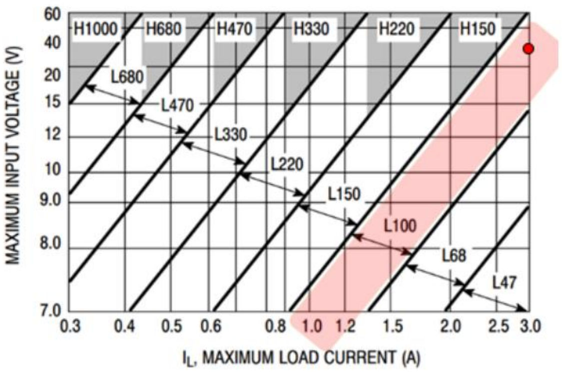
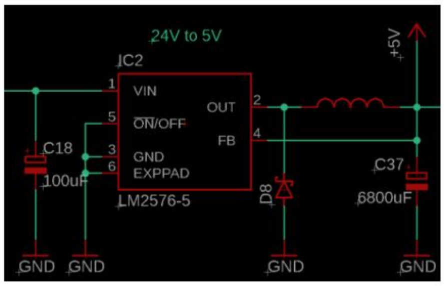


Figure 19. LM2576-5

= 24

= 3



L100	100 µH	77 312	671 27000	PE−92108	RL2444

The needed spool value is:

= L100 = 100uH

12V

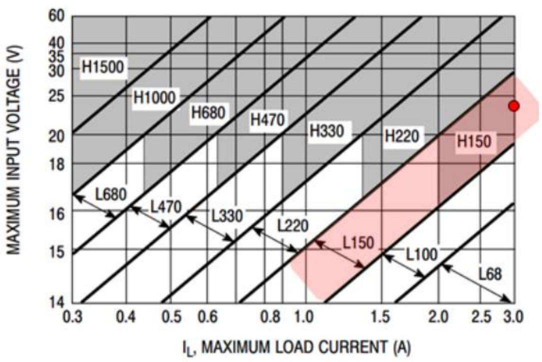
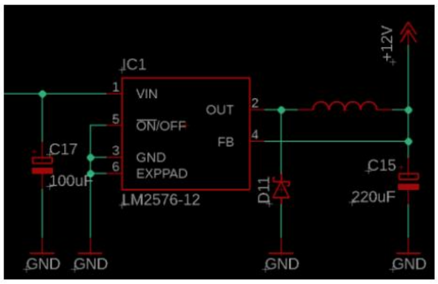


Figure 20. LM2576-12

= 24

= 3A



L100	100 µH	77 312	671 27000	PE−92108	RL2444

The needed spool value is:

= H150 = 150uH

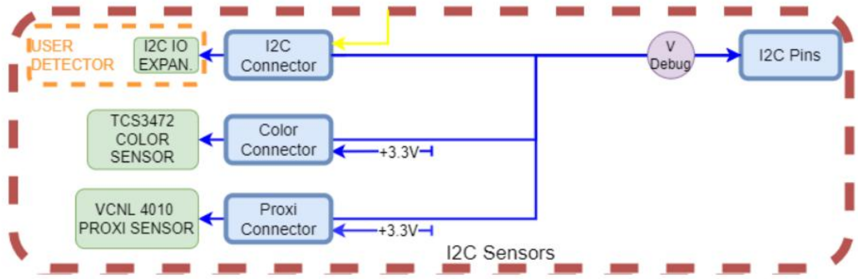
Lchosen = 100uH

A.7 Net classes

For each circuit in the PCB, a class allocation is made to determine the trace width and clearance.
The allocation is based on the range of current, and voltage level. The following classes are categorised:

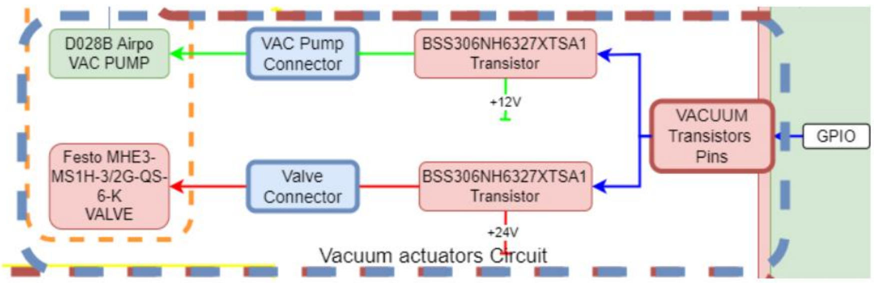
Class	currentrange	Min tracks width	Min via width
Signal	- 0.5A	0.25mm	0.35mm
Default	0.5A–1.0A	0.5mm	0.35mm
Power	1.0A - 3.0A	2.5mm	3x0.35mm
Main supply	3.0A - 6.5A	6.75mm	5x0.35mm

A.7.1 I2C Classes



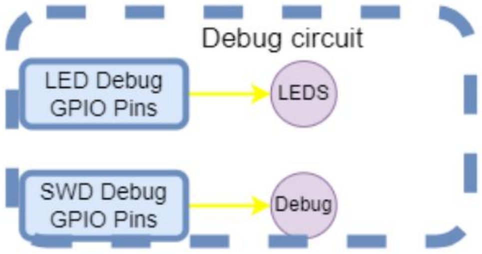
Connection	Voltage	Current	Class
User detector supply	5V	500mA	Default
color sensor supplies	3.3V	0.33mA	Signal
Proxi sensor supply	3.3V	203.8mA	Signal
I2C	3.3V	-	Signal

A.7.2 Vacuum Actuators



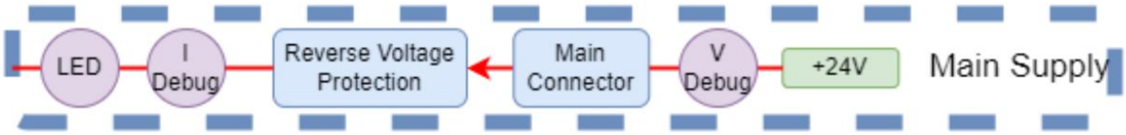
Connection	Voltage	Current	Class
transistor switch	3.3V	0.1mA	Signal
Valve supplies	12V	0.271A	Signal
pump supply	24V	1A	Power

A.7.3 Debug



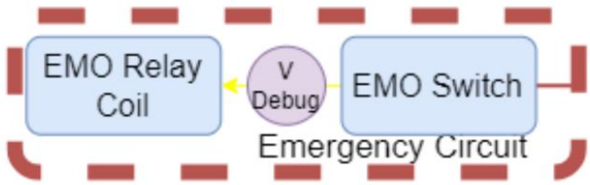
Connection	Voltage	Current	Class
LEDs		-	Signal
SWD		-	Signal

A.7.4 Power supply



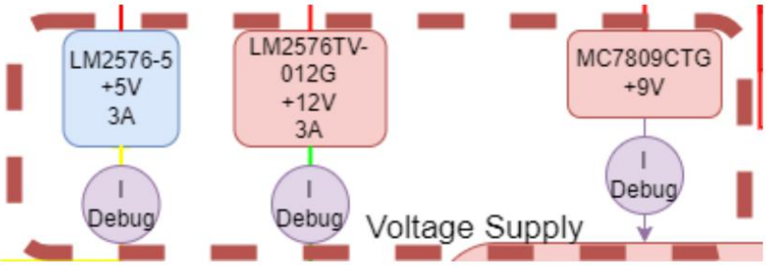
Connection	Voltage	Current	Class
LED	24V	-	Signal
RVP Gate	24V	10uA	Signal
Power	24V	6.5A	Main supplies

A.7.5 Emergency



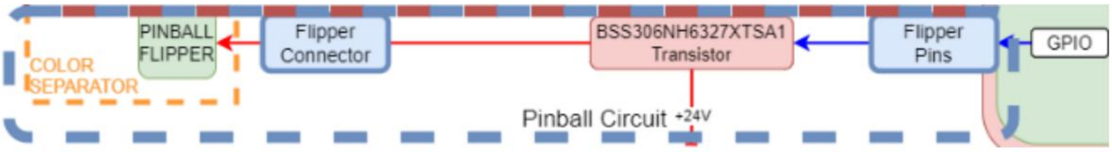
Connection	Voltage	Current	Class
relay coil	5V	106mA	Signal
Switch transistor	3.3V	0.1mA	Signal

A.7.6 Voltage supply



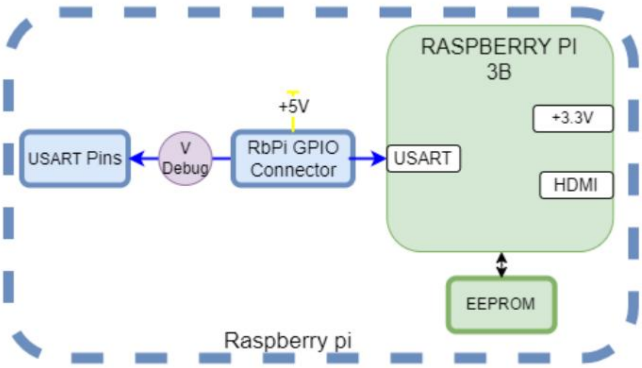
Connection	Voltage	Current	Class
5V supply	5V	3A	Power
3.3V supply	3.3V	3A	Power
9V supply	9V	1A	Power

A.7.7 Pinball



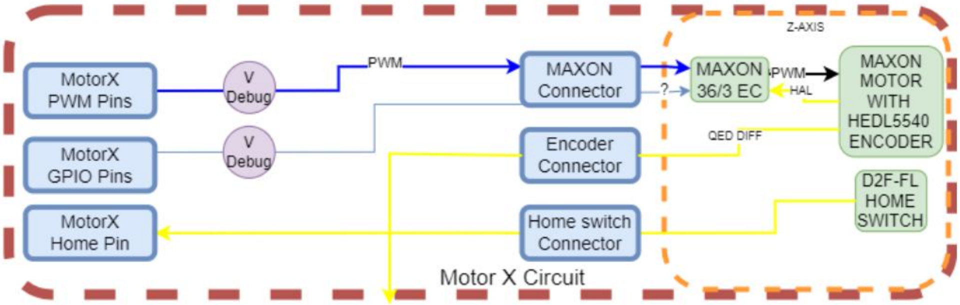
Connection	Voltage	Current	Class
Switch transistor	3.3V	0.1mA	Signal
Power pinball	3.3V	1.66A	Power

A.7.8 Raspberry pi



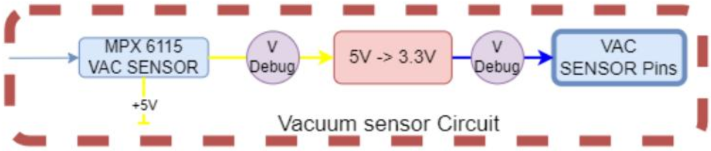
Connection	Voltage	Current	Class
USART	3.3V	-	Signal
raspberry pi	5V	?	Power

A.7.9 Engine Circuit



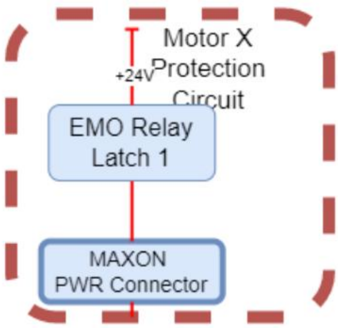
Connection	Voltage	Current	Class
PWM	3.3V	0.07mA	Signal
GPIO	3.3V	-	Signal
Home	5V	-	Signal
Encoder	5V	8mA	Signal

A.7.10 Vacuum Sensor



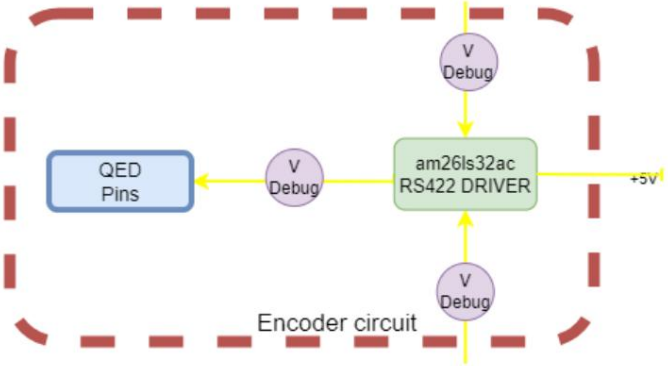
Connection	Voltage	Current	Class
Sensor supply 5V		2.8mA	Signal
Vacuum signal 3.3V/5V		-	Signal
Home	5V	100mA	Signal
Encoder	5V	8mA	Signal

A.7.11 Motor Protection Circuit



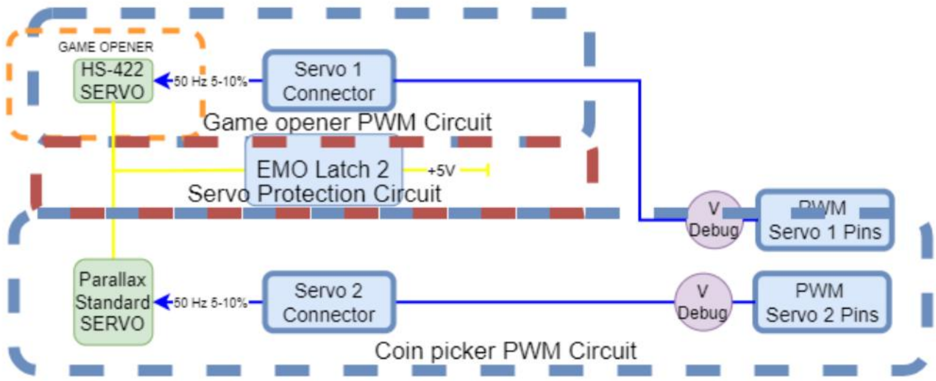
Connection	Voltage	Current	Class
Maxon supply 24V		3A	Power

A.7.12 Encoder



Connection	Voltage	Current	Class
Encoder signals 5V		8mA	Signal

A.7.13 Servos



Connection	Voltage	Current	Class
Servo PWM	3.3V	-	Signal
servo supply	5V	0.8A	Default

Appendix a. Mechanical architecture details

Connection	Pin amount	Current rating	AWG	Needed amount	Connector
I2C Connector	4	300mA	24		
Color Connector	4	300mA	24		
proxy connector	4	300mA	24		
flipper connector	2	1.7A	22		
RbPi GPIO Connector 40		20mA	-		
STM32H755 (CN8)	16	20mA	-		
STM32H755 (CN9)	30	20mA	-		
STM32H755 (CN10)	34	20mA	-		
STM32H755 (CN11)	20	20mA	-		
MAXON connector	6	130uA	24		
Engine PWR Connector	2	3A	22		
encoder connector	10	60mA	24		
home switch Connector	2	200mA	24		
Servo 1&2 Connector 3		1A	22		
VAC Pump Connector 2		1A	22		
valve connector 2		0.30A	24		
main connector	2	6.5	22		
Emergency stop Connector	2		24		

appendix b. pin list

Position	connection	Type	function	Name
1	PE2	Output	GPIO_Output	DigiIN/OUT_Z
9	PC13	Input	GPIO_Input	B1 [Blue Push Button]
10	PC14-OSC32_IN (OSC32_IN)	I/O	RCC_OSC32_IN	
11	PC15-OSC32_OUT (OSC32_OUT)	IO	RCC_OSC32_OUT	
22	PF8	IO	TIM13_CH1	PWM_Servo_Rotate
23	PF9	IO	TIM14_CH1	PWM_Servo_Slider
24	PF10	Input	GPIO_Input	Rotary_Switch_C8
25	PH0-OSC_IN (PH0)	IO	RCC_OSC_IN	
26	PH1-OSC_OUT (PH1)	IO	RCC_OSC_OUT	
28	PC0	Input	GPIO_Input	Rotary_Switch_C2
29	PC1	IO	ETH_MDC	
37	PA0	Output	GPIO_Output	Ready_Z
38	PA1	IO	ETH_REF_CLK	
39	PA2	IO	ETH_MDIO	
40	PA3	Input	GPIO_Input	Rotary_Switch_C1
43	PA4	IO	ADC1_INP18	Vaccuum_Sensor
45	PA6	IO	TIM3_CH1	Encoder_X_A
46	PA7	IO	ETH_CRS_DV	
47	PC4	IO	ETH_RXD0	
48	PC5	IO	ETH_RXD1	
49	PB0	Output	GPIO_Output	LD1 [Green Led]
50	PB1	Input	GPIO_Input	Rotary_Switch_C4
51	PB2	IO	GPIO_EXTI2	Homing_Z
59	PE9	IO	GPIO_EXTI9	Pushbutton_Rotary_Switch
61	PE11	Input	GPIO_Input	Homing_X
62	PE12	Input	GPIO_Input	Endstop_X
63	PE13	Input	GPIO_Input	Endstop_Z
66	PB10	IO	TIM2_CH3	PWM_X
67	PB11	IO	TIM2_CH4	PWM_Z
72	PB12	IO	UART5_RX	
73	PB13	IO	ETH_TXD1	
74	PB14	Output	GPIO_Output	LD3 [Red Led]
76	PD8	IO	USART3_TX	STLINK_RX
77	PD9	IO	USART3_RX	STLINK_TX
78	PD10	Output	GPIO_Output	USB_OTG_FS_PWR_EN
82	PD12	IO	TIM4_CH1	Encoder_Z_A
83	PD13	IO	TIM4_CH2	Encoder_Z_B
84	PD14	Output	GPIO_Output	DigiIN/OUT_X
85	PD15	Output	GPIO_Output	Ready_X
93	PC6	Output	GPIO_Output	Vaccuum_Valve
94	PC7	Output	GPIO_Output	Vaccuum_Pump

95	PC8	Output	GPIO_Output	solenoid
97	PA8	IO	USB_OTG_FS_SOF	
98	PA9	IO	USB_OTG_FS_VBUS	
100	PA11	IO	USB_OTG_FS_DM	
101	PA12	IO	USB_OTG_FS_DP	
109	PC10	IO	GPIO_EXTI10	Coin_INT
110	PC11	IO	GPIO_EXTI11	Prox_INT
111	PC12	IO	UART5_TX	
112	PD0	Output	GPIO_Output	Enable_PWR
113	PD1	IO	GPIO_EXTI1	Read_EMO
115	PD3	Output	GPIO_Output	Debug 1
116	PD4	Output	GPIO_Output	debug 2
117	PD5	Output	GPIO_Output	Debug 3
120	PD6	Output	GPIO_Output	debug 4
124	PG11	IO	ETH_TX_EN	
125	PG12	Output	GPIO_Output	Direction_X
126	PG13	IO	ETH_TXD0	
132	PB5	IO	TIM3_CH2	Encoder_X_B
136	PB8	IO	I2C1_SCL	
137	PB9	IO	I2C1_SDA	
138	PE0	Output	GPIO_Output	Direction_Z
139	PE1	Output	GPIO_Output	LD2 [Yellow Led]

appendix c. order list

Device	Farnell	Price	Amount Price		Link
BA17809FP-E2	2343120 €	4.64	3 € 13.92 https://nl.farnell.com/2343120 2 € 43.06		
ABPMRRV015PDAA5 3643133 € 21.53			https://nl.farnell.com/3643133 9 € 4.23 https://		
BSS306NH6327XTSA1 2443468 € 0.47			nl.farnell.com/2443468 3 € 4.14 https://nl.farnell.com/		
BA17809FP-E2	2343120 €	1.38	2343120 3 € 6.78 https://nl.farnell.com/2478586 2 €		
Print clamp	2478586 €	2.26	9.24 https://nl.farnell.com/1845602 1 € 8.76 https://		
Power inductor	1845602 €	4.62	nl.farnell.com/2068198 2 € 2.04 https://nl.farnell.com/		
Relay	2068198 €	8.76	1700668 5 € 2.04 https://nl.farnell.com/2463713 2 €		
FDS6679AZ	1700668 €	1.02	0.13 https://nl.farnell.com/1871011 10 € 2.35 https://		
CAT24C32WI-GT3	2463713 €	0.41	nl.farnell.com/3542526 2 € 0.13 https://nl.farnell.com/		
CAP POL 0.1uF	1871011 €	0.07	1871013 15 € 5.37 https://nl.farnell.com/2611939 4 €		
0 ohm jumper	3542526 €	0.24	0.52 https://nl.farnell.com/9451285 10 € 1.53 https://		
CAP POL 0.33uF	1871013 €	0.07	nl.farnell.com/1894185 22 € 4.75 www.digikey.nl/ 12 €		
CAP 47uF	2611939 €	0.36	3.52 www.digikey.nl 3 € 11.16 https://nl.farnell.com/		
CAP POL 100uF	9451285 €	0.13	2069009 10 € 0.56 https://nl.farnell.com/1894322 10 €		
R 1.1k	1894185 €	0.15	3.44 https://nl.farnell.com/2628294 15 € 4.67 https://		
JST PA 2M	Digikey € 0.22 Digikey €		nl.farnell.com/1652080 5 € 0.61 https://nl.farnell.com/		
JST PH 6M	0.29		2675186 20 € 0.59 https://nl.farnell.com/1759122 2 €		
CAP POL 6800uF	2069009 €	3.72	0.62 https://nl.farnell.com/9451420 10 € 0.11 https://		
R 2.4k	1894322 €	0.06	nl.farnell.com/3019380 20 € 0.28 https://nl.farnell.com/		
Schottky Diode	2628294 €	0.34	9233385 10 € 0.20 https://nl.farnell.com/9233423 10 €		
LEDs	1652080 €	0.31	0.14 https://nl.farnell.com/9233440 20 € 0.28 https://		
zener diode	2675186 €	0.12	nl.farnell.com/9233334 10 € 1.17 https://nl.farnell.com/		
CAP 1uF	1759122 €	0.03	1081230 12 € 1.14 www.digikey.nl/ 100 € 3.16 https://		
CAP 220uF	9451420 €	0.31	nl.farnell.com/3617210 2 € 2.38 https://nl.farnell.com/		
CAP 1000pF	3019380 €	0.01	2847248 2 € 3.38 https://nl.farnell.com/3583802 5 € 2.12		
R 1k	9233385 €	0.01	https://nl.farnell.com/1593492 2 € 1.48 https://		
R 2k2	9233423 €	0.02	nl.farnell.com/1593494 2 € 1.78 https://nl.farnell.com/		
R 3k3	9233440 €	0.01	2847247 1 € 14.60 https://nl.farnell.com/8731128		
R 470	9233334 €	0.01			
Transistor	1081230 €	0.12			
JST PH 6 F	Digikey	€ 0.10			
JST PH Contact	3617210 €	0.03			
Pin recipe 40	2847248 €	1.19			
Pin recipe 34	3583802 €	1.69			
Pin recipe 16	1593492 €	0.42			
Pin recipe 20	1593494 €	0.74			
Pin recipe 30	2847247 €	0.89			
PCB Test Point	8731128 €	14.60			
pcb		€105.39	2€210.78		

Eindhoven
1/20/2023
PUBLIC

Appendix B System Requirement Documentation

System Requirement Documentation

4-in-1-row PCB

Version: 0.1

Date: 9/7/2022

ALTEN

Lawrence Verbruggen

B.1 User Requirements

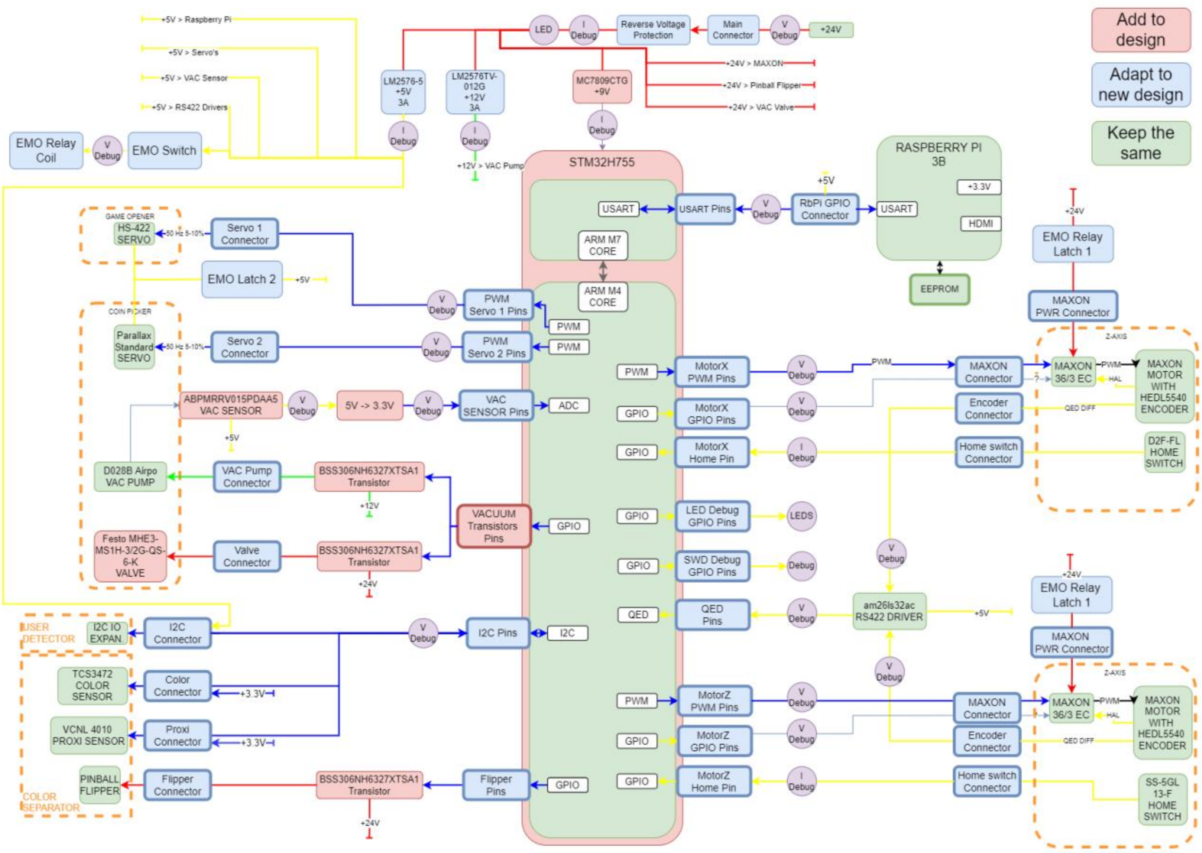
ID	Requirement	Description	MoSCoW	Engineers Remark
UR.1	The robot plays the game fully automatically.		Must	
UR.2	The robot is easily transportable to external locations in a personal car.		Must	
UR.3	The robot is plug and play.		Must	
UR.4	The robot is safe to use in public.		Must	
UR.5	The robot is built with industrial components and with competencies from Alten.		Must	
UR.6	The robot can play for 10 hours uninterrupted.		Must	
UR.7	The processing board uses the new dual-core controller		Must	
UR.8	The dual-core controller keeps the same functionality as the single-core controller.		Must	
UR.9	All software blocks are made using the software architecture's structure.		Must	

B.2 System Requirements The system requirements describe the specifications in which the STM32H755 controller and other necessary parts will be placed. During development, these requirements should be kept in mind and the final product should meet these requirements. Any parts that are added or replaced are discussed in the Module requirements

The color coding for whether requirements are changed or reused from the previous design is shown in the table below.

Color Legend		
Greentable	Existing requirement / component	
Blue Table	Adapted or changed requirement / component	
Red Table	Added requirement / component	

Certain parts have been adapted or changed, while its requirement is unchanged. This is because of the unavailability of the parts.


Add to design
Adapt to new design
Keep the same
STM32H755
RASPBERRY PI 3B
EMO Relay Coil
EMO Switch
EMO Latch 2
EMO Relay Latch 1
MAXON PWR Connector
ARM M7 CORE
ARM M4 CORE
VACUUM Transistors Pins
am26ls32ac RS422 DRIVER
EEPROM

B.2.1 Power requirements

SR.1	Power Supply UR.4,			
Ref	UR.5 & UR.8 The			
Description	range of the power supply currently in use.			
Value	Min Mean 21.6 24		Max	Unit
Voltage range			28.8	v
CurrentRange			6.5	a
Ripple & noise			200	mVp-p
voltage tolerance		+- 1.0%		
Line regulation		+- 0.5%		
Load regulation		+- 0.5%		
rationale	The system has this power supply provided.			
Data sheet	https://www.tinytronics.nl/shop/index.php?route=product/product/get_file&file=412/ LRS-150-spec.pdf [2]			

SR.2	+5V Power Supply			
Ref	UR.4, UR.5 & UR.8			
Description	The range of the LM2576-5 power supply.			
Value	Min	mean	max	Unit
Voltage range	4.75	5	5.25	v
CurrentRange			3	a
Output voltage to ground	-1			v
output leakage current	2	7.5	30	mA
rationale	The LM2576 has previously been chosen for this project.			
Data sheet	https://www.ti.com/lit/ds/symlink/lm2576hv.pdf [3]			

SR.3	+12V Power Supply			
Ref	UR.4, UR.5 & UR.8			
Description	The range of the LM2576-12 power supply.			
Value	Min	mean	max	Unit
Voltage range	11.4	12	12.6	v
CurrentRange			3	a
Output voltage to ground	-1			v
output leakage current	2	7.5	30	mA
rationale	The LM2576 has previously been chosen for this project.			
Datasheet	https://www.ti.com/lit/ds/symlink/lm2576hv.pdf [3]			

B.2.2 Supplies

Engine Power

SR.4	Power Supply MAXON 36/3 EC			
Ref	UR.4, UR.5 & UR.8 The operating			
Description	requirements of the MAXON 36/3 EC.			
Value	Min	mean	max	Unit
Operating voltage Vcc	10	24	36	v
Operating current		+-3.0		a
output voltage (factor * Vcc) output			0.98	
current time of peak		2.7	9	a
output current			4	s
rationale	The MAXON 36/3 EC is part of the provided setup			
Datasheet	https://www.maxongroup.com/maxon/view/product/control/4-Q Servokonroller/414533 [4]			

SR.5	Power Supply HS 422 Servo			
Ref	UR.4, UR.5 & UR.8 The			
Description	operating requirements of the HS 422 Servo Min			
Value	Mean Max 4.8 5.0 6			Unit
operating voltage Vcc				v
operating current		8mA/IDLE AND 150mA/NO LOAD RUNNING	0.8	a
rationale	The HS 422 is part of the provided setup.			
Data sheet	http://cdn.sparkfun.com/datasheets/Robotics/hs422-31422S.pdf [5]			

SR.6	Power Supply Parallax Standard Servo			
Ref	UR.4, UR.5 & UR.8 The operating			
Description	requirements of the Parallax Standard Servo Min Unit Mean			
Value			max	
operating voltage Vcc	4.0	5.0	6.0	v
operating current		No load voltage/current: 100 mA at 6 VDC in motion, 20 mA at rest state.		
rationale	The Parallax Standard Servo is part of the provided setup.			
Data sheet	https://docs.rs-online.com/0e85/0900766b8123f8d7.pdf [6]			

SR.7	Power Supply VAC Pump			
Ref	UR.4, UR.5 & UR.8 The			
Description	operating requirements of the D028B Airpo Vacuum Pump Min Mean			
Value			max	Unit
operating voltage Vcc		12		v
Power		12		W
rationale	The D028B Airpo vacuum pump is part of the provided setup.			
Data sheet	https://abra-electronics.com/electromechanical/other-motors/d028b-airpo vacuum-pump-12v-d028b.html [7]			

SensorPower

SR.8	Power Supply TCS3472 Color Sensor UR.4,			
Ref	UR.5 & UR.8 The operating requirements of			
Description	the TCS3472 Color Sensor Min Mean Unit 2.7 3			
Value			Max	
operating voltage Vcc			3.6	
Operating current 2.5		245	330	ÿA
Rational Datasheet	The TCS3472 is part of the provided setup. https://			
	cdn-shop.adafruit.com/datasheets/TCS34725.pdf [8]			

SR.9	Power Supply VCNL 4010 Proximity Sensor UR.4,			
Ref	UR.5 & UR.8 The operating requirements of the VCNL			
Description	4010 Proximity Sensor Min Mean			
Value			max	Unit
operating voltage Vcc	3	3.3	5	v
operating current		203.8		mA
rationale	The VCNL 4010 Proximity Sensor is part of the provided setup. https://			
Data sheet	learn.adafruit.com/using-vcnl4010-proximity-sensor/pinouts [9]			

SR.10	Power Supply am26ls32ac RS422 Encoder driver UR.4,			
Ref	UR.5 & UR.8 The operating requirements of the am26ls32ac			
Description	Min Max			
Value		mean		Unit
operating voltage Vcc	4.75	5	5.25	v
Input Current		52	70	mA
rationale	The am26ls32ac RS422 Encoder driver has previously been chosen for the design. https://www.ti.com/lit/ds/symlink/am26ls32ac.pdf [10]			
Data sheet				

SR.11	Power Supply HEDL 5540 Encoder UR.4,			
Ref	UR.5 & UR.8 The operating requirements			
Description	of the HEDL 5540 Min Max 4.5			
Value		mean		Unit
operating voltage Vcc		5	5.5	v
Input Current		57		mA
Counts		500		CPS
Velocity			30000	RPM
frequency			250	kHz
rationale	The HEDL 5540 Encoder is part of the provided setup. https://			
Data sheet	www.ontrium.com/get.aspx?id=1642490 [11]			

Processor Power

SR.12	Power Supply Raspberry Pi			
Ref	UR.4, UR.5 & UR.8 The operating			
Description	requirements of the Raspberry Pi Min Max			
Value		mean		Unit
operating voltage Vcc		5		v
operating current				mA
rationale	This Raspberry pi has previously been chosen for this project			

Solenoids Power

SR.13	Power Supply Pinball Flipper			
Ref	UR.4, UR.5 & UR.8 The operating			
Description	requirements of the Pinball Flipper Solenoid Min Unit Mean			
Value			max	
operating voltage Vcc		24		v
Resistance		14.5		ÿ
rationale	The Pinball Flipper is part of the provided setup.			
Data sheet	No data sheet			

SR.14	Power Supply VAC Valve			
Ref UR.5 **Description** The operating requirements of the MHE3-MS1H-3/2G-QS-6-K				
Valve **Value** Min Mean Unit **Operating voltage Vcc** 21.6 24 **Power**				
			Max	
			26.4	v
		6.5		W
rationale	The VAC Valve is part of the provided setup.			
Data sheet	https://www.festo.com/us/en/a/525153/?q=~:sortByFacetValues-asc [12]			

Custom Chips

SR.15	Power Supply User Detector			
Ref	UR.4, UR.5 & UR.8 The operating			
Description	requirements of the User Detector Chip Min Mean 2.3 5			
Value			Max	Unit
operating voltage Vcc			5.5	v
Input Current		500		mA
rationale	The User Detector is part of the provided setup.			
Data sheet	https://redmine.alten.nl/projects/in-a row/repository/192/raw/53.%20Electronics%20Engineering/1.%20Repo/trunk/3.%20PCBs/Photodiode%20board/SDD_photodiodeboard.docx [13]			

Transistor drain rating

SR.16 Drain Source tolerances Ref UR.4				
Description The ambient temperature allowed for the system.				
	minus	mean	max	Unit
load voltage	24			v
drain current	1.66			a

rationale	All transistors should be able to withstand the maximum load of the parts to allow for one type of transistor.

B.2.3 Pneumatics pressures

Pneumatics VAC gripper	UR.4, UR.5 & UR.8 **Ref** **Description**			
The operating requirements of the ESG-20-CN-HCL-QS gripper.				
	Min Unit **Value** Mean Max			
Operating Pressure		-0.7	0.0 (ATM)	bar
rationale	This gripper is part of the provided setup.			
Data sheet https://www.festo.com/media/pim/270/D15000100122270.PDF [14]				

SR.18	**Pneumatics VAC Pump**			
Ref	UR.4, UR.5 & UR.8			
Description The reachable pressure of the D028B Airpo Vacuum Pump Min **Value**				
provided setup.	Mean **Attainable** -0.7 **Pressure Rationale** This pump max is part of the			Unit
				bar
Datasheet https://abra-electronics.com/electromechanical/other-motors/d028b-airpo-vacuum pump-12v-d028b.html [7]				

SR.19	**VAC Valve**			
Ref	UR.5			
Description The operating requirements of the MHE3-MS1H-3/2G-QS-6-K Valve **Value** Mean				
	Min		max	Unit
Operating Pressure	-0.9		8	bar
rationale	This valve is part of the provided setup.			
Datasheet https://www.festo.com/us/en/a/525153/?q=~:sortByFacetValues-asc [12]				

B.2.4 Connectivity

USART Connection

SR.20	USART Pin Requirements Ref UR.4,			
UR.5 & UR.8 Description The signal characteristics of the USART				
communication.				
Value Mean Signal Voltage Signal Current	Min		max	Unit
Signal Speed Rationale	0		3.3	v
Datasheet				

SR.21	USART Pin Signal
Ref	UR.4, UR.5 & UR.8
Description	USART uses a GPIO Connection
Rationale	The STM32 has USART pins available for use.

I2C connection

SR.22	I2C Connection Requirements			
Ref	UR.4, UR.5 & UR.8			
Description	The output characteristics of the I2C bus, **Value**			
Mean	Min		max	Unit
Signal Voltage	0		3.3	v
Signal Speed	0	100	400	kHz
rationale	The I2C Connection is based on the requirements of the I2C devices in the design.			

SR.23	I2C Connection Signal
Ref	UR.4, UR.5 & UR.8
Description	I2C uses an I2C-GPIO Connection.
Rationale	The STM32 has I2C pins available for use.

Motor X & Motor Z PWM Connection

SR.24	Motor PWM Connection Requirements			
Ref	UR.4, UR.5 & UR.8			
Description The signal characteristics of the PWM connection.				
Value Min **Signal**		mean	Max	Unit
0-1.0 **Voltage** **Signal** **Current**			2.4-36	v
		0.07		mA
frequencyrange	10	5000	5000	Hz
Pulse Length	10		90	%
Pulse length	20		180	us
Pulse Resolution		0.1		%
Pulse Resolution		0.2		us
Rationale The Maxon motor controllers cannot operate outside of these requirements.				
Datasheet https://www.maxongroup.com/medias/sys_master/root/8930313830430/414533-ESCON-36-3-EC-Hardware-Reference-En.pdf [4]				

SR.25	Motor PWM Connection Signal
Ref	UR.4, UR.5 & UR.8 **Description**
uses a PWM-GPIO Connection **Rationale** The	
STM32 provides PWM signal pins.	

Engine X GPIO Connection & Engine Z GPIO Connection

SR.26	**Connection Requirements**		
Ref	UR.4, UR.5 & UR.8		
Description The data pins of the motors.			
Value Mean **Signal Voltage Rationale** The	Minimum	Maximum	Unit
Maxon motor controllers cannot operate outside of these requirements.	24	36	V
Datasheet https://www.maxongroup.com/medias/sys_master/root/8930313830430/414533-ESCON-36-3-EC-Hardware-Reference-En.pdf [4]			

SR.27 **Connection Signal** **Ref** UR.4,	
UR.5 & UR.8 **Description** The digital	data pins use a GPIO
Connection.	
Rationale The STM32 provides digital signal pins.	

QED Connection

SR.28 **Ref**	**QED Connection Requirements**			
Description	UR.4, UR.5 & UR.8 The signal			
Value Signal	characteristics of the QED connection.			
High Voltage	Min Mean Max 2.7 5.0			Unit
Signal Low Voltage 0				V
Signal Current -0.440			0.45	
The chosen QED driver uses			8	mA
Rational	these signals.			
Datasheet	https://www.ti.com/lit/ds/symlink/am26ls32ac.pdf?ts=1663743340393&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FAM26LS 32AC [10]			

SR.29 **QED Connection Signal** **Ref** UR.4,	
UR.5 & UR.8 **Description** QED uses a	Timer GPIO Connection
Rationale The STM32 provides digital timer pins.	

PWM Servo 1 Connection

SR.30	PWM Servo 1 Connection Requirements UR.4,			
Ref	UR.5 & UR.8			
Description The signal characteristics of the PWM connection.				
Value Min Signal 3		mean	Maximum	Unit
High Voltage Signal Speed Pulse Length Pulse Length			5	
Rationale The servo provides these signals.		50		Hz
	0.9	1.5	2.1	mS
	4.5		10.5	%
Datasheet https://www.robotshop.com/media/files/pdf/servomanual-31422s.pdf [5]				

SR.31 PWM Servo 1 Connection Signal Ref UR.4,	
UR.5 & UR.8 Description PWM Servo 1 uses an PWM- GPIO Connection.	
Rationale The STM32 provides PWM signal pins.	

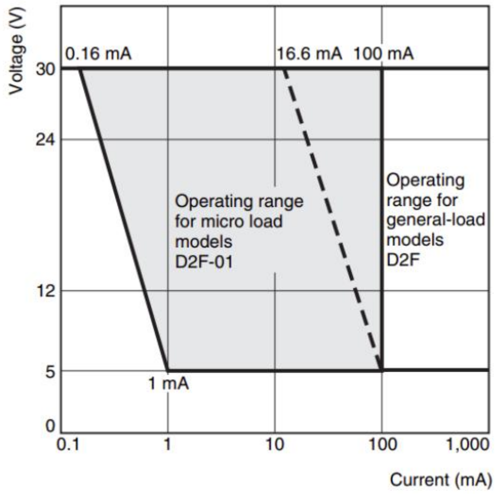
PWM Servo 2 Connection

SR.32 PWM Servo 2 Connection Requirements Ref UR.4,				
UR.5 & UR.8 Descripti The signal characteristics of the PWM connection.				
on				
Value		mean	Max	Unit
Signal High Voltage	Minimum 3.3	5.0	Vcc+0.2	v
Signal Speed		50		Hz
Pulse Length	0.75		2.25	mS
Pulse Length	3.75		11.25	%
Rational e	The servo provides these signals.			
Data sheet t	https://www.parallax.com/package/parallax-standard-servo downloads/?wpdmdl=3873&refresh=6333ccec140171664339180&ind=1600888277673&filename=900-00005-Standard-Servo-Product-Documentation-v2.2.pdf [6]			

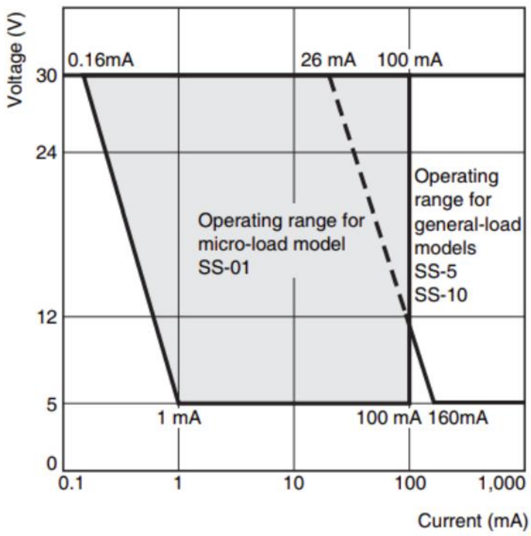
SR.33 PWM Servo 2 Connection Signal Ref UR.4,	
UR.5 & UR.8 Description PWM Servo 2 uses a PWM Servo 2 Connection Rationale The	
STM32 provides PWM signal pins.	

Maximum switch loads

SR.34	D2F-FL Home Switch Connection			
Ref	UR.4, UR.5 & UR.8			
Description The operating requirements of the D2F-FL Switch				
Value Min **Load**	The 100 D2F-FL 5 VDC **Contact resistance** is part of the provided setup **Rationale**		max	Unit
			0.5 A at 30 VDC	
			50	mÿ
Datasheet https://nl.mouser.com/datasheet/2/307/en_d2f-587403.pdf [15]				



SR.35	SS-5GL13-F Home Switch Connection			
Ref	UR.4, UR.5 & UR.8 **Description** The			
operating requirements of the SS-5GL13-F Switch **Value** Min				
		mean	max	Unit
load	5VDC 160mA			
contact resistance			50	mÿ
Rationale The SS-5GL13-F is part of the provided setup.				
Datasheet https://nl.mouser.com/datasheet/2/307/en_ss-1509069.pdf [16]				



EMO Connection

SR.36	EMO Connection			
Ref	UR.4, UR.5 & UR.8			
Description	The operating requirements of the EMO switch **Value**			
Min Max **Switching** 250 V DC **voltage Contact** mean **Current**				Unit
			5	a
Rationale	The emo switch is part of the provided setup.			
Datasheet	https://en.farnell.com/eao/51-253-022/switch-e-stop-1co-turn-reset faston/dp/1889178#anchorTechnicalDOCS [17]			

transistor connections

SR.37	Transistor switching voltage **Ref** UR.5			
Description	The needed operating requirements of the transistor Min **Value**			
		mean	max	Unit
Operating voltage	0.0		3.3	v
Rationale	The STM32 cannot provide more than 3.3V.			

B.2.5 Environmental

SR.38	Room climate operation **Ref** UR.4
Description	The temperature and climate system operated in room
Rationale	The robot is mainly used in exhibitions.

SR.39	Operating Ambient Temperature UR.4			
Ref	The ambient temperature allowed for the			
Description	system.			
Operating temperature	Min	mean	max	Unit
Entire system	0		+45	° C
24V Supply	-30		+70	° C
LM2576-5 & 12	-40		+125	° C
Raspberry Pi 3B				° C
EMO				° C
user detector				° C
TCS3472	-40		+85	° C
VCNL4010				° C
Pinball Flipper				° C
Maxon 36/3 EC	-30		+45	° C
AM26LS32AC	0		+70	° C
MAXON Engine				° C
DSF-FL	-40		+85	° C
SS-5GL-13-F	-25		+85	° C
HS422	-20		+60	° C
Standard servo	-10		+50	° C
D028B Airpo				° C
Transistor	0		+45	° C
rationale	Overheating causes damage to the robot.			

B.2.6 Dimensioning

SR.40 PCB Footprint	Ref UR.2
Description	A footprint, including the mounting holes and dimensions, are digitally available. All electronics must be contained in this footprint.
rationale	There is only limited space in the robot.

SR.41	PCB Height		
Ref	UR.2		
Description	The PCB, including thickness, cannot exceed the limit.		
Value Min	mean	Max	Unit
Height		100	mm
Rationale	The PCB will not fit under the robot.		

B.2.7 Performance

SR.42 Uptime **Ref**	
UR.4 **Description**	robot The
can be playing for 10 hours without trouble.	
Rationale	The robot is operating an entire day.

B.2.8 Compliance

SR.43	Norms
Ref	UR.4
Description	The robot must be compliant to the norms: IEC 60204, IEC 61010
rationale	These are standard practice for Alten

SR.44	Architecture
Ref	UR.9
Description	The software must be created using the structure of the software architecture.
Rationale	This structure is already made.

SR.45 Norms **Ref**	
UR.4 **Description**	robot The
must be compliant to RoHS and REACH.	
Rationale	These are standard practice for Alten.

B.2.9 Transportation

SR.46	pcb location
Ref	UR.2
Description	The PCB is fully contained inside the robot.
rationale	This limits damage and increases transportability.

B.3 Module requirements The
modules of the system are changed or added components that need to be developed in addition to the full system.

B.3.1 Module requirements STM32H755 The
module requirements for the STM32H775 document the requirements for the STM32 controller. These requirements will affect the new system.

supplies

SR.47	Power Supply STM32H755 (VIN method)			
Ref	UR.7			
Description	The operating requirements of the STM32H755 Controller			
Value	Min Mean Unit 9		Maximum	
operating voltage Vcc	7		11	V
operating current (Vcc=7V)			800	mA
operating current (7V<Vcc<9V)			450	mA
operating current (9V<Vcc<11V)			250	mA
rationale	This board is requested to be used by the user.			
Datasheet	https://www.st.com/en/evaluation-tools/nucleo-h755zi q.html#documentation [18]			

connectivity

SR.48	**ADC Connections STM32H755**			
Ref	UR.7			
Description				
Value	Min	Mean	Max	Unit
VDD		3.3 0.0	4.0	v
VSS	-0.3			v
Resolution 8			16	bits
VDDA	1.62	VDD	3.6	
VREF+	1.62	VDD	VDDA	
VREF-		VSS		
Voltage range	VREF		VREF+	
Rationale	The STM32H755 is equipped with an ADC. https:// www.st.com/resource/en/datasheet/stm32h755bi.pdf [19]			

Table 6. Legend/abbreviations used in the pinout table

Name		Abbreviation	Definition
Pin name		Unless otherwise specified in brackets below the pin name, the pin function during and after reset is the same as the actual pin name	
Pin type		S	Supply pin
		I	Input only pin
		I/O	Input / output pin
		ANA	Analog-only Input
I/O structure		FT	5 V tolerant I/O
		TT	3.3 V tolerant I/O
		B	Dedicated BOOT0 pin
		RST	Bidirectional reset pin with embedded weak pull-up resistor
		Option for TT and FT I/Os	
		_f	I2C FM+ option
		_a	analog option (supplied by V_{DDA})
		_u	USB option (supplied by $V_{DD33USB}$)
		_h	High-speed low-voltage I/O
Notes		Unless otherwise specified by a note, all I/Os are set as floating inputs during and after reset.	
Pin functions	Alternate functions	Functions selected through GPIOx_AFR registers	
	Additional functions	Functions directly selected/enabled through peripheral registers	

SR.49 STM32H755 GPIO Ref UR.7				
Description The requirements of the operating				
GPIO pins of the STM32H755.				
	Min Unit **Value** Mean Max			
TT_xxx				
output voltage	VSS - 0.3		4.0	v
FT_xxx				
output voltage	VSS - 0.3		VDD + 4.0	v
All Pins				
Output current per pin	0		20	mA
output current total	0		140	mA
General Purpose timer frequency			240	MHz
General Purpose timer Resolution			32 (TIM 2, TIM 5) 16 (TIM 3, TIM 4)	bit
I2C frequency	1		100	kHz
Rationale The characteristics of the STM32 GPIO				

Dimensioning

SR.50	**processor location**
Ref	UR.5
Description	Microcontroller and Pi are mounted using pin headers, and not paced on the PCB.
rationale	Production time makes it impossible to mount directly

B.3.2 Module requirements VAC Sensor The
module requirements for the vacuum sensor document the requirements for the sensor which will be added in the system. These requirements will affect the new system.

Supplies

SR.51	VAC Sensor Power			
Ref	UR.5			
Description	The operating requirements of the needed VAC Sensor			
Value	Min	mean	max	Unit
Operating voltage	3.3		24	v
Rationale	By using an existing power supply, no new supplies need to be added.			

Pneumatics pressures

SR.52 VAC Ser**Ref** UR.5				
Description The operating requirements				
of the needed VAC Sensor Min **Value** Mean				
			max	Unit
Absolute Operating Pressure	-1.0		1	bar
Rationale	The sensor should be able to stand with normal atmosphere pressure and should be able to read over the entire operating range of the pneumatic system.			

Connectivity

SR.53	Signal		
Ref	UR.4		
Description	The voltage level of the sensor.		
Value	Min Mean 0 The ADC	Maximum	Unit
voltage levels	cannot tolerate 5V.	3.3	v
rationale			

Environmental

SR.54	Operating Ambient Temperature			
Ref	UR.4 The ambient temperature			
Description	allowed for the system.			
Value	minus	mean	Max	Unit
Operating temperature	0		+45	°C
rationale	Overheating causes damage to the robot.			

Eindhoven
1/20/2023
PUBLIC

Appendix C Master test plan

Master Test Plan

4 in a row robot

Version: 01

Date: [date]

ALTEN

Lauren Verbrugge

VersionHistory

Version	Date	State	Author	Remark
[Manager]				

Acronyms and Abbreviations

Term	Explanation
system	The STM32H755 controller and any component that is changed or added to the system according to the SDD.

Referenced documents

ID	reference	Title	date	Author
01	SDD	SDD 4o1r		
02	SRD	System Requirements PCB		

C.1 Scope

C.1.1 Introduction

The 4-in-a-row robot will use a new main processing board. The STM32H755 controller will replace the STM32F. The robot will play the 4-in-a-row game using the provided setup.

C.1.2 Goal

The goal of testing is to demonstrate the functionality of the main processing board. All components from the setup should be initialized and tested to allow for behavior to be programmed.

C.1.3 Test base

• Plan of Approach •
Initialization protocol document • SRD
(System Requirements Document)

C.1.4 Entry criteria

Module Testing • PCB
of the main processing board with the STM32H755 controller is finished • A power supply, oscilloscope and function generator are available. • Components or modules are available.

System Testing

• Module testing is complete. •
Redesign of PCB is complete. •
Software for toggling and reading STM32H755 pins. •
Configuration of the STM32H755 controller is complete. •
Documentation is up-to-date. • Test plan for integration testing is complete.

Requirement Testing

• System testing is complete. •
Redesign of system is complete if necessary. • Test plan for system testing is complete.

Acceptance Testing

• Requirement testing is complete. • All bugs and faults of system are fixed. • All System Requirements are met. • Test plan for acceptance testing is complete.

C.1.5 Exit criteria

Module Testing •

The PCB does not have any shortages. •
Components function as expected.

System Testing

• The STM32 operates the components of the module as expected and shows the same behavior as in module testing. •
Actuators function as expected. • Sensors function as expected and are correctly read by the STM32.

Requirement Testing

• The robot and its components operate as expected.
• The M4 and M7 cores of the STM32H755 controller communicate with each other.

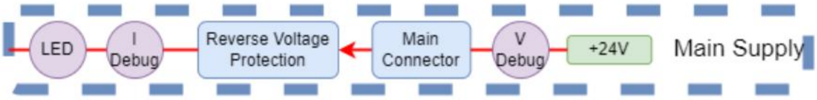
	operation
VAC Valve	Switch
Pinball Flipper	Switch
MAXON 36/3 EC	Move to Home
VAC Pump	Switch
STM32H755	Communication
MPX 6115 VAC Sensor	Init
RS422 Encoder Driver Init	
user detector	Init
HS 422 Servo	Move to home
Parallax servo	Move to home
RaspberryPi	Communication
TCS3472 Colour	Init
VCNL 4010 Prox	Init

Acceptance Testing •

The components of the entire robot are able to perform the initialization operations.

C.2 Approach C.2.1

Functional testing *Main supply*



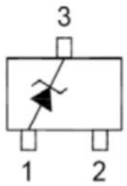
setup

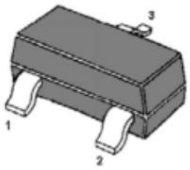
1.Mount Q1
2.Mount D1 and R29
3.Mount Led1 and R30
4.Mount X4 and X3

Needed: Soldering, voltage supply (24V), voltage probe

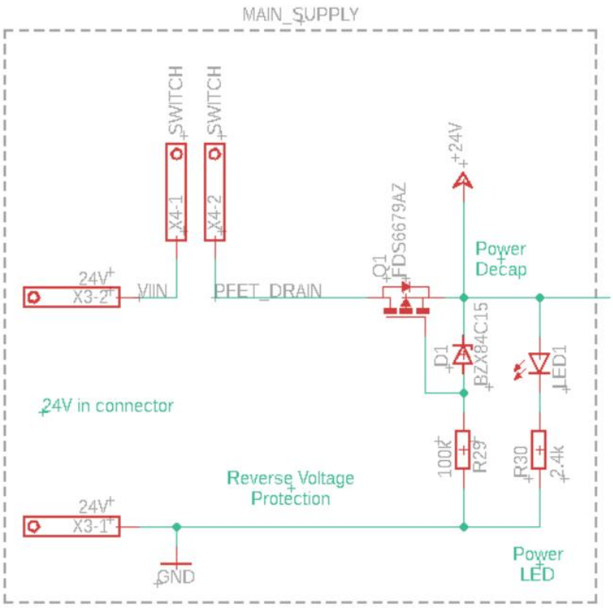
Test no.	test items	Test Approach	Conditions	Notes
1	Check voltage level of the 24V supply with no load	Apply a power supply normally to the connector. Check the voltage level of the output.	Main supply is completely isolated	
2	Check if Reverse voltage protection triggers when a negative voltage is applied.	Apply a power supply in reverse to the connector. Check the voltage level of the output.	Main supply is completely isolated	
3	Test LED's current draw	Apply signal voltage to leds Check brightness of the led	Debug circuit isolated	

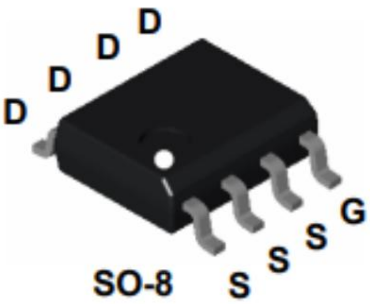
Reference sheet

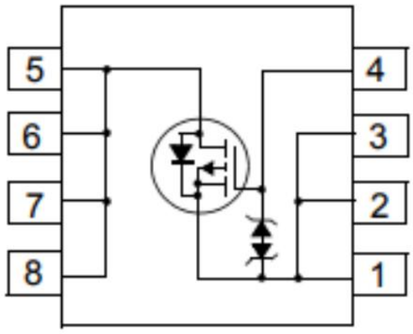


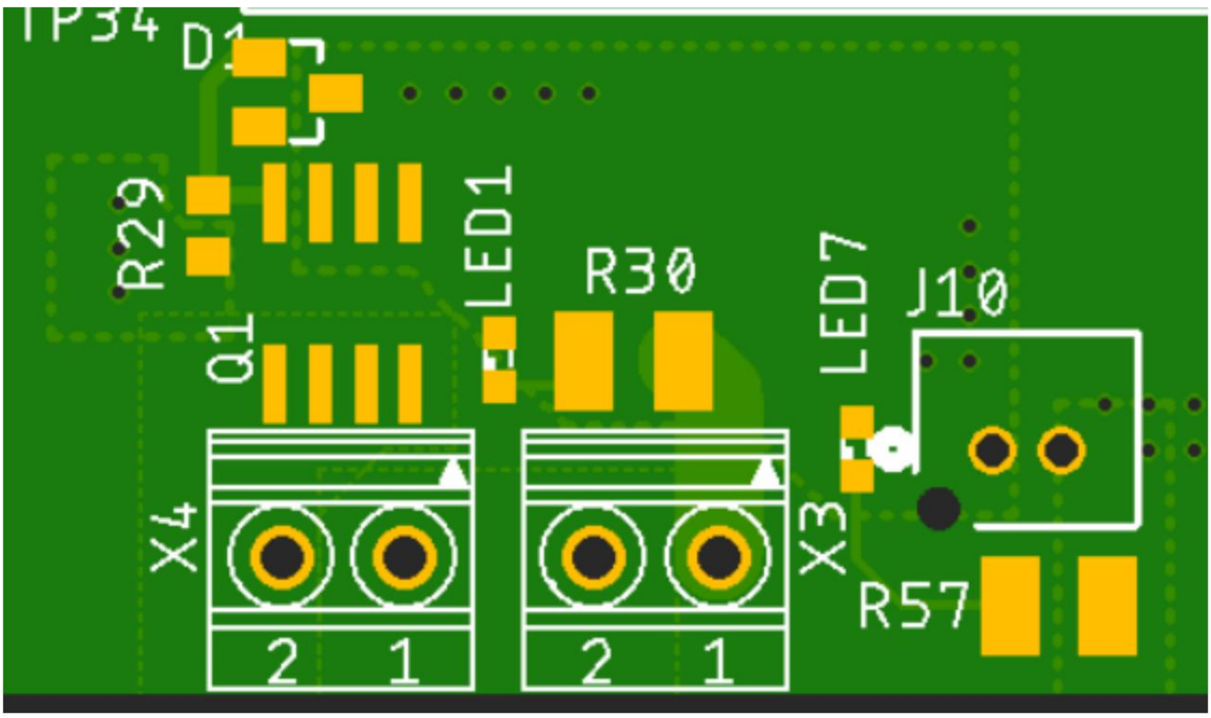


1. Anode 3. Cathode

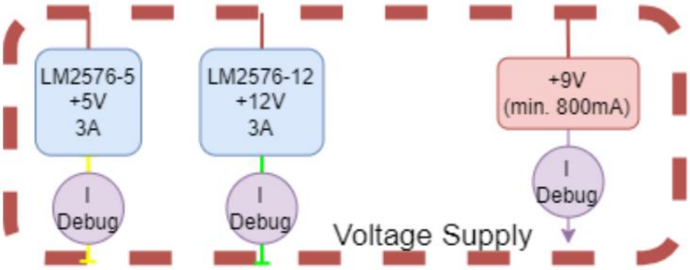








voltage supply



setup

1. Mount IC3, L2, C13, D3 and C17

Test NO. 4

2. Mount IC1, L1, C12, D2 and C16

Test NO. 5

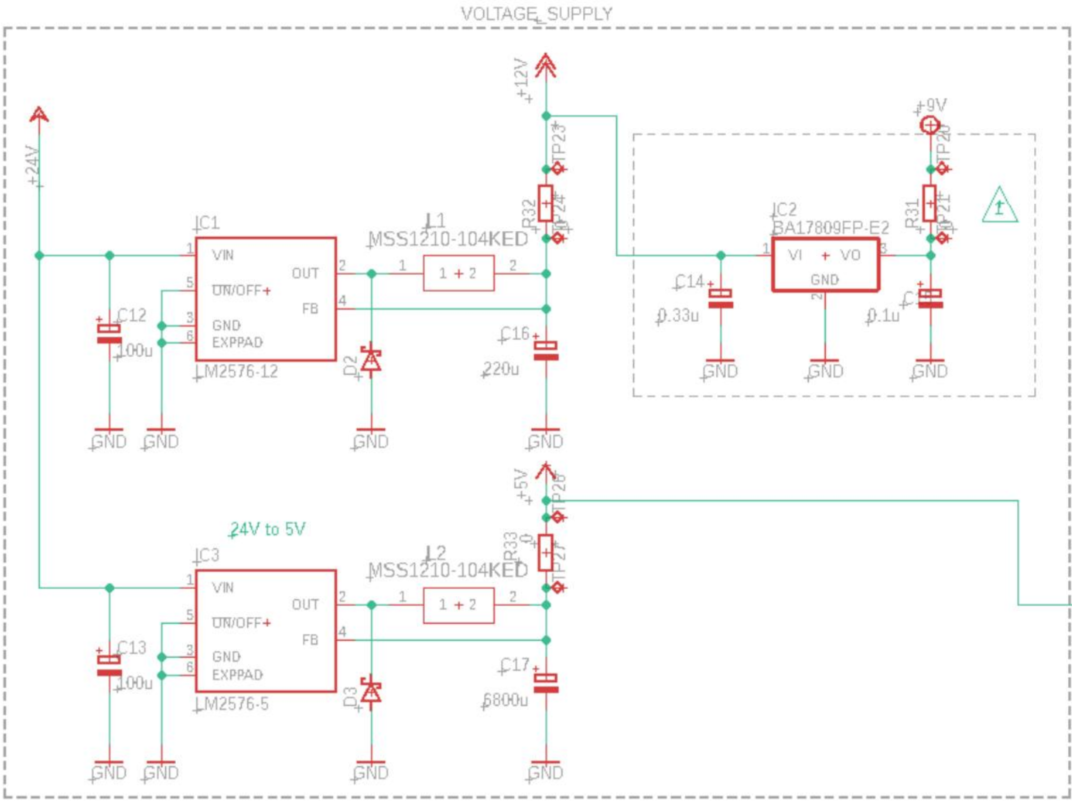
3. Mount IC2, C14 and C15

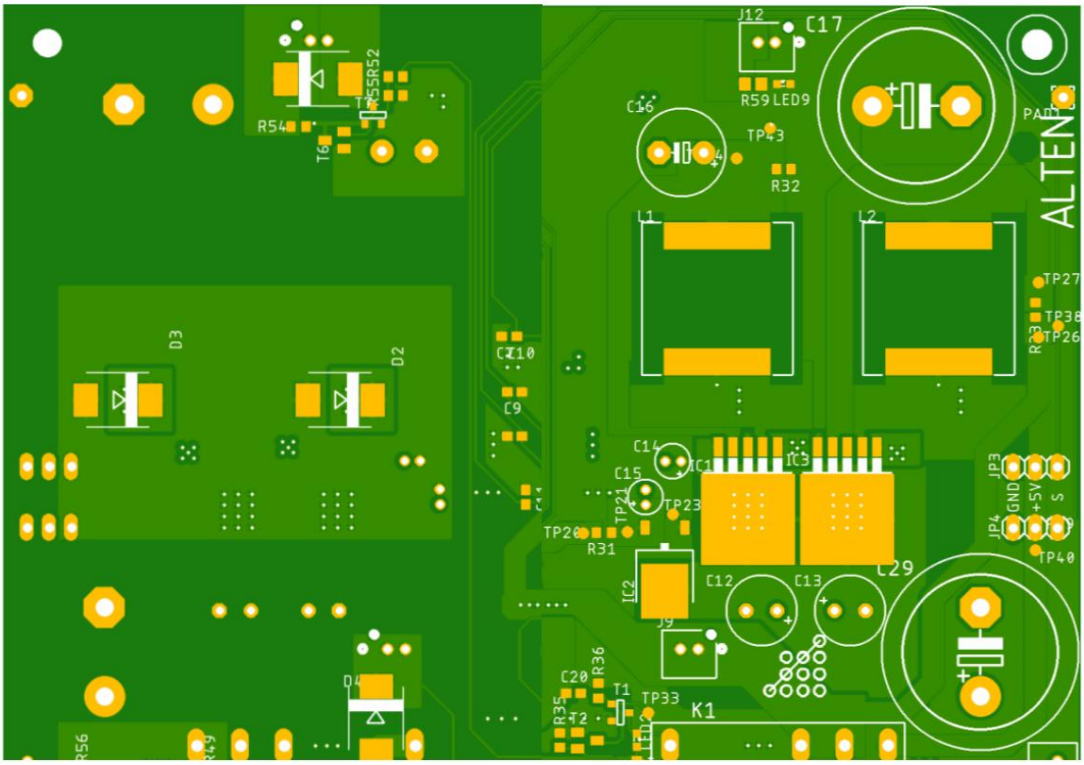
Test NO. 6

Needed: Soldering, voltage supply (24V), voltage probe

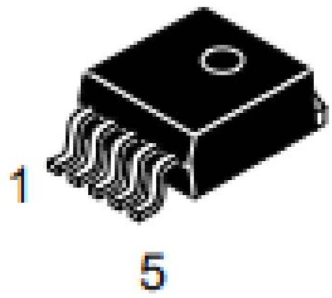
Test no.	test items	Test Approach	Conditions	Notes
4	Test if 5V supply provides the correct voltage level.	Apply the 24V supply to the voltage supply circuit, and check voltage level	Voltage supply and main supply are isolated together	Make sure to have tested the main supply first
5	Test if 12V supply provides the correct voltage level.	Apply the 24V supply to the voltage supply circuit, and check voltage level	Voltage supply and main supply are isolated together	Make sure to have tested the main supply first
6	Test if 9V supply provides the correct voltage level.	Apply the 24V supply to the voltage supply circuit, and check voltage level	Voltage supply and main supply are isolated together	Make sure to have tested the main supply first

Reference sheet

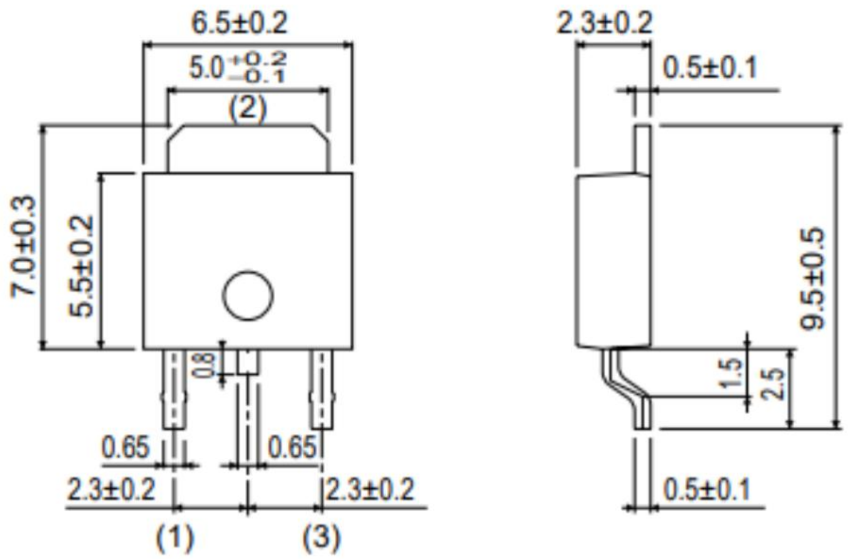




Pin 1. V_{in}
2. Output
3. Ground
4. Feedback
5. $\overline{\text{ON}}$/OFF

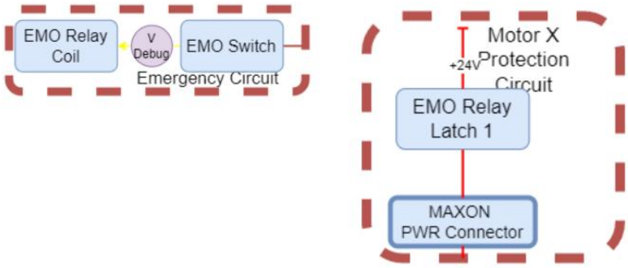


D²PAK
D2T SUFFIX
CASE 936A



(1) INPUT
(2) COMMON
(3) OUTPUT

emergency circuit



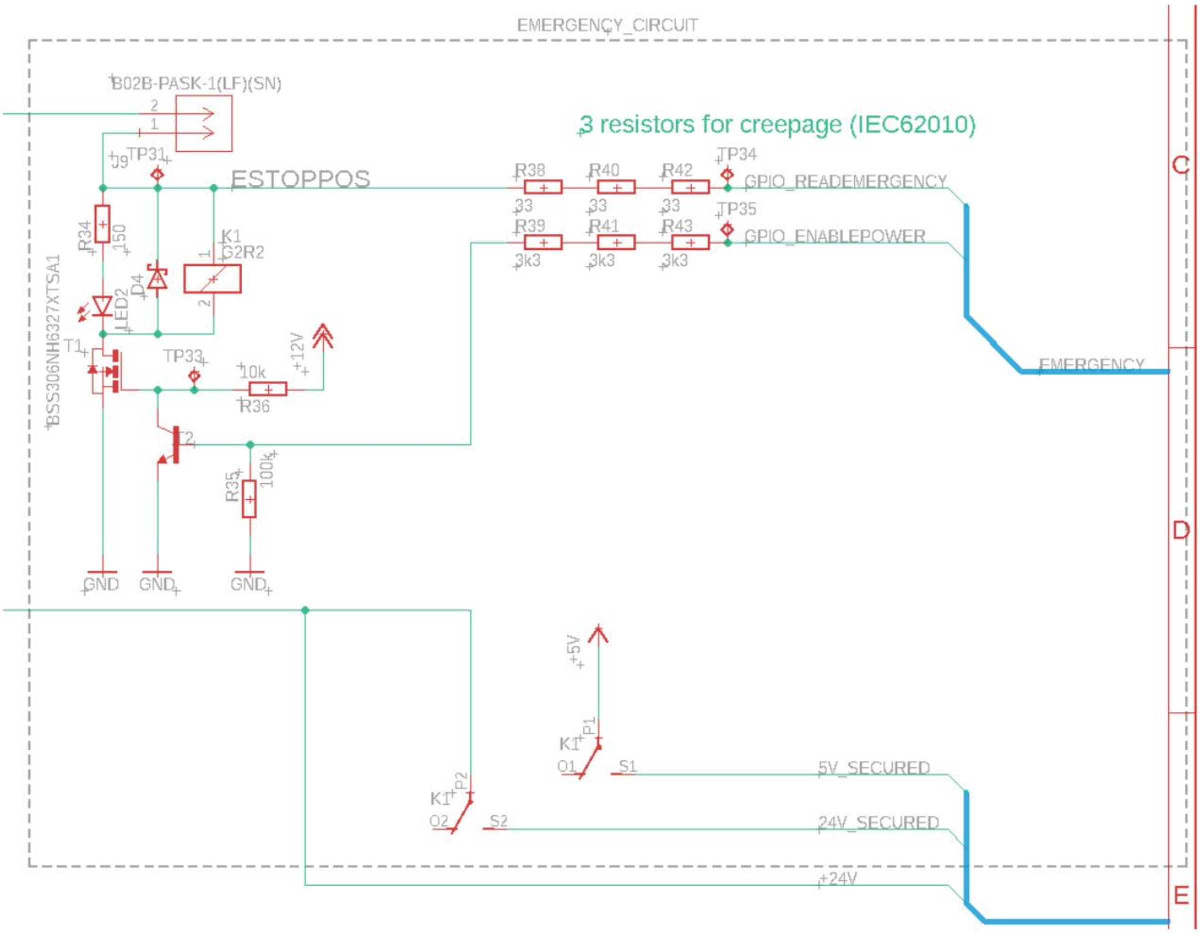
setup

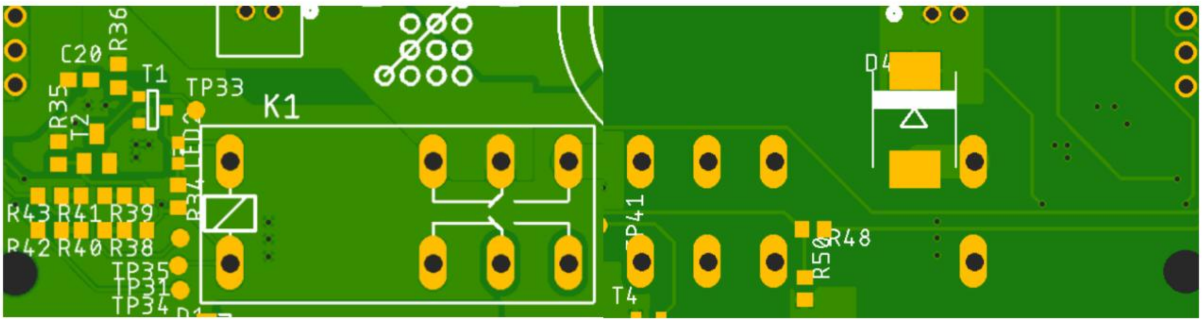
1. Mount T1, R36, C20, R35,

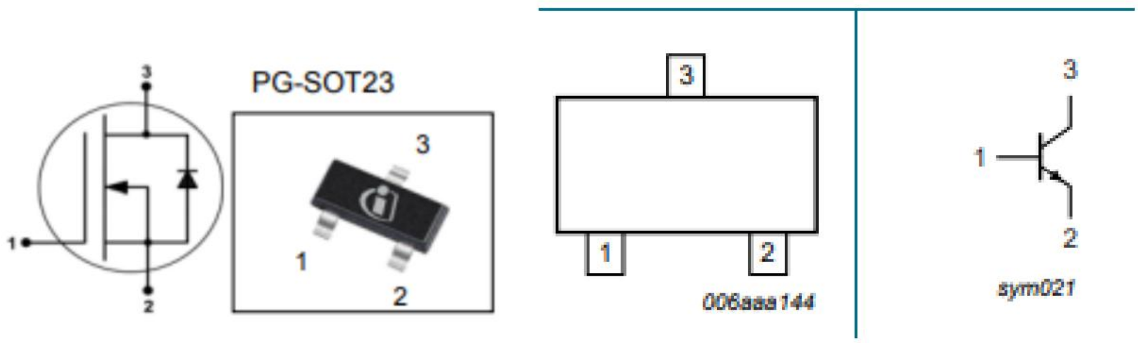
Needed: Soldering, voltage supply (24V), voltage probe

Test no.	test items	Test Approach	Conditions	Notes
7	Test if EMO Relay Latch switches without load, with external signal, and measure resistance.	Apply threshold voltage on coil Measure resistance over drain	engine protection circuit isolated	2 Relay Latches are installed
8	Test voltage level on secured traces.	Apply threshold voltage on coil Measure voltage on secured traces	Secured components disconnected	
9	Test led luminosity	Apply signal voltage to leds Check brightness of the led	Debug circuit isolated	

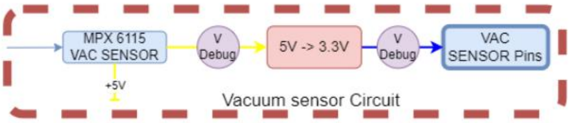
Reference sheet







Vacuum sensor circuit



setup

1. Mount U2, R4, R3, C2 and C21

Test NO. 11

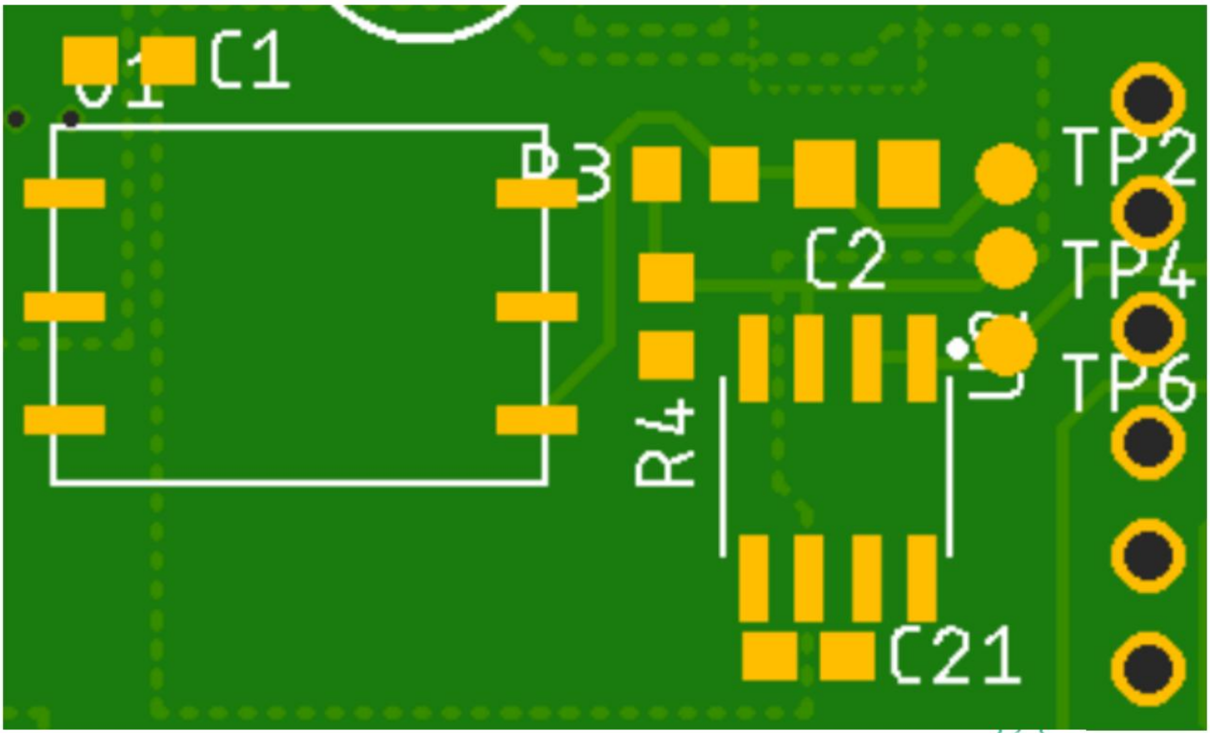
2.Mount U1 and C1

Test NO. 10

Needed: Soldering, voltage supply (5V), voltage probe

Test no.	test items	Test Approach	Conditions	Notes
10	Test VAC Sensor voltage level in comparison to applied pressure	Apply a power supply to the sensor, apply pressure to the fitting, measure output. (TP2 or TP6)	VAC sensor completely isolated	
11	Test 5V to 3.3V with external supply.	Apply a power supply to the circuit (TP2), measure output voltage (mid: TP4, out: TP6)	5V to 3.3V circuit is completely isolated.	

Reference sheet



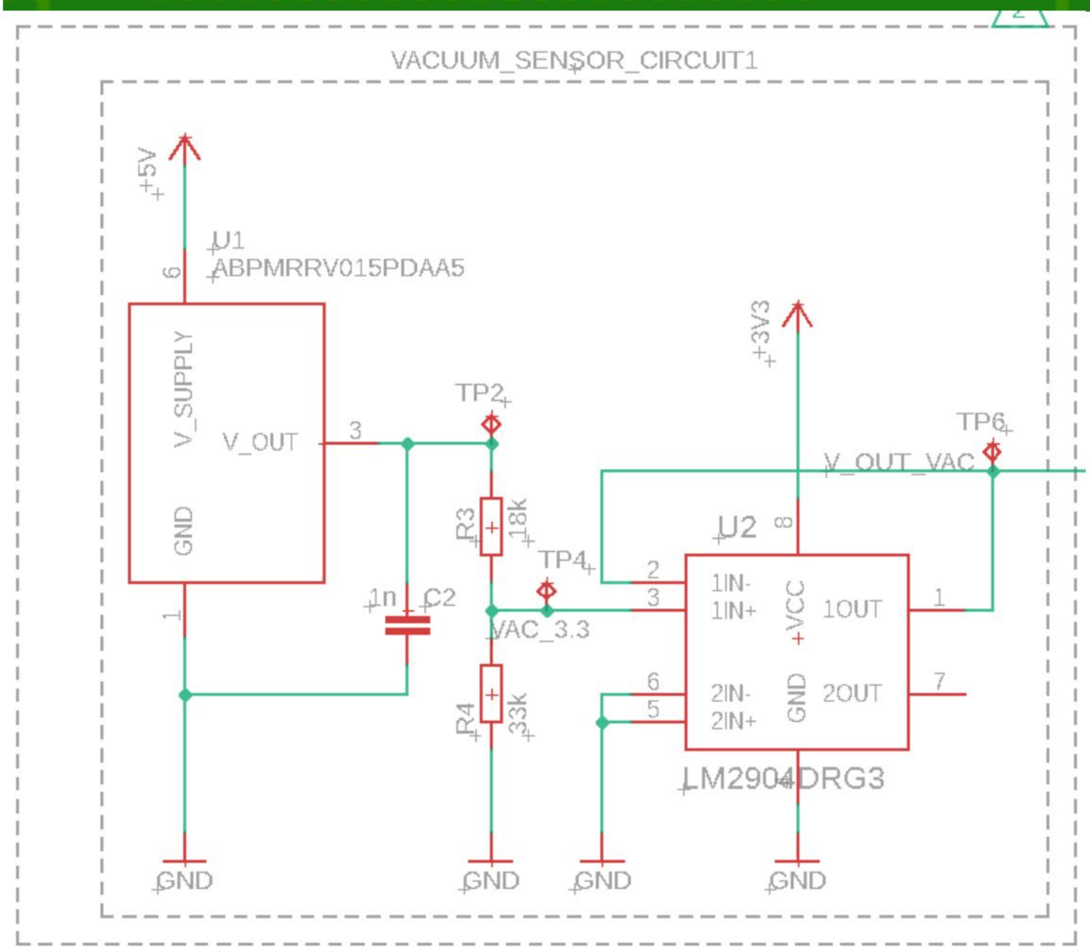
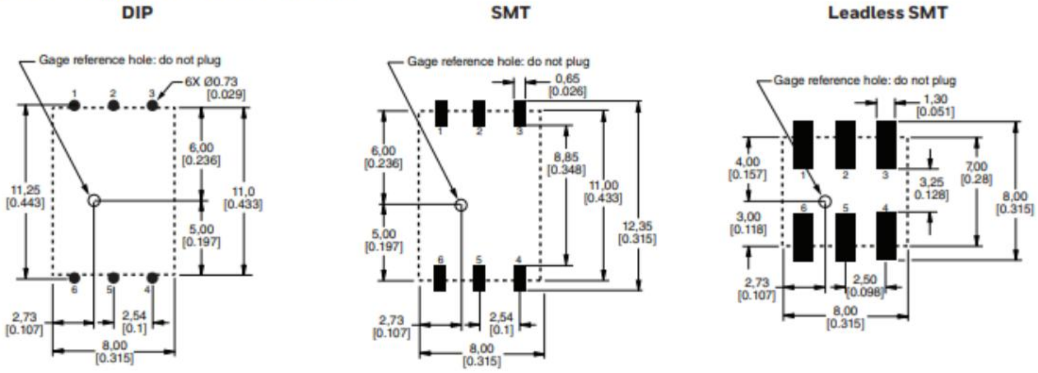


TABLE 8. PINOUTS						
OUTPUT TYPE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6
I²C	GND	V_{supply}	INT	NC	SDA	SCL
SPI	GND	V_{supply}	SS	NC	MISO	SCLK
analog	GND	NC	V_{out}	NC	NC	V_{supply}

FIGURE 8. RECOMMENDED PCB LAYOUTS



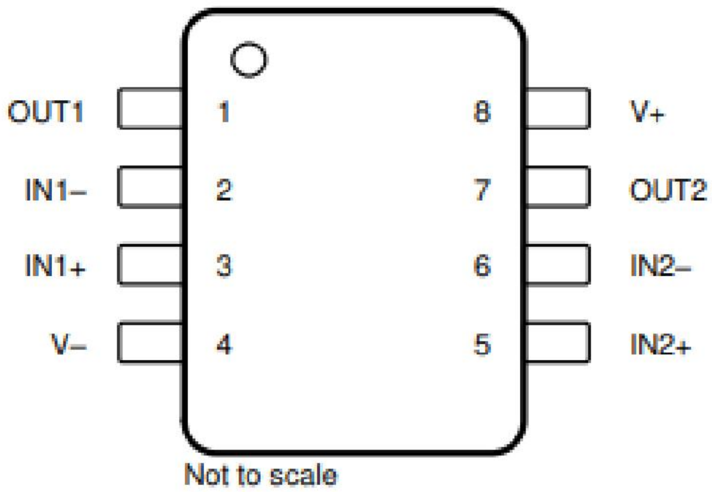
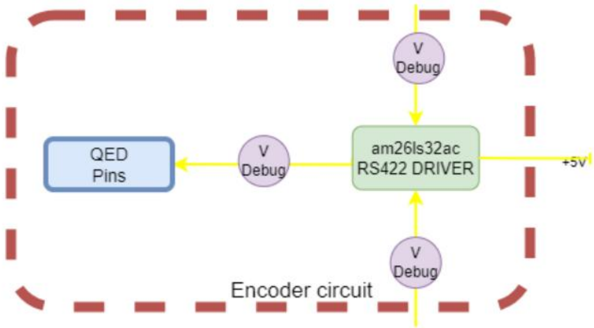


Figure 5-1. D, DDF, DGK, P, PS, PW, and JG Package
8-Pin SOIC, SOT23-8, VSSOP, PDIP, SO, TSSOP, and CDIP
Top View

encoder circuit



setup

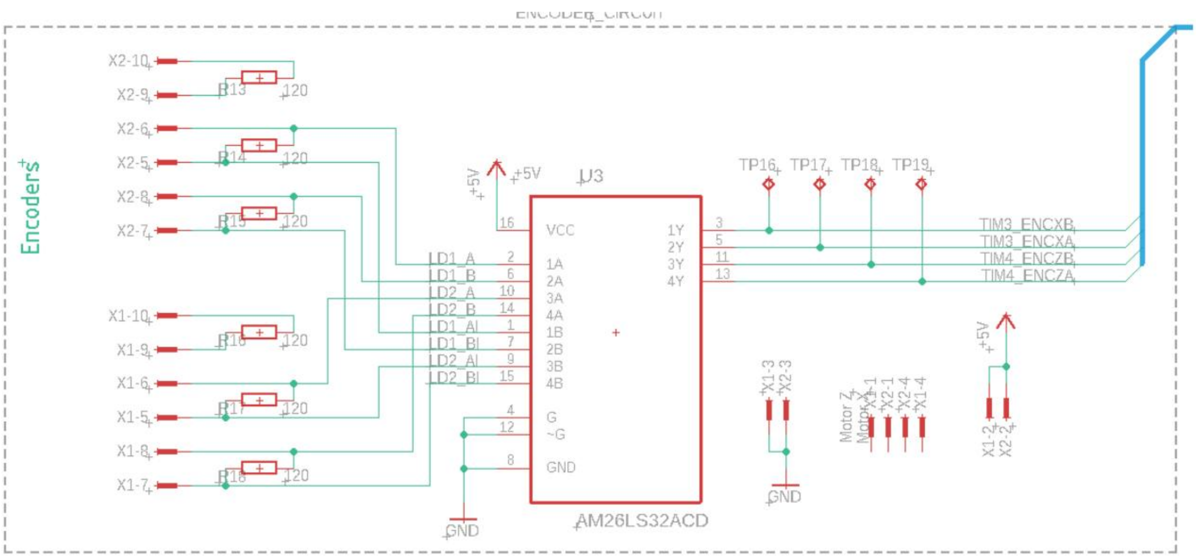
1. Mount U3, R13, R14, R15, R16, R17, R18, C25, C26, and C27

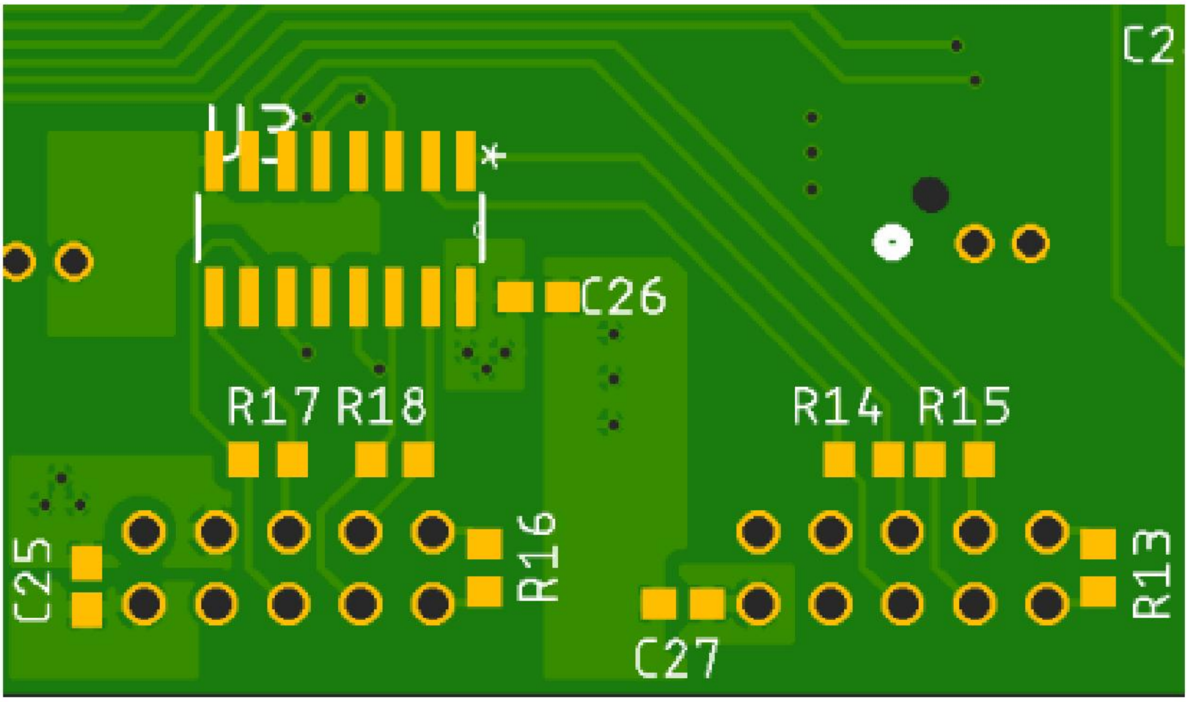
Test NO 12.

Needed: Soldering, function generator, voltage probe

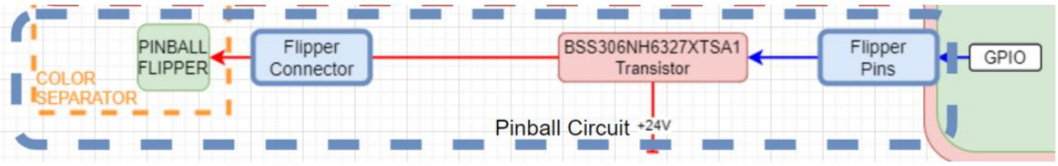
Test no.	test items	Test Approach	Conditions	Notes
12	Test if RS422 driver converts QED signal to the correct encoder signal with external function generator	Apply a function generator to the circuit, check RS422 behaviour.	RS422 drivers completely isolated	2 inputs test

Reference sheet

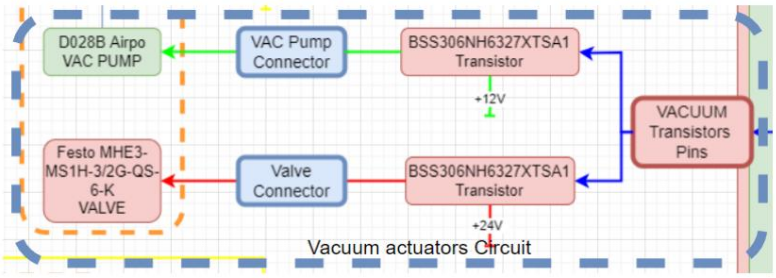




actuator circuit



setup



1. Mount T6, R54, T7, R55, R52 and D7

Test NO. 15

2. Mount T5, T8, R56, R51, R53 and D8

Test NO. 16

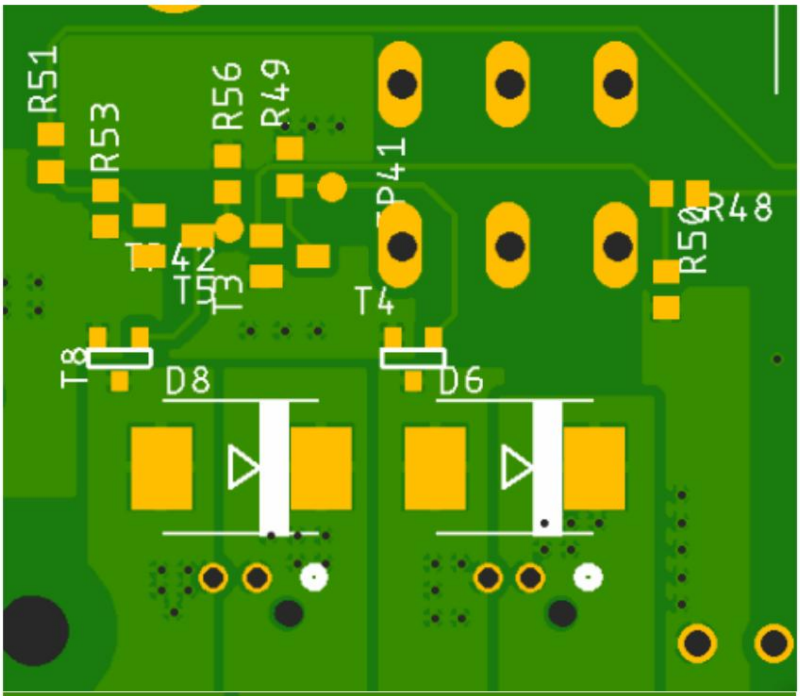
3. Mount T3, T4, R48, R50, R49 and D6 4. Mount R59, Led9, R57, Led7, R58 and Led 8

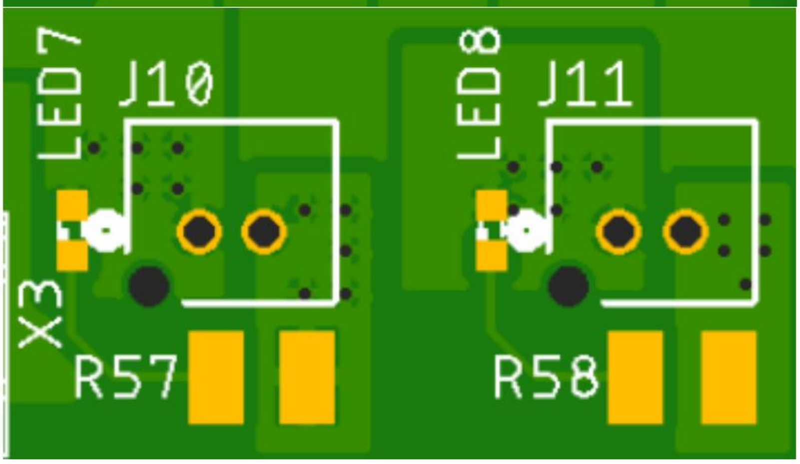
Test NO 18

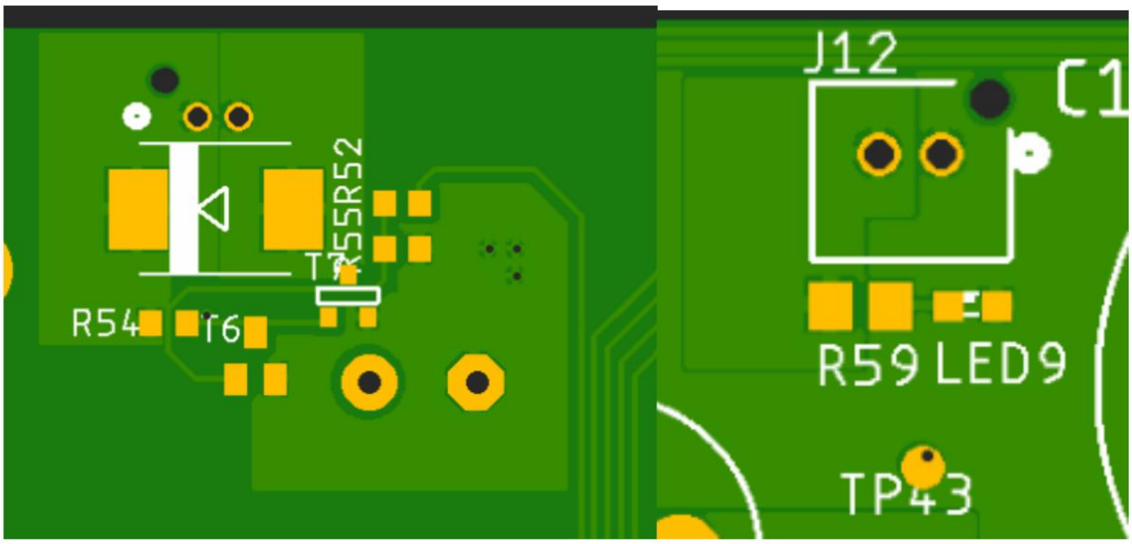
Needed: Soldering, voltage supply (3.3V), voltage probe

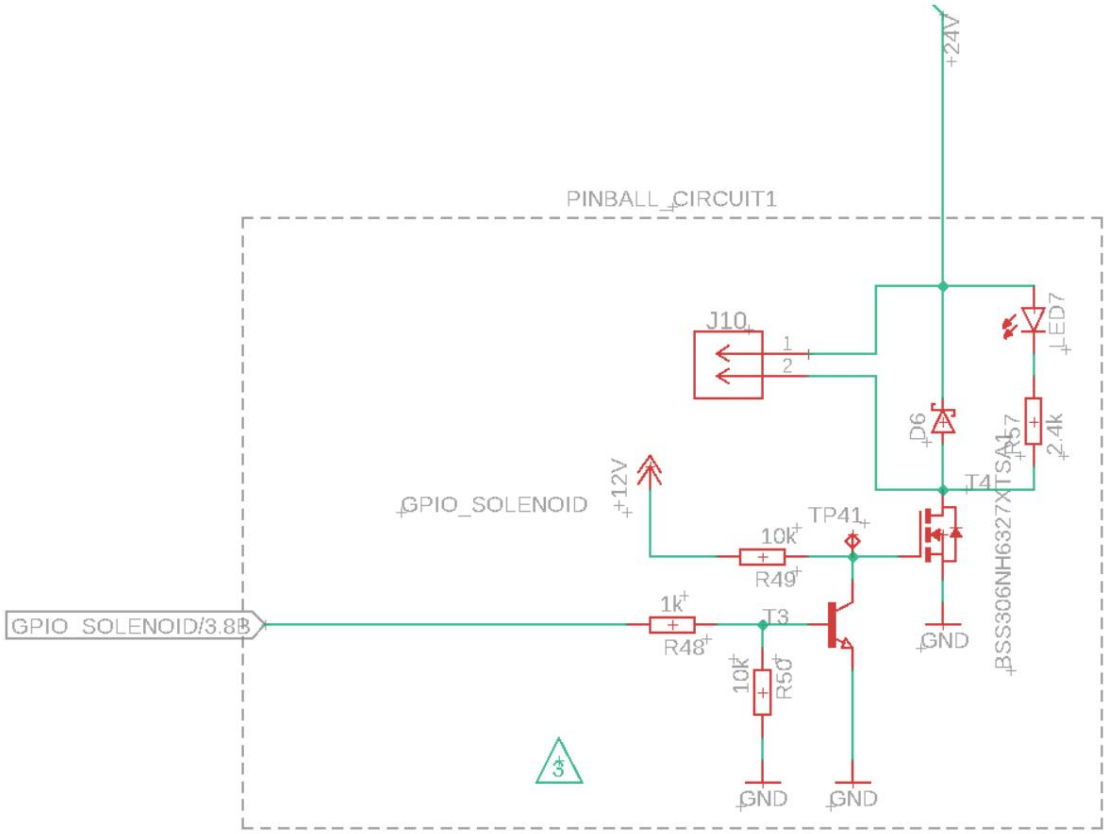
Test no.	test items	Test Approach	Conditions	Notes
15	Test if the vacuum pump transistor and mosfet switches without load, with external signal, and measure resistance	Apply threshold voltage on transistor Measure resistance over drain	transistor is completely isolated.	
16	Test if the valve transistor and mosfet switches without load, with external signal, and measure resistance	Apply threshold voltage on transistor Measure resistance over drain	Transistor is completely isolated.	
17	Test if the pinball transistor and mosfet switches without load, with external signal, and measure resistance	Apply threshold voltage on transistor Measure resistance over drain	transistor is completely isolated.	
18	Test LED current draw	Apply signal voltage to leds Check brightness of the led	Debug circuit isolated	

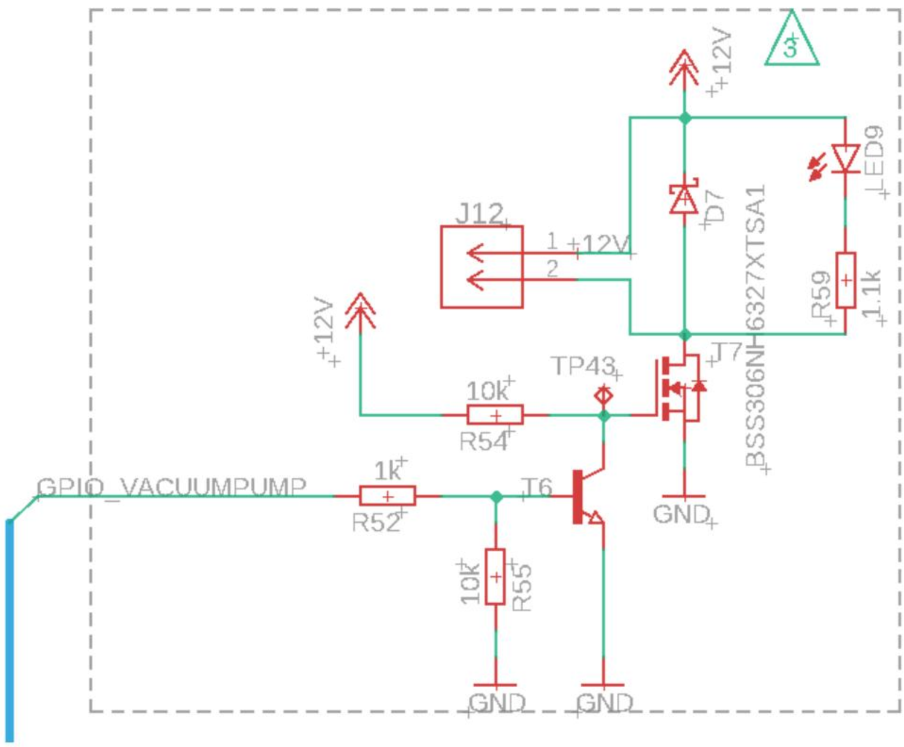
Reference sheet

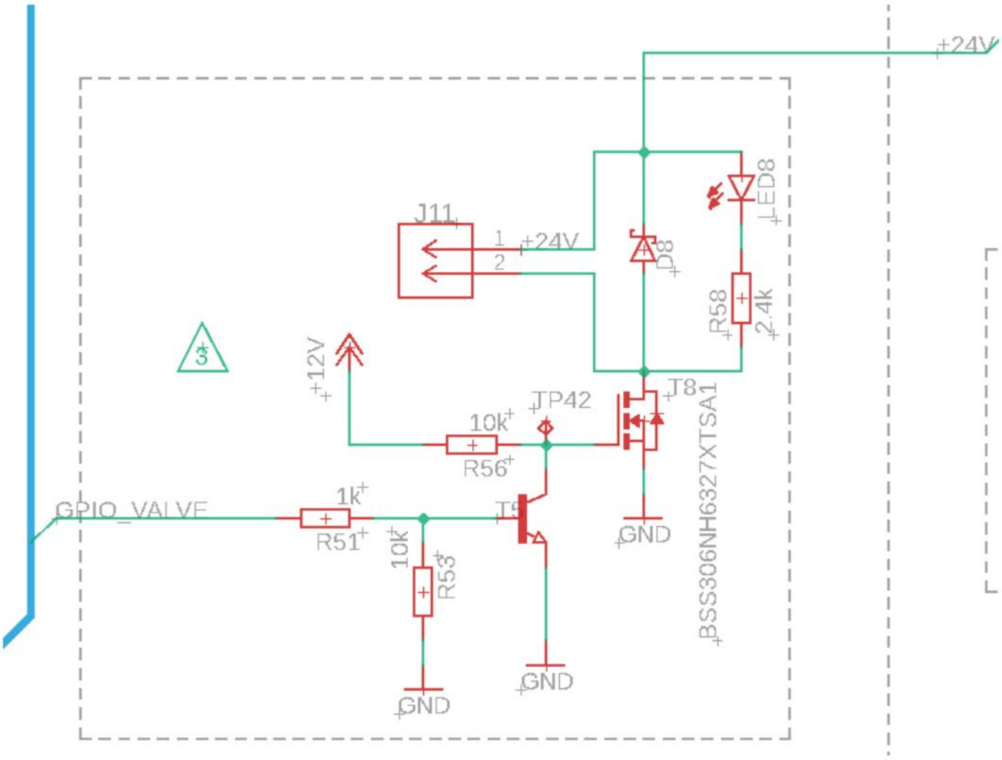







+24V
PINBALL_CIRCUIT1
J10
1
2
LED7
D6
R57
2.4k
T4
BSS306NH6327XTSA1
+12V
GPIO_SOLENOID
TP41
10k
R49
GPIO_SOLENOID/3.8B
1k
R48
T3
10k
R50
GND
GND
GND
3


+12V
3
LED9
D7
J12
1
2
+12V
R59
1.1k
BSS306NH6327XTSA1
T7
+12V
TP43
10k
R54
GPIO_VACUUMPUMP
1k
R52
T6
10k
R55
GND
GND
GND


+24V
J11
1
2
+24V
D8
LED8
R58
2.4k
+12V
3
10k
R56
TP42
T8
BSS306NH6327XTSA1
GND
GPIO_VALVE
1k
R51
10k
R53
T5
GND
GND

Further testing

test no.	test items	Test Approach	Conditions	Notes
Module testing				
	Test homing switch signal with external applied power	Apply a power supply to the circuit, measure output voltage	Homing switch is completely isolated.	2 homing switches are installed
	Test servo operation with applied PWM signal with external signal generator	Apply a function generator to the circuit, check servo behavior.	PWM Circuitry isolated	2 PWM Tracks installed
System testing				
test no.	test items	Test Approach	Conditions	Notes
	Test led switching with STM32 signals.	Toggle the LED pins on the STM32. Check led brightness		
	Test ADC feedback or entire VAC Sensor circuit.	Apply pressure to the VAC sensor, and read ADC value.		
	Test if the transistor switches without load, with STM32 signal, and measure resistance.	Toggle the transistor pins on the STM32. Check transistor resistance.		3 transistors are installed.
	Test if the VAC Pump turns on with STM32 signal to the transistor	Toggle the VAC pump transistor with STM32. Check pump for behaviour.		
	Test if the Valve turns on with STM32 signal to the transistor	Toggle the VAC valve transistor with STM32. Check valve for behaviour.		
	Test if the pinball flipper turns on with STM32 signal to the transistor.	Toggle the pinball flipper transistor with STM32. Check pinball for behaviour.		
	Test if RS422 driver converts QED signal to the correct encoder	Rotate the encoder and read RS422 output with the STM32.		2 encoders channels

	signal with encoder values.			are installed.

requirements testing				
Test no.	test items	Test Approach	Conditions	Notes
	Test if EMO Relay Latch switches during normal operation	Operate robot, press emo switch during movement.		2 engine circuits are installed.
	Motor safely switches off when EMO switch is pressed	Operate robot during peak speed, press EMO switch during movement.		2 engine circuits are installed.
	Test voltage drop of the Raspberry pi during normal operation.	Operate robot during normal movement. Measure voltage level.		
	Servo safely switches off when EMO switch is pressed	Operate robot during peak speed, press EMO switch during movement.		2 servers circuits are installed.
	Test I2C signal characteristics during normal operation	Operate sensors normally, check I2C signal		
	Measure the amperage of the 5V supply.	Operate robot during peak speed, measure amp draw at power supply		
	Measure the amperage of the 9V supply.	Operate robot during peak speed, measure amp draw at power supply		
	Measure the amperage of the 12V supply.	Operate robot during peak speed, measure amp draw at power supply		
	Measure the voltage level of the 5V supply.	Operate robot during peak speed, measure voltage level at power supply		
	Measure the voltage level of the 9V supply.	Operate robot during peak speed, measure		

		voltage level at power supply		
	Measure the voltage level of the 12V supply.	Operate robot during peak speed, measure voltage level at power supply		
	Check voltage level of the 24V supply during normal operation.	Operate robot during peak speed, measure voltage level at main supply		
	Measure the amperage of the 24V supply.	Operate robot during peak speed, measure amp draw at main supply		

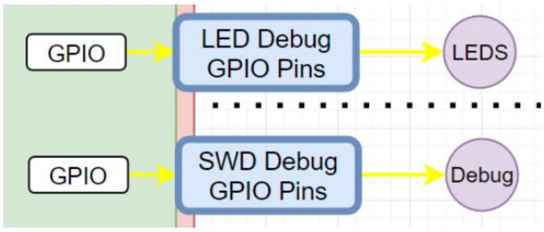
C.2.2 Non-Functional testing

Efficiency

- Test current draw 24V
- Test current draw 12V
- Test current draw 9V
- Test current draw 5V
- Test current draw 3.3V
- Heat production by system

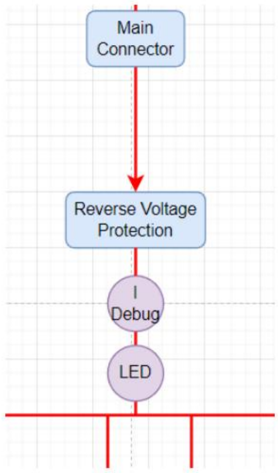
Maintainability

In the design multiple debug points are installed.



1. At every data connection, a probe to measure voltage is present.
2. At the voltage supplies a current measurement pin is installed.
3. An extra connection is installed for led feedback.
4. An additional connection is installed for Serial Debugging.

Using these points, the stability of data signals can be tested, draw current can be measured, and feedback can be given to the user.



Portability

The processing parts of the system are mounted on connectors and can be disconnected and replaced.

Reliability

- The robot operates within SR.46 and SR.43 over a period of 10 hours.

C.2.3 Structural testing

1. The 24V supply cannot give sufficient power.
2. The 5V supply cannot give sufficient power.
3. The 12V supply cannot give sufficient power.
4. The 9V supply cannot give sufficient power.
5. The 3.3V supply of the raspberry pi cannot give sufficient power.
6. The EMO switch doesn't trigger fast enough in case of an emergency.
7. The user detector board doesn't register the coins.
8. The color sensor doesn't detect the coin color.
9. The proximity sensor doesn't detect the coin in the system.
10. The pinball flipper draws too much current and breaks.
11. The data signals of PWM, QED, or I2C are significantly malformed.
12. The GPIO individual pin max current is exceeded.
13. The GPIO pins total current exceeds the maximum.

C.2.4 Experience-based testing 1.

Ambient temperature during operation.

2.Other environmental requirements.

3. Norm requirements testing.

C.3 Test plan

C.3.1 Effort

Main testing is done by Laurens Verbruggen.

Experience testing is asked to be done by the system architect or other experienced consultant.

C.3.2 Risk

The following components are critical to the success of testing, and the guidelines should be kept per component.

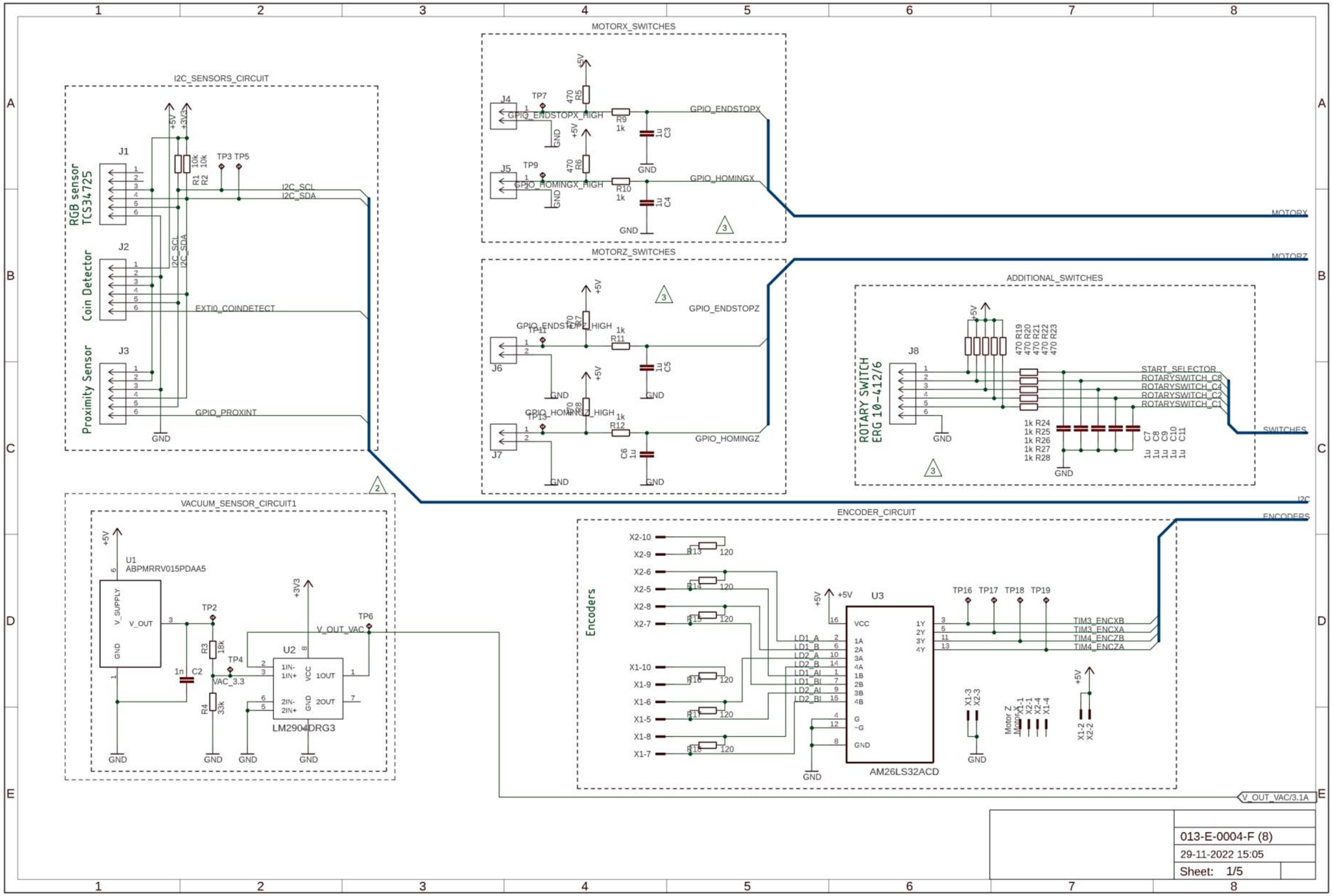
STM32H755

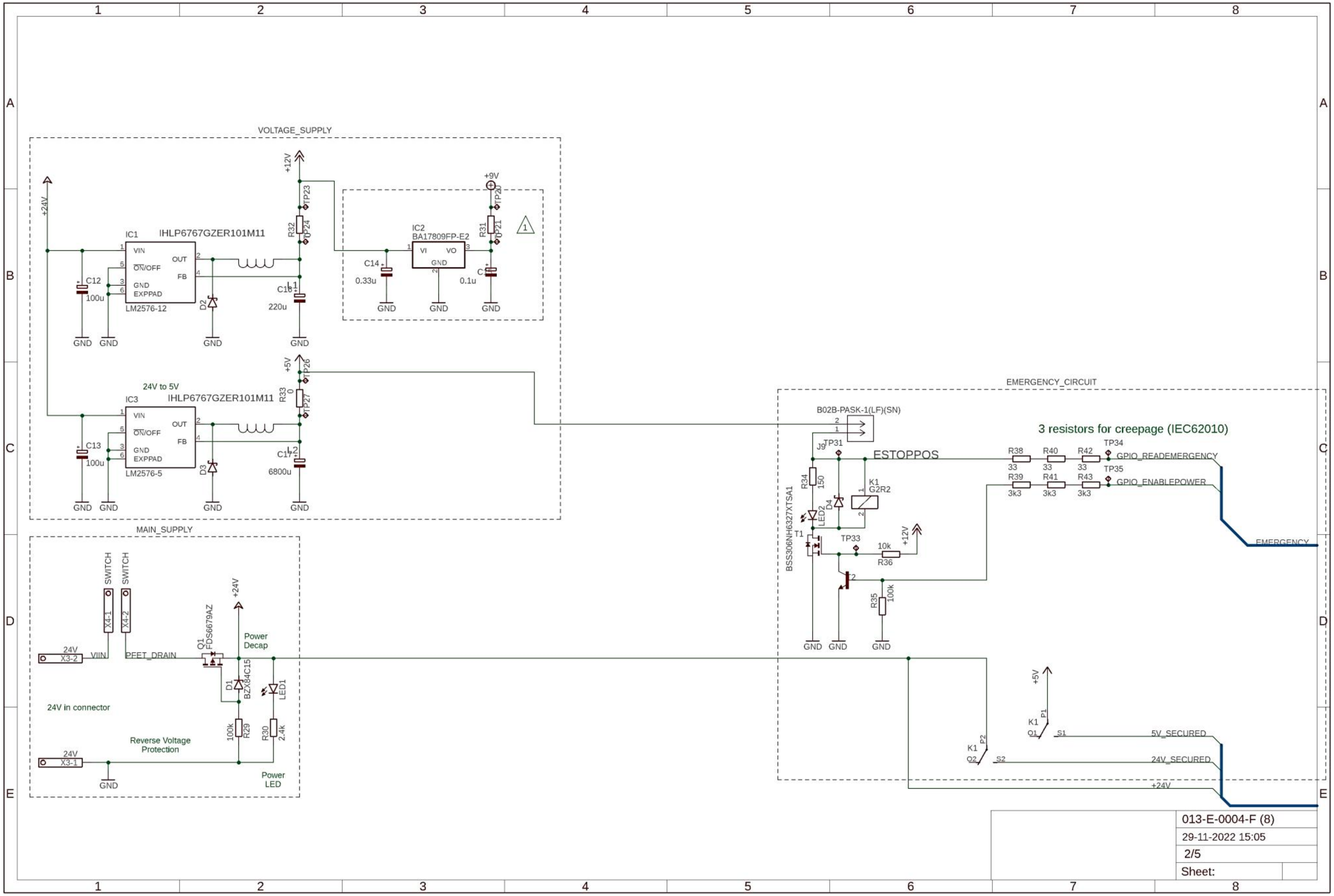
Current draw of the GPIO pins should be tested before the STM32H755 is connected to the system.
Voltage level and current draw of the voltage supplier for the STM32H755 should be measured before connecting the STM32H755.
ESD regulations should be kept to prevent damage.

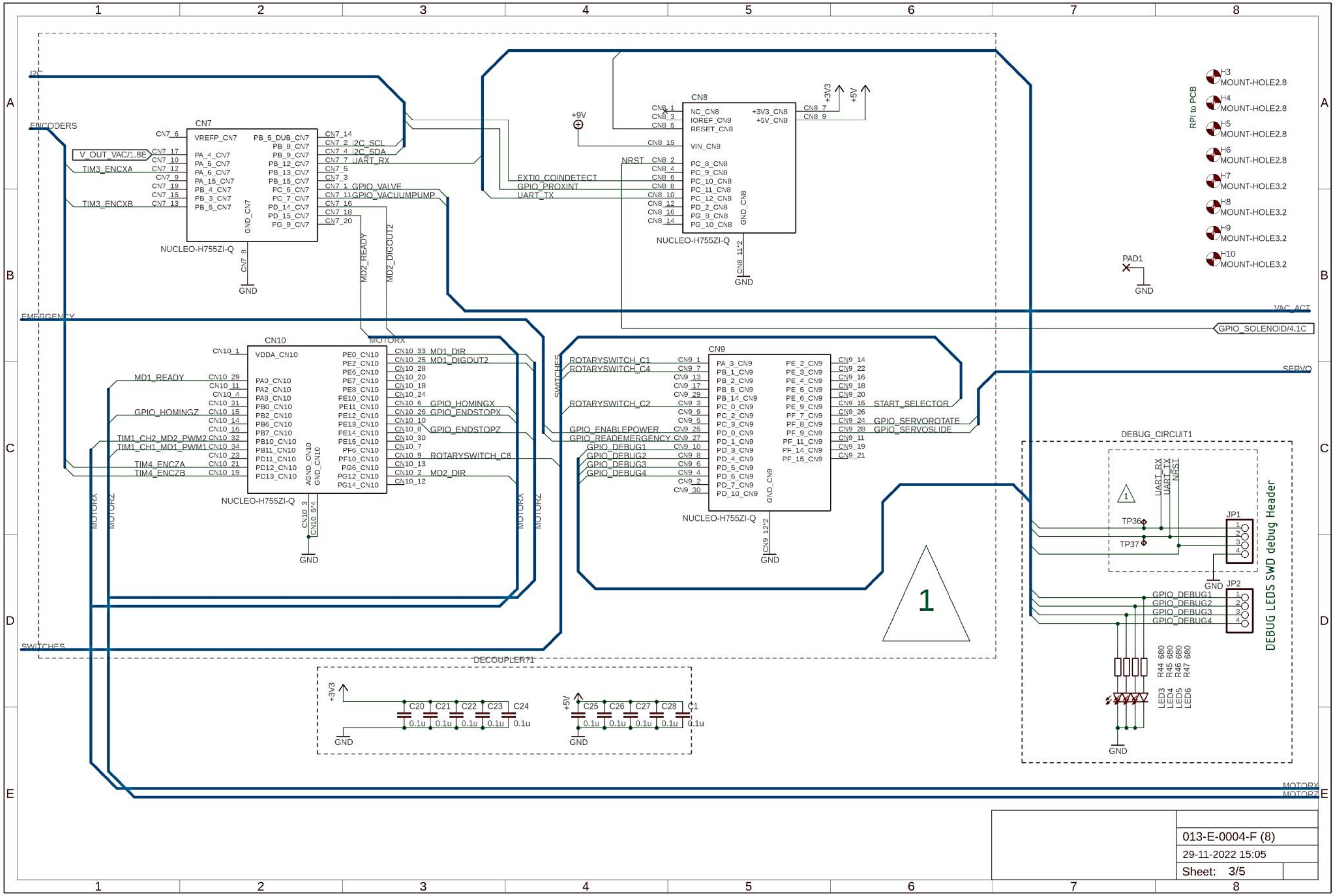
Once the STM32H755 is connected, disconnection should be minimized to keep connection issues low.

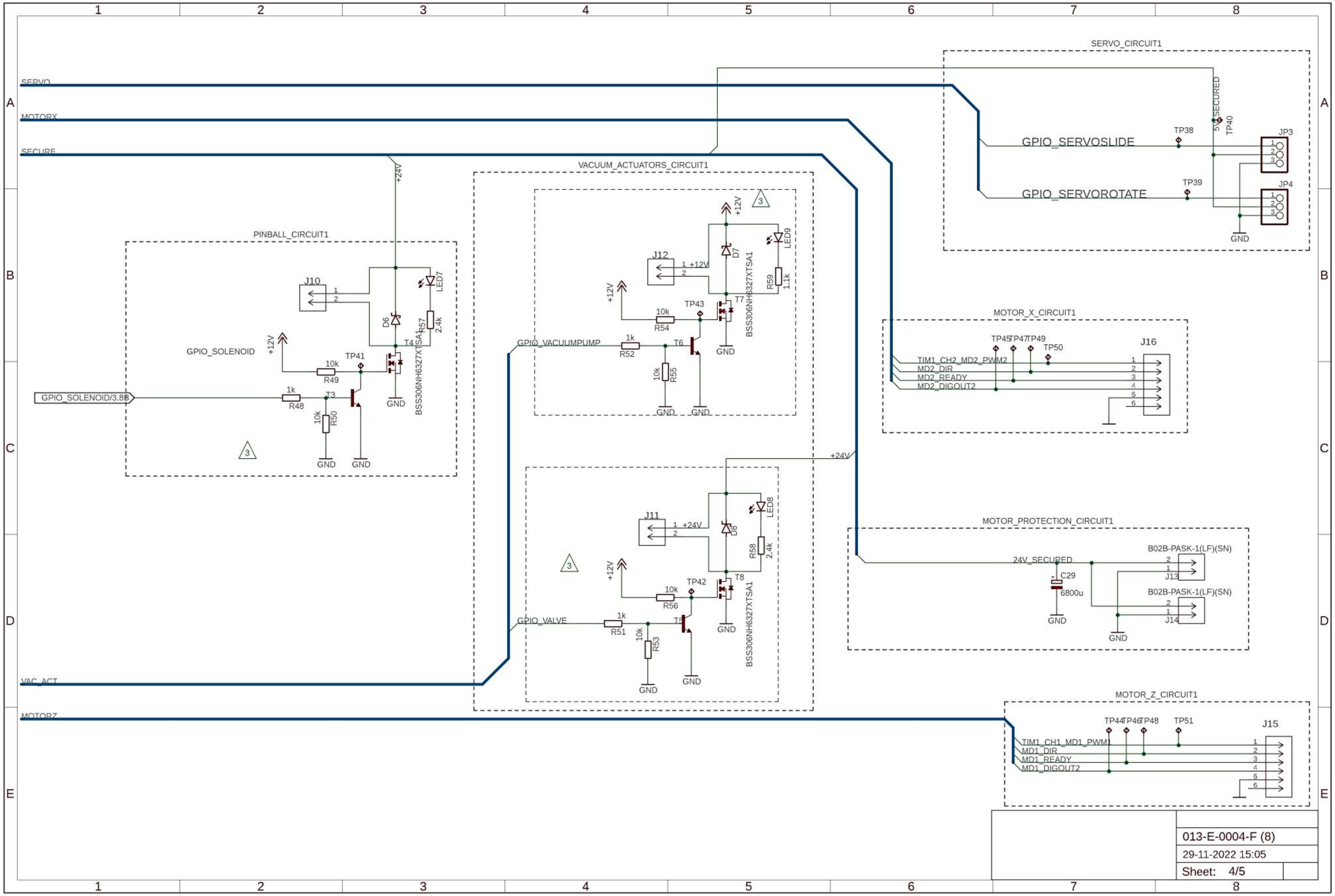
Raspberry
Pi The voltage level of the supplier should be measured before connection. Current draw and voltage drop should be measured at connection.

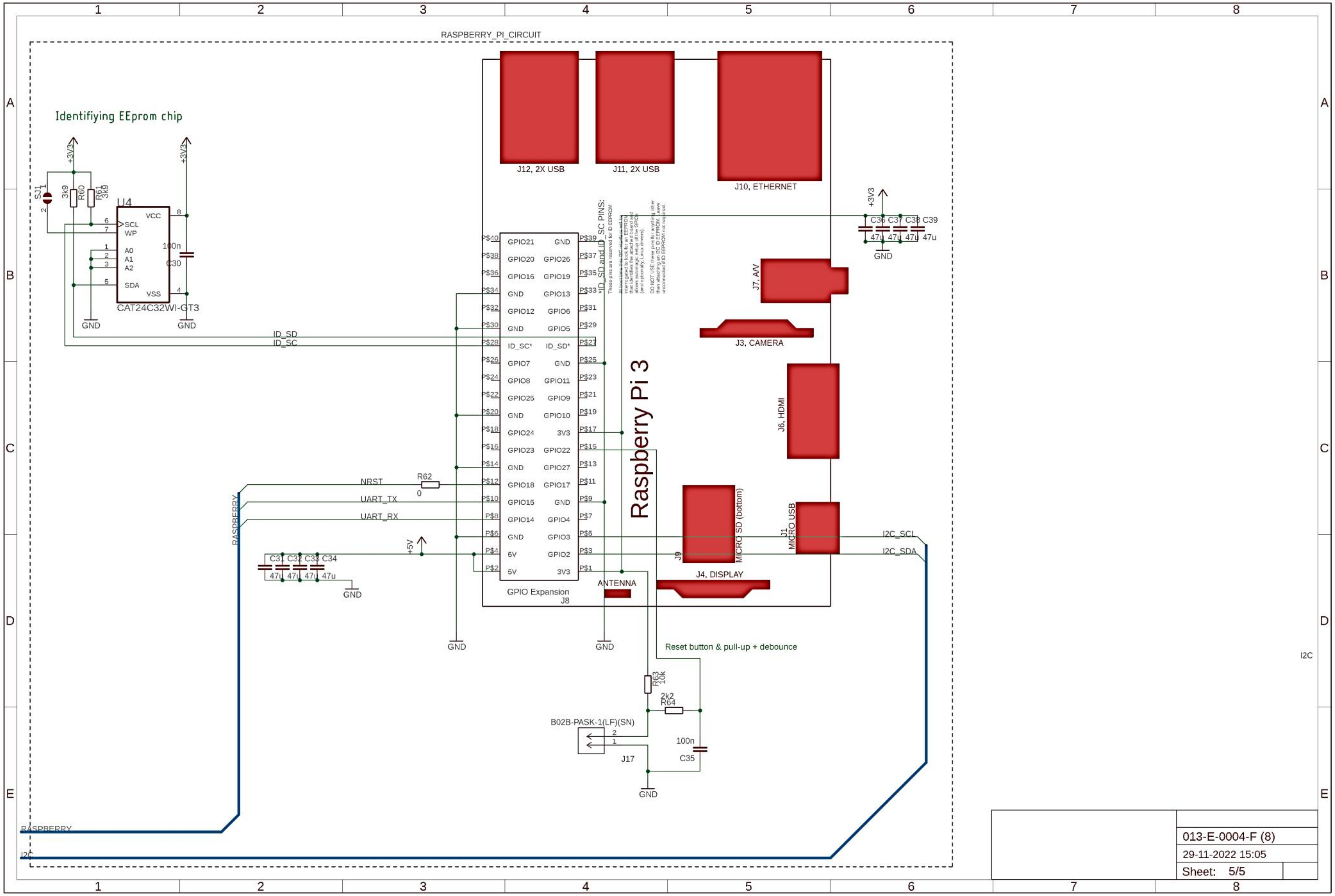
Appendix D Electronic design



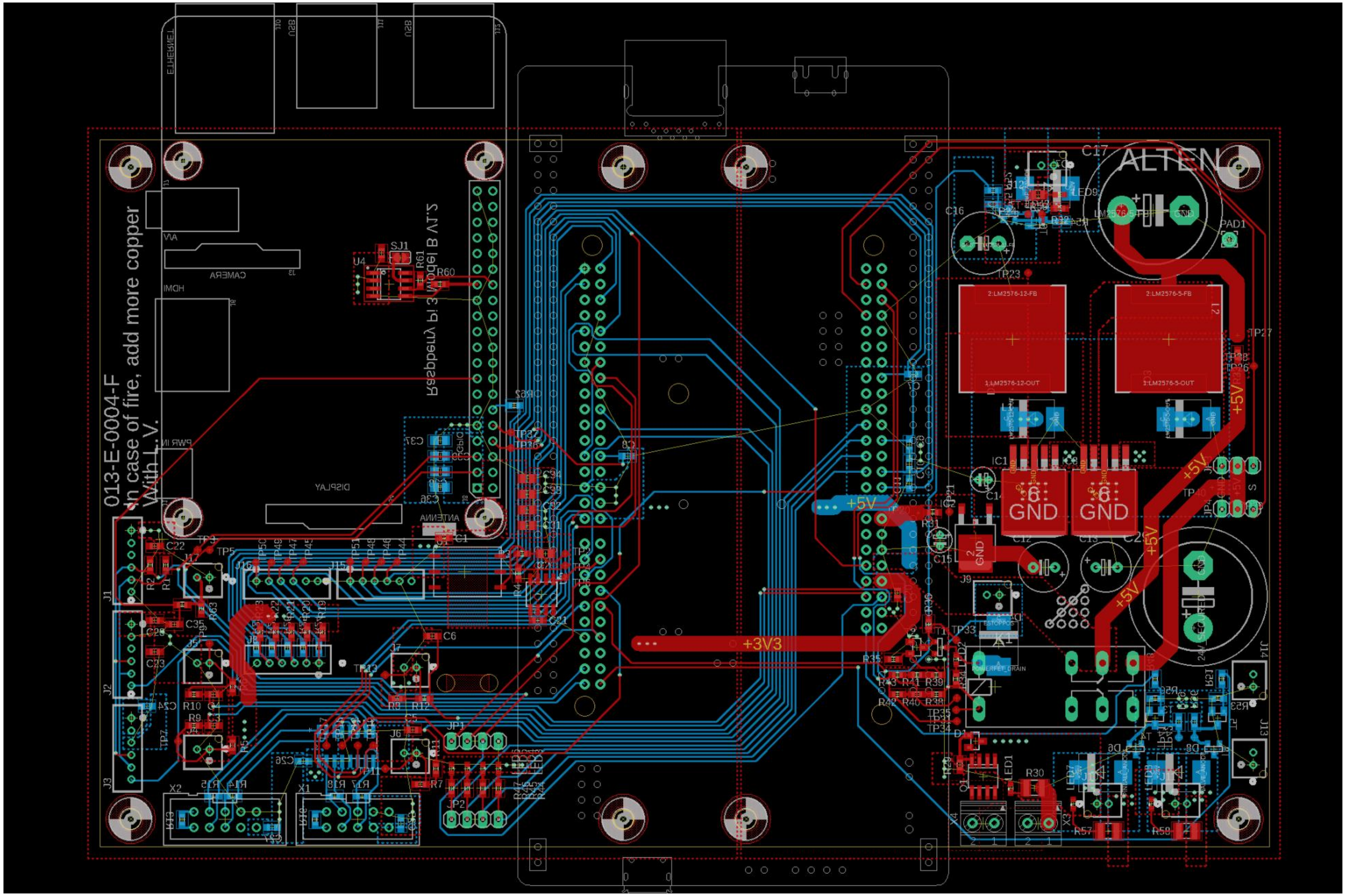

VOLTAGE_SUPPLY
IC1 IHLP6767GZER101M11
LM2576-12
IC2 BA17809FP-E2
24V to 5V
IC3 IHLP6767GZER101M11
LM2576-5
MAIN_SUPPLY
24V in connector
Reverse Voltage Protection
Power Decap
Power LED
EMERGENCY_CIRCUIT
B02B-PASK-1(LF)(SN)
3 resistors for creepage (IEC62010)
ESTOPPOS
GPIO_READEMERGENCY
GPIO_ENABLEPOWER
EMERGENCY
5V_SECURED
24V_SECURED
013-E-0004-F (8)
29-11-2022 15:05
2/5
Sheet:


I2C
ENCODERS
V_OUT_VAC/1.8E
TIM3_ENCXA
TIM3_ENCXB
CN7
NUCLEO-H755ZI-Q
I2C_SCL
I2C_SDA
UART_RX
GPIO_VALVE
GPIO_VACUUMPUMP
MD2_READY
MD2_DIGOUT2
GND
EXTI0_COINDETECT
GPIO_PROXINT
UART_TX
NRST
+9V
CN8
+3V3
+5V
VAC_ACT
GPIO_SOLENOID/4.1C
EMERGENCY
CN10
MOTORX
MD1_DIR
MD1_DIGOUT2
MD1_READY
GPIO_HOMINGZ
GPIO_HOMINGX
GPIO_ENDSTOPX
GPIO_ENDSTOPZ
TIM1_CH2_MD2_PWM2
TIM1_CH1_MD1_PWM1
TIM4_ENCZA
TIM4_ENCZB
ROTARYSWITCH_C8
MD2_DIR
MOTORZ
SWITCHES
ROTARYSWITCH_C1
ROTARYSWITCH_C4
ROTARYSWITCH_C2
GPIO_ENABLEPOWER
GPIO_READEMERGENCY
GPIO_DEBUG1
GPIO_DEBUG2
GPIO_DEBUG3
GPIO_DEBUG4
CN9
START_SELECTOR
GPIO_SERVOROTATE
GPIO_SERVOSLIDE
SERVO
RPI to PCB
H3 MOUNT-HOLE2.8
H4 MOUNT-HOLE2.8
H5 MOUNT-HOLE2.8
H6 MOUNT-HOLE2.8
H7 MOUNT-HOLE3.2
H8 MOUNT-HOLE3.2
H9 MOUNT-HOLE3.2
H10 MOUNT-HOLE3.2
PAD1
DEBUG_CIRCUIT1
UART_RX
UART_TX
NRST
TP36
TP37
JP1
JP2
DEBUG LEDS SWD debug Header
R44 680
R45 680
R46 680
R47 680
LED3
LED4
LED5
LED6
1
DECOUPLER?1
C20 C21 C22 C23 C24
C25 C26 C27 C28 C1
0.1u
013-E-0004-F (8)
29-11-2022 15:05
Sheet: 3/5

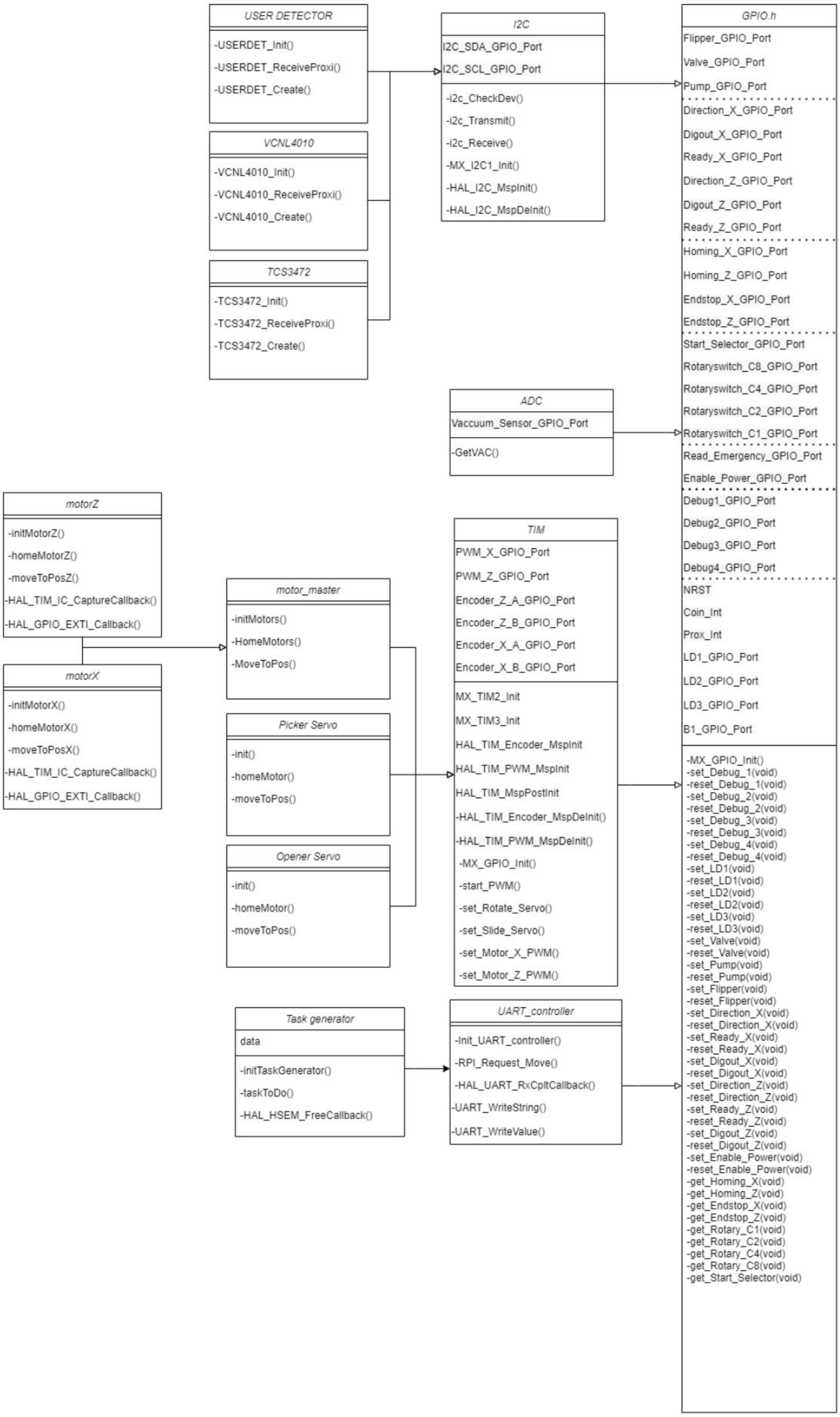

SERVO
MOTORX
SECURE
VAC_ACT
MOTORZ
SERVO_CIRCUIT1
GPIO_SERVOSLIDE
GPIO_SERVOROTATE
5V_SECURED
TP38
TP39
TP40
JP3
JP4
GND
VACUUM_ACTUATORS_CIRCUIT1
PINBALL_CIRCUIT1
GPIO_SOLENOID
GPIO_SOLENOID/3.3B
GPIO_VACUUMPUMP
GPIO_VALVE
BSS306NH6327XTSA1
MOTOR_X_CIRCUIT1
TIM1_CH2_MD2_PWM2
MD2_DIR
MD2_READY
MD2_DIGOUT2
J16
MOTOR_PROTECTION_CIRCUIT1
24V_SECURED
B02B-PASK-1(LF)(SN)
C29
6800u
MOTOR_Z_CIRCUIT1
TIM1_CH1_MD1_PWM1
MD1_DIR
MD1_READY
MD1_DIGOUT2
J15
013-E-0004-F (8)
29-11-2022 15:05
Sheet: 4/5


RASPBERRY_PI_CIRCUIT
Identifiying EEprom chip
U4
CAT24C32WI-GT3
J12, 2X USB
J11, 2X USB
J10, ETHERNET
J7, A/V
J3, CAMERA
J6, HDMI
J1 MICRO USB
J9 MICRO SD (bottom)
J4, DISPLAY
ANTENNA
Raspberry Pi 3
GPIO Expansion
J8
NRST
UART_TX
UART_RX
ID_SD
ID_SC
I2C_SCL
I2C_SDA
Reset button & pull-up + debounce
B02B-PASK-1(LF)(SN)
J17
RASPBERRY
I2C
013-E-0004-F (8)
29-11-2022 15:05
Sheet: 5/5

Appendix E Electronic Layout



Appendix F Software design



~~Include this form in the internship report~~

ORIGINALITY STATEMENT

with the internship report with the title:

Implementing the control system of the 4 in 1 row robot ***

I hereby declare that the submitted report as mentioned above, originally signed by the undersigned, was drawn * is: it is because of me, the up and drawn up personally.

In order to be able to prepare this piece, I have carried out the necessary research myself.

Where I have used other people's work, I have indicated this in the relevant piece of text bibliography. ** and in the

Date : 20-1-2023

Name : …Laurens Verbruggen…………………………………….

Student signature:

Recoverable signature

X LV

Lawrence Verbruggen

Signed by: c9e596c4-f9ab-4a3d-a6c7-24f053d7a9d2

……………………

* The University has access to control software with regard to originality. It reserves the right to use this software in appropriate cases

** Literally copied work must be provided with the source reference immediately before the text begins: the title of the work quoted from, as well as the name of the author.

*** Mandatory inclusion in the report

This concerns:

Chapter	Written by
Project definition	Lawrence Verbruggen
Project documentation and architecture	Lawrence Verbruggen
System design	Lawrence Verbruggen
module design	Lawrence Verbruggen
System implementation	Lawrence Verbruggen
Test results	Lawrence Verbruggen
Future possibilities	Lawrence Verbruggen
Conclusion and recommendations	Lawrence Verbruggen