Construction of universal mount and design of new hardware layout.

Universal enclosure mount and general improvements of hardware on autonomous bicycle.

Bachelor's thesis in Electrical Engineering

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Gothenburg, Sweden 2022
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Bachelor's thesis 2022

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This thesis describes the work put into making a component-enclosure easily attachable to different bicycles. Beyond this it will also explain various changes made to improve and further improve the enclosure and hardware.

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Cover: The bicycle with the new enclosure attached.

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Abstract

This thesis focuses on recreating a set of electronic equipment that was used to construct a self-driving bicycle in a previous project. As well as improving and further develop the accessibility of the enclosure and improve the durability to be able to withstand more stress and so on. To achieve this a portable version of the hardware was created. Where the mount is designed to be removed and reattached to bikes of different models. This helps reduce the dependency on a bicycle-manufacturer or a bicycle-model. As well as means the equipment can be used on replacements would something happen to the current bicycle. A new layout was also designed that made it possible to decrease the size of the hardware-enclosure. Which further improved the mobility of the hardware even more. Several of the problems encountered during the project have required custom-made solutions. These solutions was modelled in the CAD program Catia V5 and then 3D-printed. During the project many new ideas and solutions came to being which were added to the results and evaluated in order to obtain the best new version. In the end the main issue was the deliverance of components as some of the main components never arrived in time for them to be put into the new layout. The project was finalized as well as could be done, leaving instructions for the future on both what to do when the components arrive and how to further develop the results produced by this thesis.

Keywords: Autobike, autonomous bicycle, enclosure mount, FSESC, VESC, universal mounting.

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In addition we would not have been able to done much of the work in this thesis without the old bicycle present so a big thanks to Henrik Falk and his students at Mälardalens University.

We would also thank PhD student Yixiao Wang and all previous students who worked on the bicycle project for guiding and providing their information on to us.

Lastly thanks to the CASE-lab association for allowing us to conduct large parts of our work in their lab and to use their equipment.

Andréas Strömberg & Thor Leikvik, Gothenburg, June 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Design
DPST	Double-Pole Single-Throw
GPS	Global Positioning System
IMU	Inertial Measurement Unit
LED	Light Emitting Diode
NC	Normally Closed
NO	Normally Open
PDB	Power Distribution Board
SPST	Single Pole Single Throw

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1 Introduction

In collaboration between Chalmers University of Technology and Mälardalen University, bachelor and master theses have been carried out in several rounds. The goal has been to design and program an autonomous bicycle that can be used in various test runs. This chapter provides an overview of this thesis and the bicycle project in its entirety. In the following sections, the background for the project will be given. Thereafter the aim and limitations will be presented and clarified.

1.1 Background

The automotive industry is constantly evolving and always looking for new opportunities to further improve its vehicles. Something that has been given a very high priority in this development is traffic safety, where the car must be able to detect and avoid accidents. A vehicle that cars often has to interplay with in traffic is bicycles, where for example there are bicycle lines next to the car lanes and special crossings for the cyclists. When then the cars are becoming more autonomous the bicycle riders are increasingly putting their lives in the hands of the programmers and the engineers of the autonomous cars algorithms. In order to ensure that the safety mechanisms of the cars work as they should to prevent accidents, many tests and simulations has to be done for validating the systems.

When cars get more advanced technology and become smarter, the tests also need to become more real and complex. This creates a demand for bicycles for which can be crash-tested and tried around autonomous car prototypes, without putting any human at risk. The self driving bicycle are therefore in this project not designed to accommodate users to the fullest extent possible but instead to simulate the human unpredictability in traffic as close as possible.

The project started in 2018 and has taken different paths, like becoming two separate bicycles at the universities because of different programming languages and function implementations. Since the bicycles always can be further improved and made more effective the project has continued and is still in progress and could be as long as people are willing to help develop it. This means that new versions can be delivered to the companies when improvements have been made. This thesis will be another project to further improve and develop the autonomous bicycle.

1.2 Aim

The aim from the origin has been to manufacture a completely autonomous bicycle that can be used in crash preventing tests by various companies in the transport sector. This have already been accomplished in previous years, the aim of this thesis is therefore to further improve and expand the functionalities of the old bicycles onto a new version. This means that a portable version of the hardware will be constructed onto a new bicycle made to fit different models, which will be easier to connect and take off. This will lead to less costs in the future as well as the availability to test different bicycle models. The second aim of the project is to optimize the electrical solution by creating a new layout that reduces the size of the enclosure and still contains all the hardware. Beyond the portable hardware and the layout, it also shall be looked into if it is possible to measure the speed of the bicycle directly from the motor. This is to help verify and provide the information when testing the bicycle, while also removing the need of mounting hall-sensors to the wheel and reducing the number of components.

1.3 Limitations

This thesis will only focus on the hardware and external signals of the bicycle and therefore leave out software and algorithms for steering and balancing the bicycle. Because of the variation in bicycle designs, the portable solutions will not work on every bicycle but instead only on some variations. The portable solution will focus on standard adult-sized bicycles as there is currently no access to smaller models.

1.4 Clarification of research questions

The following questions will be accomplished in the thesis.

- As much of the same components that were used in the previous project carried out by Mälardalen University will be ordered and then connected in a new enclosure that shall be placed on to a new bicycle.

- Redesign the layout of the components to minimize the size of the enclosure and optimize the space.

- Find a solution for attaching the IMU in a horizontal angle.

- Construct a mount for the steering motor that is similar to the one in the previous project.

- Design and construct a new mounting solution for the hardware enclosure that can be detached and easily put back on.

- It shall be possible to attach the hardware enclosure on different bicycle models.
- Look in to possible solutions for measuring the speed without hall sensors.
- All work in the project shall be well documented to support further work in the future.

2

Theory

This chapter provides basic information about the previous project carried out by Mälardalens University. In the upcoming sections the previous bicycles design, used hardware and the mounting of the various parts is introduced. Which should provide a deep enough knowledge to be able to follow and understand the remaining parts of the thesis.

2.1 Previous bicycle

The previously used bicycle is a model from the manufacturer Monark with a red color and is showcased in Figure 2.1 below. It is of a smaller size than the models that have been used by Chalmers.

Figure 2.1: The image displays the old bicycle that was previously used. The rings and arrows in the image indicates were some of the hardware was placed.

Figure 2.1 gives an overview of the old bicycles construction with indications on different parts that are mounted on it. The upper black ring is showing the placement of the steering motor and the other black ring placed by the pedals of the bicycle is showing the forward motor. Beyond the motors the rest of the hardware is not possible to see on the image as it is located in the the large grey enclosure mounted on the middle of the bicycle.

2.1.1 Old Layout

The layout and set-up from the red bicycles enclosure was a functional and complete construction as seen in figure 2.2. While in its current state after delivery to Chalmers at the start of the thesis did miss some parts and had a few loose parts as seen in figure 2.3. When this enclosure was constructed the main focus was on functionality which meant order and tidiness was lacking, as also can be seen in the figures the enclosure was very oversized relative to the components inside. There had been some help in organizing the enclosure by for example creating a list with cable indexing and having numbers put on to all cables to help identify said cables.

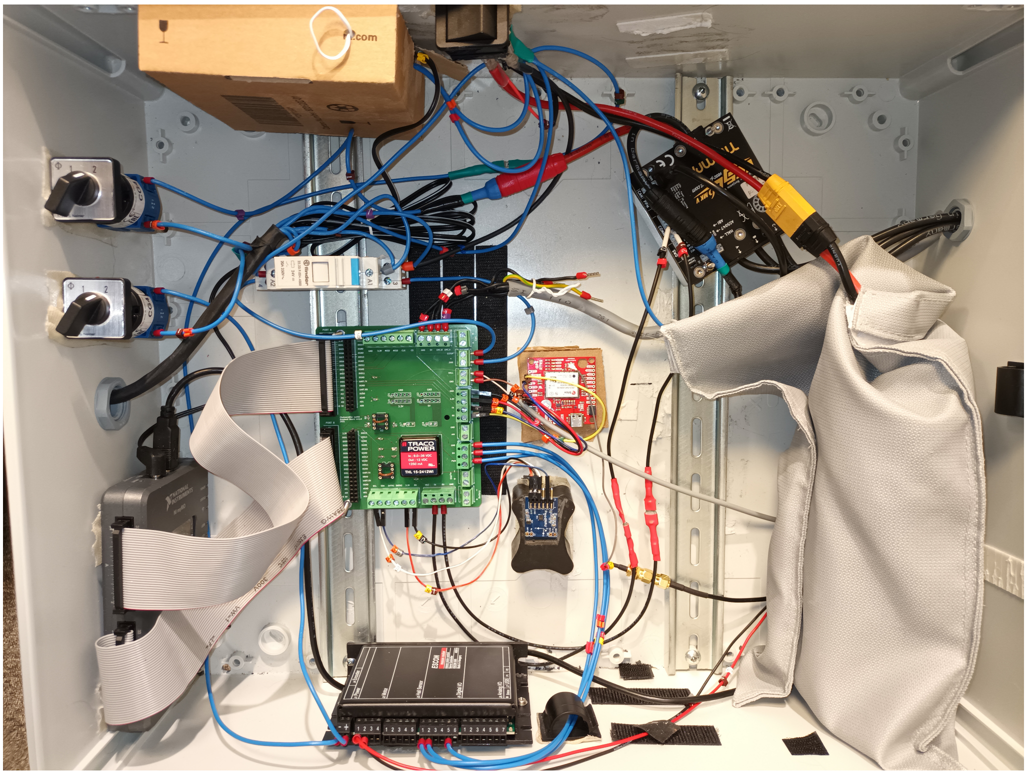

Figure 2.2: The old layout inside the enclosure from the red bicycle with everything in its place.

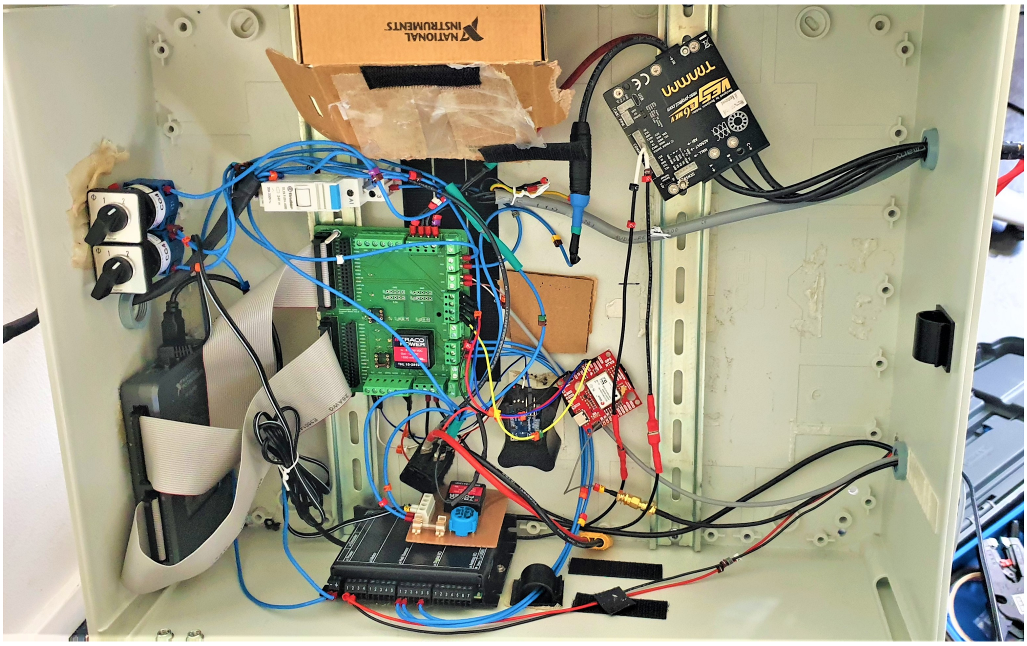

Figure 2.3: The old layout inside the enclosure from the red bicycle the new layout was designed from, lacking certain parts in the image such as a battery.

Two DIN-rails and double sided tape had been the most common ways of attaching the components inside the enclosure. The power switch and circuit breakers were only attached by tape on one of their sides against the wall of the enclosure, which came off easily when the buttons were pressed upon. On the same wall as the circuit breakers the microcomputer is also attached with tape, as well as the steering motor controller on the bottom wall of the enclosure. Some of the larger components are instead attached to the DIN-rails such as the relay, breakout board and the forward motor controller. The breakout board is also supported with some velcro which is also used to attach wires at a few places. The GPS-module and PDB are just connected to cardboard which then also is attached to the enclosure using tape. The IMU has a special holder which attaches to the enclosure with tape once again. The battery is placed in a protective bag and placed in one of the corners of the enclosure. Some of the wires and cables are attached to the walls to alleviate the abundance of wires and cables above components. Most wires and cables are internal meaning they connect two or more components inside the enclosure, but some wires and cables have holes in the walls where they connect to parts outside the enclosure such as the motors and the emergency stop box. The enclosure has plenty of space that remains unused since the wires and cables do not take up much space and the enclosure is very large compared to the components placed inside it.

2.1.2 Mountings

The underside of the enclosure had two rails which went down either side of the bicycle frame. These rails had then been welded onto the bicycle frame. This meant the enclosure was very difficult to remove or replace. The benefit of the welding was however that the enclosure was extremely sturdy and not very affected by force and other mechanical strains to the enclosure mounting. Though as previously mentioned in 2.1.1 most of the components inside were only loosely attached with double sided tape. This meant even though the enclosure was securely attached, outside force could lead to components falling off inside it. Because of the size of the enclosure it could only be attached to a female bicycle model under the saddle which was the only place with enough space. The emergency stop box was connected with wires from inside the enclosure and could be carried around as well as be placed on the front of the enclosure using burdock.

The steering motor mount was placed above the front wheel on the frame leading up to the handlebars as seen in figure 2.4. In order for the motor to be able to turn the front wheel axle a contraption of mechanic parts were placed in relation to the front wheel axle and steering motor. On the bicycles frame two u-bolts and a timing belt pulley with a locking bush are holding the steering motor mount connected to the bicycle. On the other side, the motor is connected to a locking bush here too which is placed inside a timing belt with two u-bolts holding the motors body in place. The u-bolts are then holding on to a metal plate in order to stabilise the motor while the timing belt pulley is connected to the other timing belt pulley using a timing belt. These two timing belt pulleys acts as gears which allows the motor to spin the front wheel. The encoder is placed at the bottom of the steering motor where it then feeds into the enclosure using wires.

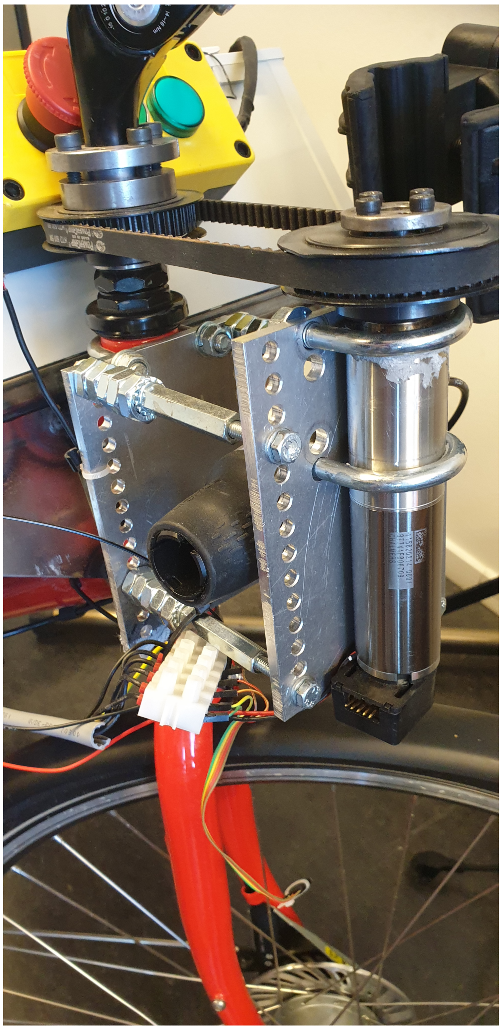

Figure 2.4: The steering motor mount on the red bicycle placed above the front wheel.

2.1.3 Hardware

This section and subsections explain the components functionality in general and also how it was used in the autonomous bicycles system.

2.1.3.1 Microcomputer

National Instruments myRIO-1900 is a configurable microcomputer that can be used to create control systems. It is used as the central part in the autonomous bicycles system. With an embedded FPGA-board and a microprocessor it is transmitting and receiving signals to all of the hardware. The myRIO has a supply voltage between 6 to 16VDC and consists of analog and digital ports, which are both in and out ports. It is also equipped with a USB connection which is used to configure the device by loading in code from a host computer [1]. In addition to the myRIO a customized break out board has been made to simplify the coupling of cables. Therefore the hardware is connected to the break out board and then transmitted through two IDE cables to the myRIO.

2.1.3.2 Steering motor

The steering motor is mounted on the front of the bicycle and the one used is DCX32L manufactured by Maxongroup, which is a DC motor with graphite brushes. The purpose of the steering motor is to adjust the handlebar of the bicycle and thus be able to decide the direction of movement. The motor has a nominal voltage of 24V and a nominal torque of 112mNm with a maxspeed of 11300rpm. The outer diameter of the motor is 32mm and the length is 72mm [2].

In one of the previous projects it was calculated that the needed torque to steer the bicycle is 8,5Nm [3]. For that reason a gearhead needs to be connected on to the steering motor to increase the nominal torque. The gearhead used is of the model GPX32Hp manufactured by Maxongroup and is a high power planetary gearhead with a reduction of 111:1. This increases the nominal torque to 12.432Nm. The outer diameter of the gearhead is 32mm and the length is 61.3mm [4].

2.1.3.3 Encoder

HEDS-5540#A11 is the encoder used for the steering motor. It is a incremental rotary encoder with a supply voltage of 5VDC. The maximum velocity is 30 000 rpm with an acceleration up to 250 000 rad/sec^2 and the maximum resolutions of 1024 counts per revolution. The encoder is mounted on the steering motor in order to measure the steering angle and then transmit the angle to the myRIO [5].

2.1.3.4 Steering motor controller

To be able to steer the bicycles path the steering motor needs to be controlled and for this the motor controller Escon 50/5 designed by Maxongroup is used. The Escon receives an angle from the myRIO and then it decides the movement of the steering motor. The supply voltage of the controller is 10 to 50VDC with a maximum output voltage of 49VDC and the maximum current is 15A with a maximum peak output current of 20 seconds. The controller is equipped with pulse width modulation(PWM) that functions at a frequency of 53,6kHz. To set up the PWM Maxon has created its own software called ESCON Studio which can be downloaded from their website.

The motor controller features both analog and digital in- and outputs. The analog inputs has a range of -10 to 10V and a resolutionen of 12 bits. Meanwhile the analog outputs has a range of -4 to 4V with a resolution of 12 bits. As a user interface there is a LED that either illuminates green that indicates ready or red that stands for error. The maximum effiency of the motor controller is 90%. There is also some protection functions that will turn the controller off if the received current gets above 22,5A or the received voltage get below 7,2V or above 58V [6].

2.1.3.5 Forward motor

The forward motor that is used on the bicycle is from Shimano Steps E6000 series and is of the model DU-E6010. It is a brushless DC motor and is mounted between the pedals of the bicycle. The motor has a max torque of 50 Nm and is rated for 36 VDC. The continues power rating of the motor is 250 W with a maximum power rating of 500 W. All inputs to the motor is received from the motor controller. The motor has a weight of 3,05kg and is used for accelerating the bicycle [7].

2.1.3.6 Forward motor controller

To control the acceleration and deceleration of the bicycle the Vedder Electronic Speed Controller(Vesc) MK V has been used, which is a motor controller manufactured by Trampa. The purpose of the controller is to receive signals of the desired speed from the myRIO and then supply the forward motor with the right amount of power to reach the wished upon speed. The motor controller can handle up to 100A continuous current and a burst current of 120A. The supply voltage is 6 to 60V and the output for external electronics has two modes, either up to 5V and 1A or 3V and 0,5A. The communication ports for the Vesc is UART, USB, and CAN. It can also be controlled with analog signals or Pulse Position Modulation(PPM). With the help of Vescs own software Vesc tool it is possible to configure the RPM, current, voltage and power limits. There is a built in LED in the motor controller to indicate the status. The motor controller supports input sensors such as hall effect sensors and features measurements of current and voltage of all phases [8].

2.1.3.7 Battery

The power supply of the bicycle is the lithium battery Tattu Plus manufactured by Gens Ace. It has a discharge rate of 240A and a capacity of 12000mAh. The battery consists of 6 lithium cells connected in series with a supply voltage of 22.2V. Tattus plus is a smart battery that features BMS which monitors the temperature across the pack to extend the battery using life. The connections on the battery is AS150 and XT150 [9].

2.1.3.8 Relay

In the project a relay with two poles from the manufacturer Finder is used. It consists of 6 ports and a button, where the button acts as a test button. Port 1 is connected to port two with a SPST switch that is normally open and port 3 is connected to port 4 with a SPST switch that is normally closed. The rated continuous current is 20A and the maximum peak current is 30A. The relay has a nominal voltage of 12 to 24VDC and a minimum switching load of 1000mW. The function of the relay is to increase the safety of the bicycle as it cuts off the power if something goes wrong [10].

2.1.3.9 GPS

The configuration of the bicycles Global Positioning System(GPS) consists of 2 parts, a GPS antenna and a GPS module. The GPS antenna used is GPS_WP/TRK/SMA_3.0 manufactured by CTI, which is waterproof with an IP-rating of IP67. It features a magnetic mount and has been mounted outside of the enclosure on the bicycle. The function with the antenna is to receive and amplify radio signals, then convert to electronic signals and transmit them. The antenna connects through a RG174 coaxial cable with an impedance of 50Ω and supply current of 15mA. The center frequency is 1575.42MHz with a bandwidth of ±5MHz [11].

The GPS module used is the ZED-F9P GNSS module manufactured by U-blox and its purpose is to obtain the output of the GPS antenna and transmit the bicycle position. The GPS modules supply voltage is 3.3V and the current consumption is 130mA. It has a operational speed up to 500m/s and the module has a configurable frequency from 0.25Hz to 10MHz. The GPS module can communicates through UART, SPI and USB. It also features a backup battery that if needed can supply the module with 1.65 to 3.6V and a current of 80 μA [12].

2.1.3.10 IMU

For the bicycle to be able to keep balance the exact position it is in needs to be known and an Inertial Measurement Unit(IMU) can provide a variety of orientation related data. The IMU used is of the model Pmod NAV manufactured by Digilent which is a device with sensors that measures the specific force on the bicycle in three axis, which is illustrated in figure 2.5. To collect data of the acceleration, rotation and orientation 16-bits full scale registers are used, and for pressure data resolution of 24 bits is used. With the collected data it is possible to keep track of if the bicycle is falling and which direction it is facing. The IMU has a supply voltage of 3.3V and has a SPI interface. The sensor for magnetic flux has a range of ±16G, the range of the linear acceleration is ±16g and the angular rate range is ±2000dps [13].

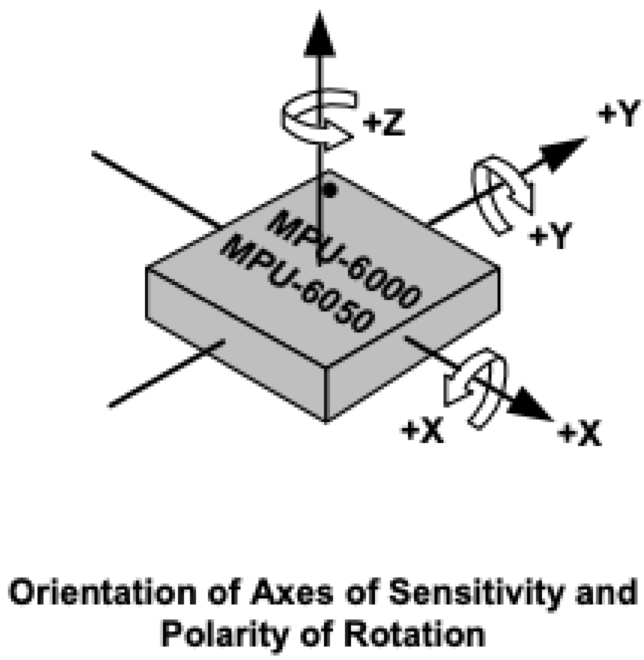

Figure 2.5: The image illustrates the three axis of orientation in the IMU. [14]

2.1.3.11 Power distribution board

To be able to supply the myRIO with the right amount of power a DC-DC converter is used. It is a custom made Power Distribution Board (PDB) with various built in components that can be seen in Figure 2.6. The PDB is connected between the battery and the myRIO.

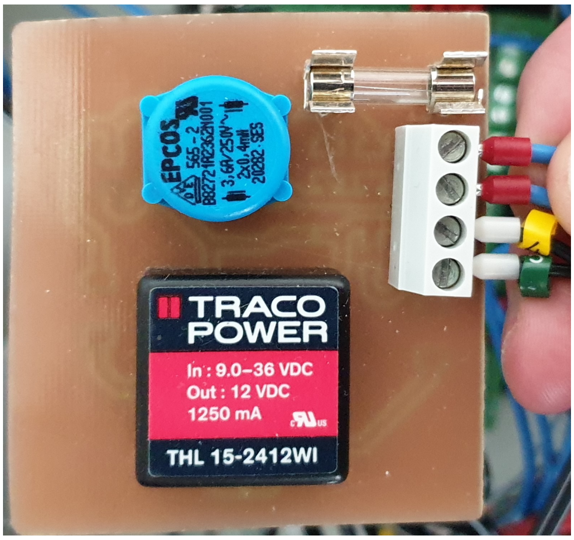

Figure 2.6: The image shows the PDB used by the red bicycle.

2.1.3.12 Switches

The electrical system is equipped with 2 circuit breakers and 1 power switch. The circuit breakers used are of the model CG4 A220-GBA12EF from Kraus & Naimer. They are connected to the motors where one of them cuts the supply to the steering motor and the other to the forward motor. They features a rotary knob with 2 modes where default is closed. The rated voltage is 440V and the maximum current of the circuit breakers is 10A [15].

The power switch used is from the Arcoelectric series manufactured by Bulgin. It is an on-off rocker switch with a DPST connection and has a contact current rating of 16A. The power switch is connected between the battery and the rest of the hardware. It has four terminals with 6.3mm blades and the default state is closed [16].

2.1.3.13 E-stop box

The emergency stop box consists of more than just an emergency stop button, it also contains a LED-light to indicate when the motors are powered and ready to be controlled. The last thing on the emergency stop box is the reset button which initializes the motors and prepares for the usage of the two motors. The emergency stop button is a turn to release-button meaning when pressed it locks in place until it is turned where it then goes back to a state where it can be pressed again. The buttons head is connected to a NC contact block which is the OMRON A22-01 rated for 380VDC. At 24VDC it can withstand 10A flowing through it and operates in the temperature range of -20 to 55°C. The reset button is a green illuminated push button connected to a NO-contact block Schneider Electric ZBE101, this block also allows 10A to flow through with capability of isolation potential differences up to

600V. The button works in temperatures ranging from -40 to 70°C. The contact block for the LED is a 24V light block Schneider Electric ZBV-B3 to which a green cover is placed as the head. The light block operates under 24V and consumes 18mA. Between -40 to 70°C is the operating temperature for the light block.

2.1.3.14 Hall sensors

To be able to measure the speed of the bicycle a hall sensor from Assam tech Europe was used. It is mounted on the frame of the bicycle at the rear wheel and there are also 5 magnets mounted on wheel. The function of the sensor is to send pulses to the myRIO every time a magnet on the wheel is passing and with that information it is possible to calculate the speed. The maximum carry current is 1A and the switching current is 0,5A.

3
Methods

This chapter gives an overview of how the work has been carried out. First section explains the workflow of the project and after that the validation plan is presented.

3.1 Workflow

The first part of the project was the preparation phase which is about getting to know the bicycles system and obtain a deeper knowledge of the various parts. This was done by reading about and comparing the previous projects that has been carried out as well as studying the existing bicycles and the various data sheets of the hardware. This gave a clear idea of the structure and what components that differ between the bicycles. After that it was possible to make up a list of what hardware that is needed for the construction of a new autonomous bicycle. The second part of the preparation phase was an inventory of the existing material that has been left over from the previous year, to see what already existed and what needed to be purchased.

To make it easier to move the hardware between different bicycles as much components as possible need to be placed inside a enclosure or enclosures. For determining the needed size of the enclosure research had to be done. The first step was to examine which components are sensitive to noise and which causes noise, these should then be placed far apart. Next step was to take notes of the components dimension and start making the layout. When this was done it was possible to decide the size of the enclosure. To ensure that the enclosure fits on the bicycle before purchased, measurements were made on the previous bicycles to see what space that was available for attaching it.

For being able to create an optimal solution for the portable attachment information gathering was performed to find different alternatives. These were documented with pros and cons, then the option that best met the criteria was chosen. Then the attachment for the enclosure was constructed in Catia and 3D-printed. After this it was mounted on the back of the enclosure and held on to the bicycle by hose clamps.

To ensure that the hall sensors are no longer needed and thus reduce the components that have to be attached to the bicycle a different way of measuring the velocity had to be created. Which means that the velocity needed to be determined directly from the forward motor. To accomplish this something needs to read the output from the motor and then convert it into velocity. As it is now, the supply of the motor is controlled by a Vedder Electronic Speed Controller(VESC) which is a motor controller. By measuring the current and voltage between the VESC and the motor, it should be possible to estimate the velocity of the bicycle.

3.2 Tools

Various programs and methods were vital in producing and validating the results. These tools are listed below.

3.2.1 CAD program for 3D-modelling

In order to 3D-print parts they first had to be modelled in a CAD-program. The program used for the prints in this thesis is Catia V5 developed by Dassault Systèmes. This program also allowed for producing of files for the laser-cutter which was used to cut out the mounting plates for attaching hardware in both the box and cover.

3.2.2 3D-Printers

The 3D-printers used for all parts in this thesis were from Ultimaker which is a 3D-printer manufacturing company. The printers that were used was both Ultimaker extended S3 for most prints and the Ultimaker S5 for the larger prints. The 3D-model files rendered from Catia V5 were sliced in Ultimakers own slicing program Ultimaker Cura. Slicing allowed for the 3D-models to be read by the 3D-printers. These printers were owned by the Case-lab association.

3.2.3 Continuity testing

Continuity testing is done using a multimeter where the multimeter can be set to the continuity setting. This setting means that a beep will be heard when connecting the multimeter to both ends of a wire or cable. By doing these tests the integrity and validity of the wire and cable is tested to ensure it is capable of leading current from one end to the other.

3.3 Verification and validation

To make sure that the new implementations work as intended many tests had to be made. The validation have been done on the portable attachment and on all the connections made. All tests performed and results from the validation are shown in the following chapter results.

4

Results

This chapter presents the results made during the project. It will first present the general changes in hardware and the new features. Then the new layout for optimizing the electrical system will be explained. After that the constructed portable mount for the hardware-enclosure will be described and all the parts that has been 3D printed during the project. The final part of the chapter explains the validation that has been done.

4.1 Portable attachment

As previously stated the primary goal was to produce a mount which could attach the enclosure to different bicycles models. For that to be possible the same mount had to accustom different diameters of bicycle frames. The mount also had to be relatively easy to attach and detach as anybody should be able to do this in a reasonable time. Previous versions had been welded on and used a locking mechanism which had been limited to a very specific diameter. This was because it only had been designed for being suitable for a single bicycle.

Many different designs were considered but eventually a simple but effective solution was discovered by using hose clamps similar to those shown in figure 4.1. Since hose clamps are adjustable to a certain range of diameters a single hose clamp could fit on multiple different bicycles with varying frame diameters. Even if one hose clamp did not fit it could easily be replaced by a hose clamp either slightly larger or slightly smaller. Which then could increase the range of possible diameters even more.

Figure 4.1: Normal hose clamps in varying sizes. From [17]. CC BY-SA 3.0

The problem that remained was how to attach the hose clamps to the enclosure at the same time as it is attached to the bicycle. The solution to this was a 3D-printed mount, shown in figure 4.2. This mount meant that by being attached to the enclosure the hose clamps could then be opened and put around the mount first and then because of the shape of the mount also fit perfectly on the bicycle, see figure 4.3. The hose clamps could then be tightened around both the mount and bicycle which meant a durable solution which also could fit on many different bicycles.

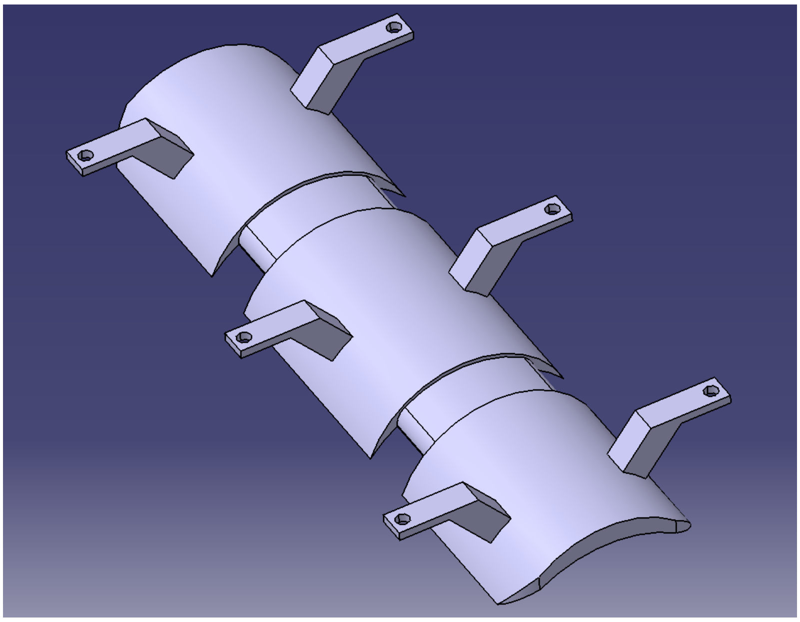

Figure 4.2: The enclosure mount showing where the hose clamps have two tracks to sink into.

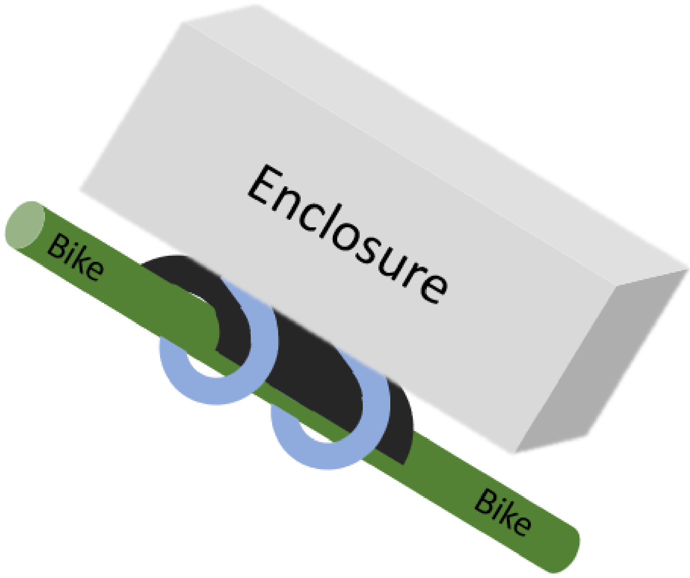

Figure 4.3: The mechanism of mounting the enclosure on the bicycle. The black part is the mount and the blue parts are the hose clamps.

4.2 General changes

This section explains the changes in hardware and other updates made on the new bicycle.

4.2.1 Forward motor

The forward motor used on the new bicycle is HS 2440 designed by Crystalyte Europe. This motor is a high speed brushless motor with direct drive and is mounted on the front wheel. The output range is 250W to 1500W and the voltage range is 24V to 48V. The motor has a maximum current of 40A and a torque range of 40 to 65Nm. The new motor is heavier than the old one with a weight of 5,5kg [18].

4.2.2 Forward motor controller

As stated earlier the previous forward motor controller was the VESC 6 Mk V, however this was an outdated model and was therefore not available for purchasing any longer. This meant a new one needed to be ordered, which was the FSESC 6.7. While this would mean some change to the old bicycle construction it was also an upgrade since the new FSESC 6.7 is based on the VESC 6. Because of this the new forward motor controller was not a major variation from the old version and could then be well adapted and used in the same circuit and set of equipment as the old forward motor controller.

There are some changes and new features on the new FSESC 6.7, the new modes of output for external electronics is now either up to 5V and 1.5A or 3V and 1A. The new features also include an anti spark button. Which is designed for avoiding electrical sparks and thus prevent the power contact from oxidation. Other than the new button there has been new resistors added to the controller and some of the capacitors has change. This is to make the voltage changes more stable and efficient [19].

4.2.3 Connectors

On the red bicycle the wires either went out of the enclosure directly from a drilled hole or through cable glands. This could create unwanted damage on the hardware because of cables getting tightened in the event of the bicycle falling over. Because of this it was chosen to order friction-locked connectors which can be disconnected and thus protect the hardware from wear out and other damages. The new connectors are also more user-friendly when moving the hardware-enclosure to a new bicycle as all the cables can easier be detached. The connectors used are two models, the first one is from the manufacturer Lutronic of the model T22CB100. It is equipped with a quicklock and has 7 contacts. The connector is rated for 12 A and has a rated voltage of 500V [20]. The other connector used is made by Neutrik of the model NL4MP. It is also equipped with a quicklock and has 4 contacts. This connector is rated for 40A and has a rated voltage of 250V [21]. The cables need to be soldered on the contacts when attaching to the connectors.

4.2.4 E-stop box

Every component in the new emergency stop box is from Schneider Electric which includes the box chassis Harmony XALK push button enclosure to which the 2 push buttons and LED are connected. The emergency stop button head is the XB5AT842 Schneider Electric Harmony Emergency Stop Push Button which is a push-pull button unlike the previous button which was a turn to release-button, this part includes both the head and contact block for the emergency stop. This contact block can withstand 10A and has a voltage rating of 600VAC, the temperature range is from -40 to 70°C. The reset button is the same green illuminated push button connected to a NO-contact block as in the previous version. Also the contact block for the LED is the same 24V light block with a green cover as before. All heads are connected to their respective contact blocks with Schneider Electrics collars for the Harmony XB5 series. Every component in the emergency stop box is from or compatible with the Harmony XB5 series which has a high industrial standard of emergency stops and push buttons [22].

4.2.5 USB connector

In the previous construction the enclosure had to be open in order to access the myRIO. To make it easier for the user and provide the opportunity of working with either an open or closed enclosure, a USB connector was mounted on the enclosure. It is mounted on one of the walls of the cover and has a USB socket on the outside and a USB cable on the inside that is connected directly to the myRIO. The connector used is PX0844 which is manufactured by Bulgin. It is waterproof with an IP 68 and is of the USB series 2.0. On one side it has just an USB B female connection and on the other side it has a cable with another USB B male connection [23].

4.2.6 Hardware-enclosure

The largest change is the change of the enclosure or container the majority of the components are placed in. Previously the enclosure was overdimensioned which left a lot of empty space which made it more clunky and difficult if said enclosure were to be removed. This however was also impossible to do in a uncomplicated way as the previous enclosure was welded onto the frame of the bicycle. The new enclosure was chosen after careful planning and measuring what would be the optimal size for a enclosure which still could fit everything from the old enclosure. Previous bachelor students had begun this job in their thesis and had ordered enclosures for just this, however these enclosures had been the wrong size and thus the students had never started with the size optimisation of the enclosure. When comparing the newly calculated dimensions to the previous students there was disagreement between the required sizes as the previous students had done two theoretical enclosure sizes with one of them being a division of the components into two different enclosures [3]. As the goal of this thesis was to make the enclosures easily portable two enclosures would most likely mean twice as much work when mounting and dismounting, thus this idea was scrapped early on. The new enclosure is a waterproof container manufactured by Fibox with the dimensions 360 x 200 x 151mm [24].

4.2.7 PDB

As previously mentioned the old PDB is custom made and there were none in reserve. Therefore a new one had to be manufactured for the current bicycle. The files of the PDB that could be found were of the wrong format and Chalmers did not have any licenses on the software that could convert it. The supervisor for the project then created new files that made it possible to construct new versions of the PDB, which can be seen in figure 4.4. The updated versions is smaller and has a different design but function exactly the same as the previous PDB.

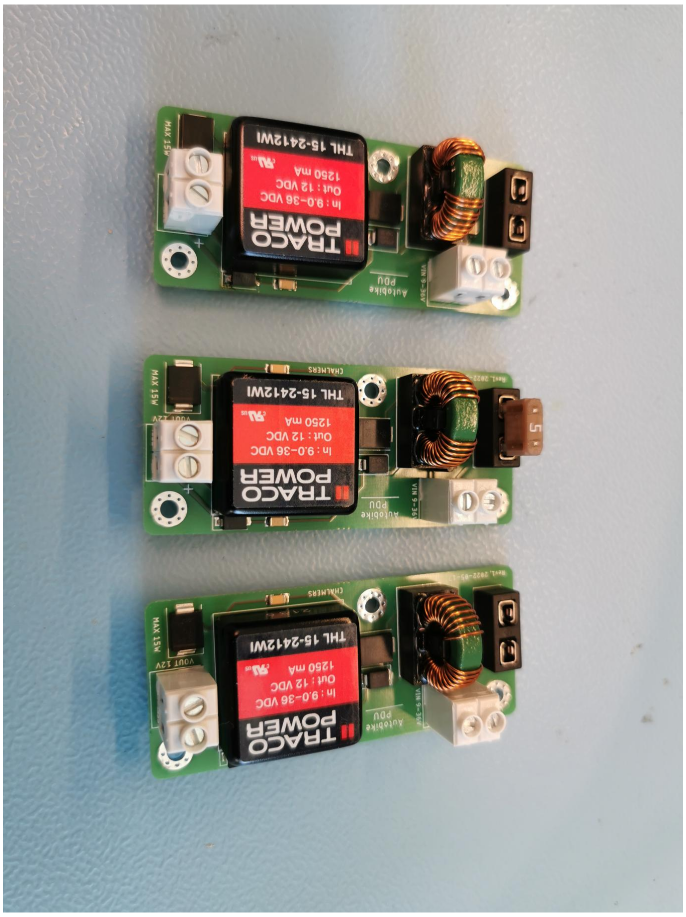

Figure 4.4: Picture of the new designed PDB. It was created two extra for future project.

4.2.8 Mounting plate

To ease the attachment of components, mounting plates in acrylic plastic were designed and then placed inside the enclosure. The plates are attached on the bottom and on the ceiling of the enclosure, then the components is mounted to them with screws. To construct the mounting plates a drawing first had to be made in the software Catia which then could be used for laser cutting.

4.3 New layout for optimizing space

In order to reduce the size of the enclosure and still fit all the hardware a new organization of the circuit had to be done. Before this could be accomplished the components had to be divided into two areas, those that are sensitive to noise and those that emit noise. These should then be placed as far apart as possible. It were then established that the hardware that causes noise are the ones that consume high power, which primarily is the two motor controllers, the power switch and the PDB. The sensitive hardware is instead the ones that handle the signals such as the break out board, the IMU and the GPS module. To then decide the size of the enclosure all components dimensions was needed which is listed in table 4.1.

Table 4.1: In the table all the hardware dimensions are listed.

Component	Length x Width x Height (mm)
Battery	200 x 73 x 62
Microcomputer	136,6 x 88,6 x 24,7
PDB	50 x 24 x 8
Power switch	30,2 x 25 x 25,3
Steering motor controller	115 x 75,5 x 24
Forward motor controller	100 x 92 x 22,5
Relay	84 x 17,4 x 58,4
Circuit breaker	28 x 28 x 38,5
GPS module	44 x 43 x 3
IMU	20,5 x 15,8 x 3,4
Break out board	90 x 80 x 5

In order to make full use of the enclosure it was desirable to use both the bottom of the box and the bottom of the cover for placing components. With that in mind and the knowledge of the dimensions of all components it was possible to start drawing the new layout. This layout is illustrated in figure 4.5.

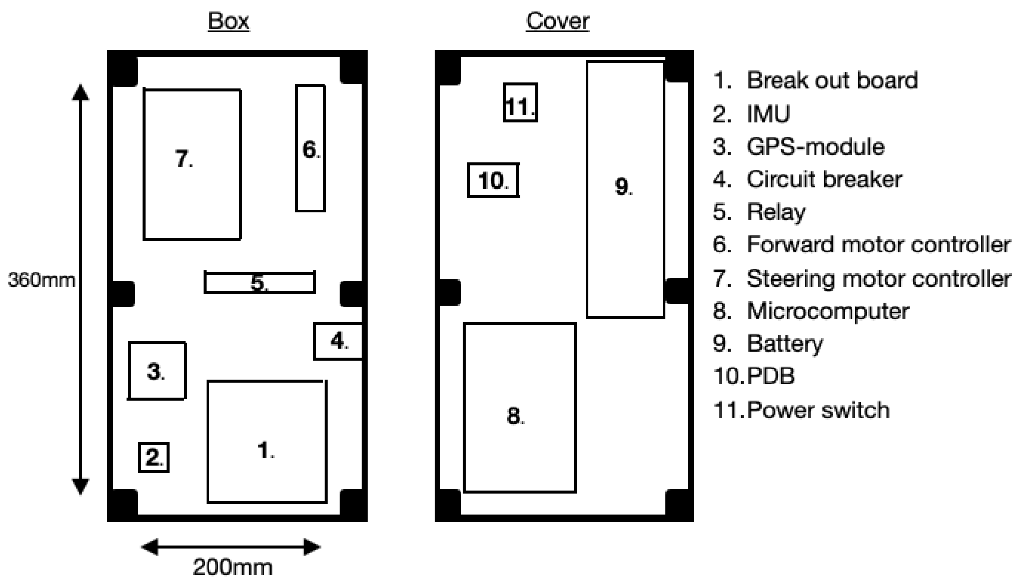

Figure 4.5: The image displays the design of the new layout. The list on the right side indicates were which component is placed.

Figure 4.5 shows the new designed layout where on the left side the box is placed and the cover is placed on the right side, with all the hardware drawn inside. The components that causes noise have been placed in the front of the enclosure and the sensitive components have been placed on the opposite side. After that the layout was drawn, research were made on which dimensions of enclosure that were available. Then the enclosure that had the best fit was ordered, which was a enclosure with the dimensions 360 x 200 x 151 mm. After then constructing the mounting plates that was described earlier in the chapter, the next step was to start attaching all components on the inside of the enclosure. How all components were mounted in the enclosure is shown in table 4.2 below as well as how they were mounted in the previous construction on the red bicycle.

Table 4.2: The table shows the different attachments used for the components.

Component	Old attachment	New attachment
Battery	No attachment	Stripes
Microcomputer	Tape	Screws
PDB	Tape	Screws
Power switch	Tape	Through the ceiling
Steering motor controller	Tape	Screws
Forward motor controller	Screws	Screws
Relay	DIN rail	DIN rail
Circuit breaker	Tape	Through the wall
GPS module	Tape	Screws
IMU	Tape	Printed mount
Break out board	Screws	Screws

As shown in table 4.2, all the components are now put in place with a strong attachment. Which will require the enclosure to be exposed for severe force for them to come loose. This means that the risk of the components becoming damaged in the case of the bicycle falling over or crashing is significantly reduced. The printed mounts that is used for some of the components will be described later in the chapter. Other than that, the power switch and circuit breakers have been mounted through the cover and the walls of the box with the buttons on the outside of the enclosure. This has solved the problem with the old mount were they only were attached with tape and easily could fall of. It also gives the possibility to turn off and on the power supply from the outside of the enclosure which makes it more user friendly.

4.4 Steering motor mount

Another thing that has been constructed during the project is the mount for the steering motor. It has the same functionality as the old one on the red bicycle, but with some parts that differs. The changes made are that the two plates made of metal has been replaced with plates made out of acrylic plastic. These are 8 mm thick and have been made by laser cutting. Other than that the u-bolt that holds the plate against the frame of the bicycle has also been replaced with two hose clamps. The change of material was done because acrylic plastic and a laser cutter were available for usage at Chalmers and thus did not need to be ordered. Which would have been the case with the metal plates. The reason for changing to hose clamps was because they are more adjustable for changes of the size of the bicycle frame than the u-bolts. Which makes them more likely to fit on different bicycle models and thus simplifying moving the mount.

4.5 3D-prints

During the project some problems have occurred with finding suitable parts to establish the wanted functionality.Which meant that new solution had to be constructed. This has been done by designing several constructions with 3D cad which then could be printed. In the upcoming subsections these solutions will be further explained.

4.5.1 IMU attachment

Since the IMU is a sensor for keeping the balance and orientation of the bicycle its ideal placement is completely horizontal. This helps to avoid calibrating offset degrees in order to read accurate data from the IMU. The goal was to incorporate the IMU into the enclosure which was to be mounted at an angle on most bicycles. Which would most likely lead to the IMU always having the same tilt as the rest of the enclosure. This problem was solved by using a 3D-printed mechanism capable of rotating the IMU 150 degrees on one axis as seen in figure 4.6. Which allows the enclosure to be mounted at up to a 75 degrees angle since 150 degrees means the total movement in both directions. This was enough to make the IMU horizontal on both axes as the other axis already left the IMU straight as long as the enclosure was mounted straight. As the enclosure would usually be mounted on to frames leaning at somewhere between 25 degrees and 60 degrees. This meant that the IMU would not have to be re-calibrated on most bicycles. In order to find the angle to set the IMU attachment a spirit level can be used to find the angle where the IMU is at 0 degrees angle. Then the screw shown as the circle with an x in figure 4.6 can be tightened to lock the angle in place.

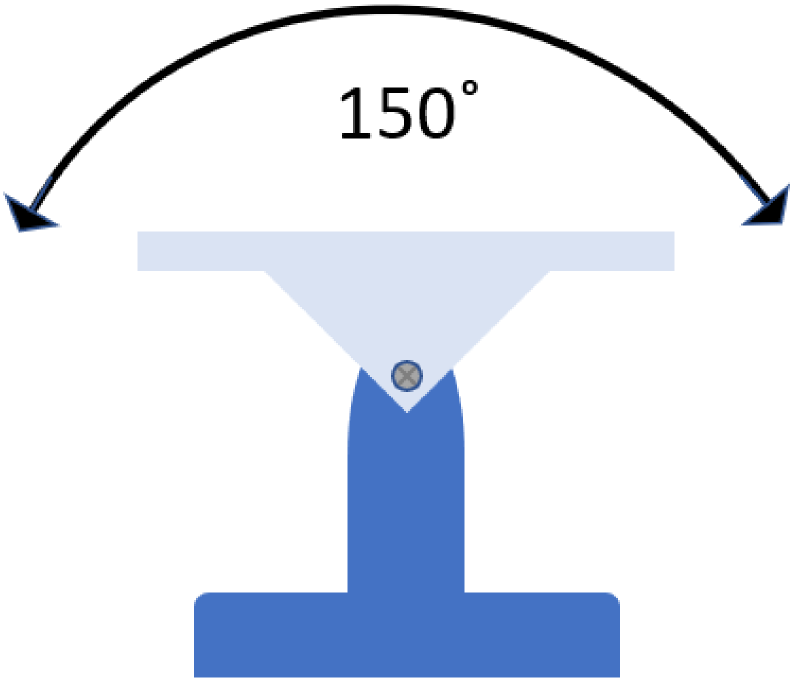

Figure 4.6: Shows the possible angular correction for the IMU where the light blue indicates where the IMU is mounted and what part that turns.

4.5.2 Hinges

The new enclosure consisted of a box with a separate cover which was possible to fix together with included screws. However when doing the layout of the enclosure the cover was included in the plan. As some of the components could be attached to it in order to use more of the limited space of the enclosure. This meant that there would have to be wires going between the components placed in the box and the components placed in the cover. In order to be able to open the enclosure without accidentally pulling anything out the cover and box would need to be closed by and opened very carefully each time. To make opening of the enclosure easier and more protected from wires being pulled out an idea of using hinges on one side originated. This would mean that the cover and box always would be connected and be easily closed and opened. All without accidentally pulling out wires. Since if the wires were long enough when the enclosure was opened they would never have to extend any more. This also meant that the screws could still be used to make sure the enclosure was completely closed.

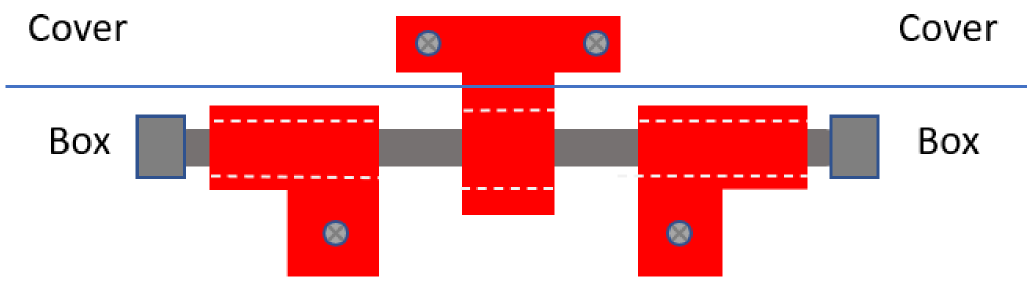

Figure 4.7: Shows the hinges mounted on the box and cover, notice the oversized holes and distance between the parts.

As seen above in figure 4.7 the idea with the hinges was mainly just to keep the cover and box connected and not to perfectly keep them lined up. Because of this the holes made for the axle was made much larger than needed, in order to be able to adjust the cover and line it up with the holes for the screws. In addition to this, by placing the hinges parts with distance between them, it allowed for moving the cover sideways to make sure the cover always could fit perfectly on the box. The part of the hinges mounted on the box was made with two sides having a 45 degree angle, this is to help alleviate stress on these parts when being pulled in those directions.

4.5.3 Timing belt pulleys

Figure 4.8: A typical but small timing belt pulley. From [25]. CC BY-NC-SA 2.0.

The previous timing belt pulleys were bought and made of metal similar to figure 4.8 except much larger. However because of a lack of documentation these same pulleys could not be found. They had to have a specific hole size for the locking bushes to fit which made them hard to obtain. The solution to this was to 3D-print new ones, this would mean they could be customized and be made in any way that was needed. The requirements for the pulleys came from the timing belt having a specific number and size of teeth or pitch as the distance between the belts teeth was called. The new timing belt pulleys were then made with the same pitch and teeth that would fit the belt. The other requirement was the size of the locking bushes had to fit into the the pulleys hole. This could easily be done in the 3D-modelling program for both locking bushes. The last important requirement was the durability of the pulleys, since the old ones were metal and the new ones plastic filament. The plastic filament used for the pulleys was Acrylonitrile butadiene styrene (ABS) which is one of the stronger filaments. Which is also very common in most modern products, even being the material of the classic LEGO bricks are made from [26].

4.5.4 FSESCC-Mount

In order to ensure all components fit inside the enclosure some of the components would need to be placed in different orientations. Such as sideways or upside down for example if they were placed on the cover. One such component was the FSESC forward motor controller which was planned to be placed against one of the long-side walls orientated sideways. The FSESC already have four holes on the backside for attachment as seen in figure 4.9. Instead of mounting the FSESC to the wall directly. Which would mean more holes in the enclosure and would lead to difficulties when placing the mounting plate in the enclosure. The idea was then to place the FSESC directly on the mounting plate. However as the FSESC did not have the holes on the side a special mount had to be designed. By designing a L-shaped mount as seen in figure 4.10 the FSESC could be attached to the large vertical side and the small horizontal side could be attached to the mounting plate.

Figure 4.9: The backside of the FSESC with 4 mounting holes.

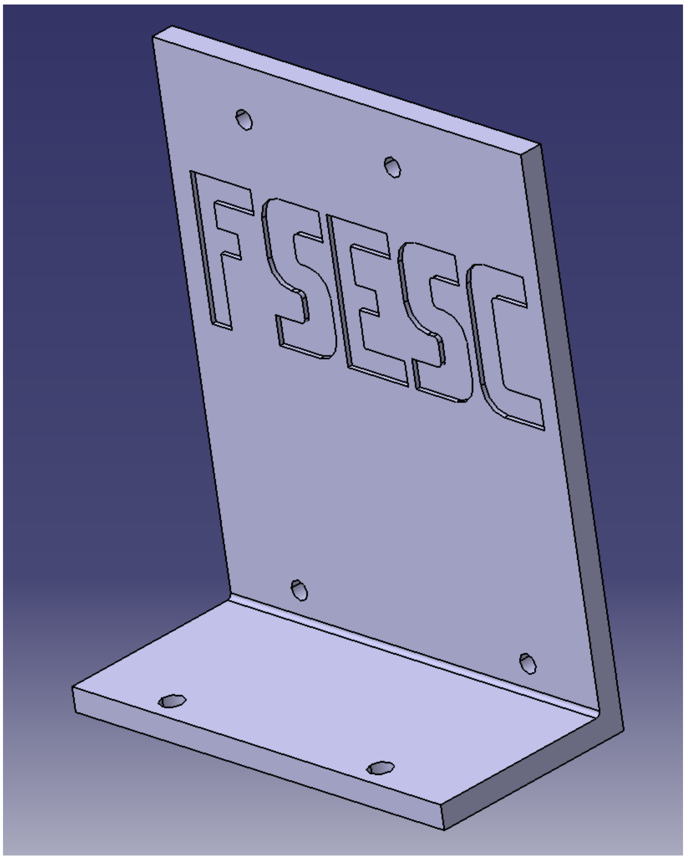

Figure 4.10: The FSESC mount without the FSESC mounted on.

4.5.5 Power switch mount

The power switch seen in figure 4.11 was, unlike the circuit breakers and connectors, not a round part but instead of a rectangular shape. Which could not be inserted into a drilled hole in the enclosure. In order to be able to access the power switch without opening the enclosure a new solution needed to be made. The idea was then to drill a hole in the enclosure big enough to bring the power switch through. Then create a thin 3D-printed plate with a rectangular hole in the center that would be adapted for mounting the power switch. The 3D-printed plate could then be mounted with screws on to the enclosure. The created solution is seen in figure 4.12.

Figure 4.11: The rectangular power switch used in the circuit.

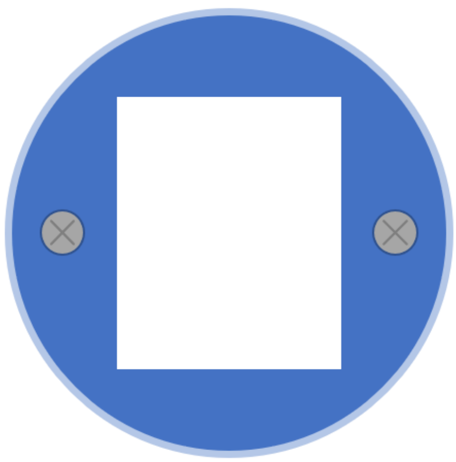

Figure 4.12: The mount for the power switch showing the central hole for the power switch.

4.6 Validation

In order to ensure the changes and results obtained were beneficial and actual improvements, validation tests had to be done. These validations had to prove the changes made had the desired effects that were set up beforehand. Each validation was done independently in order to get the most accurate and trustworthy results. Due to a lack of time the validations did not all have time to be cross validated and in cases only were tried once.

4.6.1 Universal enclosure mount validation

The main tests for the universal mount was to ensure the claims of fitting a variation of bicycles and being sturdy enough to validate the use of hose clamps. The enclosure could be mounted on at least 2 different bicycles and was also tested on poles of varying diameters which all validated the claims of a universal mount set up in this thesis to a certain degree. The enclosure will not be able to be mounted on every single bicycle however as bicycles can vary a lot and some just do not fit the enclosure even though its size. The claims of being easy to mount was also tested with two different tests. First test was to measure the time it took to mount and demount the enclosure in order to see if it was reasonable to move the enclosure between bicycles. The results was deemed acceptable since it would need to take some time in order to ensure the enclosure was mounted correctly and tightly. The other test to validate the simpleness of mounting it was to provide instructions to a third part which had never mounted the enclosure previously and see if they could manage to successfully attach and detach the enclosure. This turned out pretty well and was considered a success and allowed for improvements to be made to help further reduce complexity of mounting the enclosure. As for checking if the enclosure was sturdy and durable enough different stress tests were done. First this was to press and kick the enclosure in order to see if the hose clamps were sturdy enough. Secondly to roll the bicycle around and tilt the bicycle and watch the effects on the enclosure. Both these tests were completed with perfect results and was therefore approved.

4.6.2 Layout validation

As the layout was not completely finished and lacked a steering motor and connection to the forward motor the entire circuit could not be tested which would be the easiest test to verify the results. Instead every wire and cable was continuity tested which could verify that every wire and cable was transmitting from one end to the other. This along which extensive checks that every wire was connected correctly should mean that with a very high probability the circuits connections and layout should work.

Table 4.3: In the table all the validations that has been done is listed.

Testing on	Requirement	Validation	Pre-condition	result	Pass/ Fail
Portable mount	Fit on different frame sizes	Mounted on two different models	Attach the mount with the enclosure on two bicycles	The mount could be attached to both bicycles	Pass
Portable mount	Easy to attach and detach	Attaching and detaching mount under 15min	Attach and detach while taking time	Mounting time was inside time interval	Pass
Portable mount	Strong hold	Manually put force on the enclosure	Push and pull the enclosure in all directions	Did not move	Pass
Connections	Continuity on all cables	Check continuity on all cables	Use multimeter for continuity testing	All cables had continuity	Pass
Steering motor mount	Plastic plates not flexible	Manually put force on the plastic plates	Try to bend the plastic plates	Was not flexible	Pass
Steering motor mount	Strong hold	Manually put force on the mount	Push and pull the mount in all directions	Did not move	Pass

5 Conclusion

In this chapter conclusions from the results have been made. This is followed by what has not been achieved during the project and lastly what could be done in the future is suggested.

5.1 Achievements

The main purpose of this project has been to create solutions that make it easier to move the hardware and mountings to new bicycles of different models. Which is considered accomplished. The biggest change that has been done to improve the mobility is the portable attachment for the enclosure of the hardware. Which means that the hardware enclosure can be moved to a new bicycle model in a short amount of time. However, before changing to a new model there are two things to look up first. If there is enough space on the new bicycle and if the hose clamps fit on the frame size. The current hose claps used can be adjusted between 40mm to 55mm. Which should be enough for most bicycle frames. It could be an idea to purchase hose clamps of smaller and bigger size to have in reserve to make sure that there is always possible to move the enclosure. The detachable contacts also make the transfer of the connections smother and less time consuming. Other then that the adjustable mount for the IMU removes the need to find a new placement for the component or rewriting the code.

The steering motor mount has also become more portable as the change to hose clamps makes it less sensitive to varied sizes of the bicycle frame. There are now also two alternatives to recreating the plates for the mount. Which means that it is possible to choose which method is the least time consuming to get hold of at the moment. The new layout for the hardware has also made it possible to reduce the size of the enclosure significantly. The construction has also become more user friendly as several of the components can be accessed with the enclosure closed. What has been made accessible from the outside is the power switch, circuit breakers and the microcomputer.

5.2 Left to be done

During the project it was desired to find a solution to measure the speed of the bicycle without hall sensors. This has not been accomplish due to lack of time. The research that have been made indicates that it should be possible to configure the forward motor controller and obtain the speed from it. The configuration is done by using the software VESC tool which can be downloaded for free from the internet.

The electrical system is not fully complete as there are still some orders that have not been delivered yet. For more information about the missing parts refer to appendix A. What is left to be done when the missing parts arrive is the following.

- Change the connections to the forward motor and connect it to the hardware-enclosure.

- Assemble the mount for the steering motor and connect the cables to the hardware-enclosure.

- Configure the motor controllers and load code into the myRIO in order to test the new bicycle.

5.3 Future development

When the bicycle has been completely assembled physical test needs to be made. To make sure that all the new hardware and connections work as planned. Tests that could be done is for example to transmit a signal with a desired angle and see if the same angle is received. Another possible test is to accelerate and decelerate the forward motor and examine if the speed changes as expected.

As the enclosure has been made smaller which means that all the hardware is placed closer together than in the red bicycle. Test should be made to examine if the interference has increased. If the interference has changed it is also necessary to control if the desired signals still is received correctly. Measures to reduce eventual interference could be to put up a shielding wall between the sensitive hardware and the high power ones to make them more separated and protected from each other.

The 3D-components produced in this thesis are all prototypes and could most likely be improved as these are mainly proof of concepts. If the 3D-prints are acceptable and desirable to keep they should instead be made in a SLA- or SLS-printer as these printers offers both more durability and detail than plastic filament printers.

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Appendix 1

A.1 Ordered part not delivered

Table A.1: In the table all the missing parts are listed

Part	Part number	Comment	Ordered from
Connector M	302-38-333	Forward motor	ELFA
Connector F	302-38-330	Forward motor	ELFA
Locking bush	754-2542	For the handlebar	RS
Steering motor Gear head	DCX32L GPX32Hp	Steering motor and gear head are delivered assembled	Maxon

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