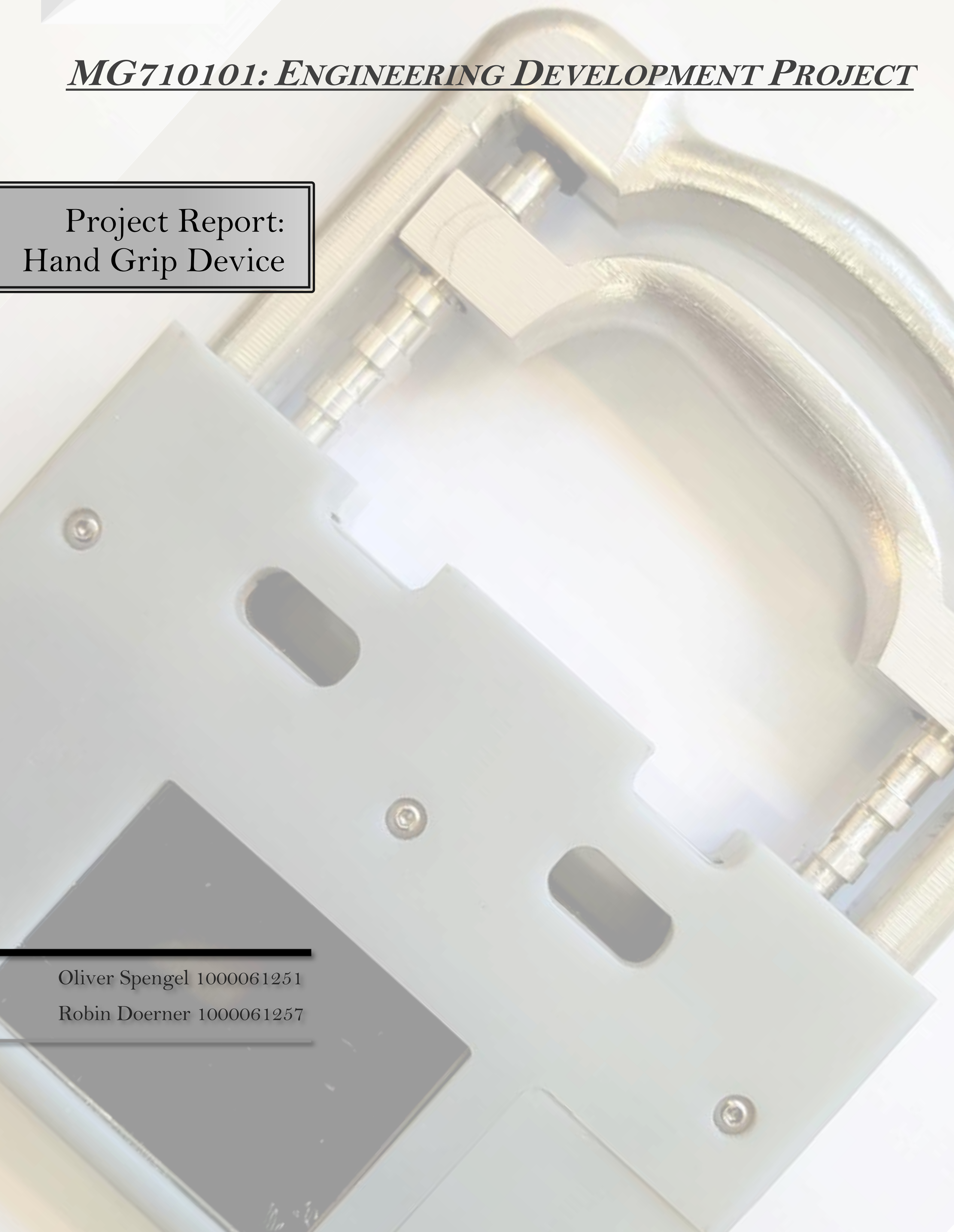
MG710101: Engineering Development Project



Project Report: Hand Grip Device

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1. INTRODUCTION

1.1. STUDENTS BACKGROUND

We are two international students from Germany, currently studying mechanical engineering at Reutlingen University. We are in our fifth semester (third year), the “practical” semester, which entails an internship of 95 days for an engineering company. However, we have chosen instead to spend a semester abroad at our partner university, Otago Polytechnic.

In consultation with our supervisor at Otago Polytechnic (Dr. Matthew King) we decided to work on the hand grip project; developing a new functional prototype of hand grip device, the primary goal of which is to be able to replicate the results achieved by an original calibrated Jamar hydraulic handheld dynamometer.

The following report details the time taken, which aims were pursued, problems we faced and our solutions.

1.2. PROJECT BACKGROUND

Grip strength is the ability of the forearm and the hand to exert a force squeezing the hand or individual fingers (Wikipedia, 2018). Grip strength not only increases overall strength and athletic performance, it is important for everyday activities. Measuring grip strength helps in assessing overall strength and fitness, identifies potential deficits and tracks improvement through rehabilitation after injury. It can also be used to establish realistic treatment goals for hand and wrist injuries. In order to take advantage of these benefits a reliable device is required to run grip strength tests. The device must be able to deliver results that are both accurate and reproduceable. Because the Jamar hydraulic handheld dynamometer brings these two qualities mentioned with it, it is used in many studies.

Jamar hydraulic handheld dynamometer devices are no longer being produced, which has left the industry unsupported. Companies stepping into the gap include ErgoKMF, which is making improvements in gathering data and user interaction. ErgoKMF has approached the Otago Polytechnic (Dr. Matthew King) in Dunedin, New Zealand, to help develop equipment. The result is an engineering project that allows students to apply and put into practice their engineering skills. (Internet Scientific Publications, 2014)

Figure 1-1 Jamar Hydraulic Handheld Dynamometer

2. BASIC INFORMATION

Before going into details of research, design, construction and production of our prototype this chapter is meant to give an understanding of the basic functionality of the product and explains the various parts included in the device.

2.1. GENERAL FUNCTIONALITY

Measuring the grip strength electronically gives many advantages compared to a hydraulic system. To begin with the device can calibrate itself every time it's turned on. Also, all the data can be recorded, saved, exported and evaluated as required. Additionally, programmes can be added to the software to increase the number of measurement processes e.g. to measure strength endurance.

By squeezing the hand, the adjustment poles connected to frame and handle are moved slightly upwards. The metal bar is not only screwed to the frame in the middle but also connected to the two adjustment poles at both ends of the bar. Hence, an upward movement of the poles applies a load on the bar forcing it to bend on both sides. The bending of the bar can be measured and calculated into an equivalent weight on the handle.

2.2. NOMENCLATURE

To create a well-structured and easy understandable naming we decided to define a nomenclature for all parts of our product, as well as the tools and resources used during the design and production process. The following illustrations and descriptions define all terms used.

The parts were structured into the following sub-assemblies:

- **Mechanical parts**
- **Electrical parts**
- **Housing parts**
- **External parts**

MECHANICAL PARTS

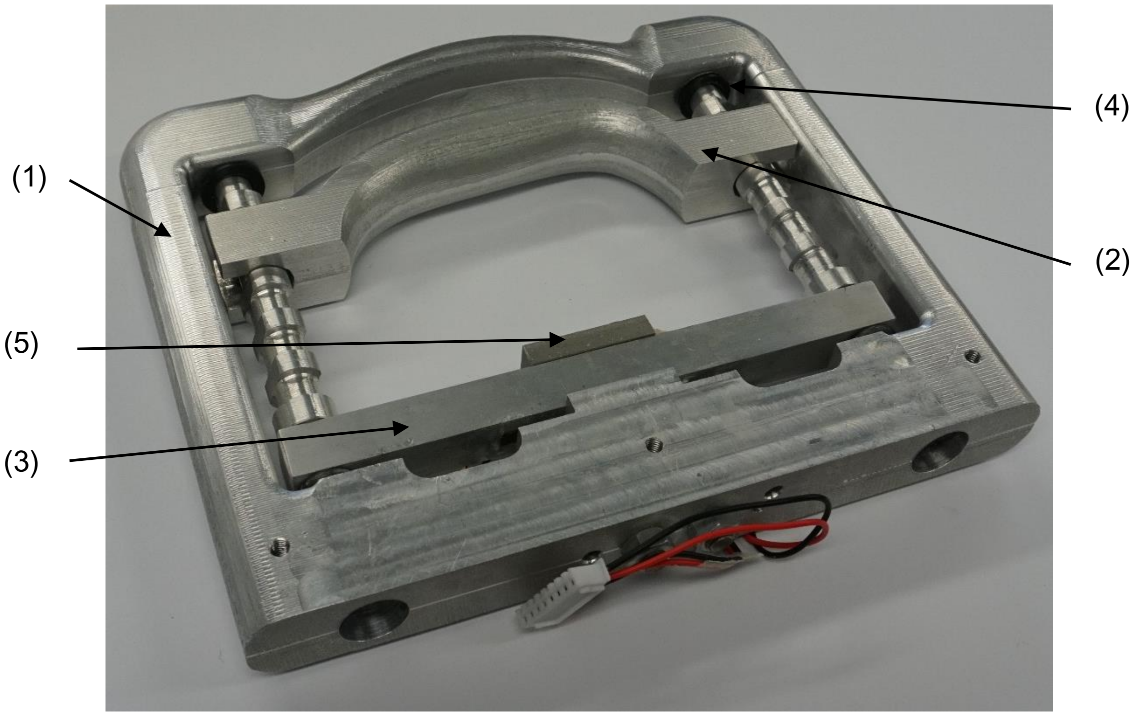


Figure 2-1 Mechanical Parts

(1) Frame: This consists of the upper part of the grip and main body and is also what the measurement bar is mounted on. It holds the mechanical components together. Additionally, it is the base for the housing parts.

(2) Handle: The lower part of the grip, the handle, is set on the adjustment poles and transfers the load from the hand into the device by pulling on the adjustment poles.

(3) Measurement bar: The measurement bar is the connecting part between the two halves of the grip. It is the most important part of the mechanical system and creates a measurable strain from the load.

(4) Rubber bushing: Small insert in the upper part of the frame. It reduces friction and keeps the adjustment poles rotatable in the frame.

(5) Support plate: creates a defined edge on the bar, to abstract the stress condition in the bar to approximate it to a calculatable stress model.

(6) Clip: To easily turn the adjustment poles by hand, there is a plastic clip on each of them. This clip is also just to lock the poles ones turned into the right position.

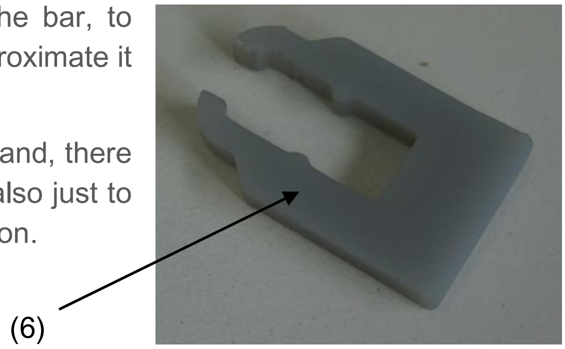


Figure 2-2 Clip

ELECTRONICAL PARTS

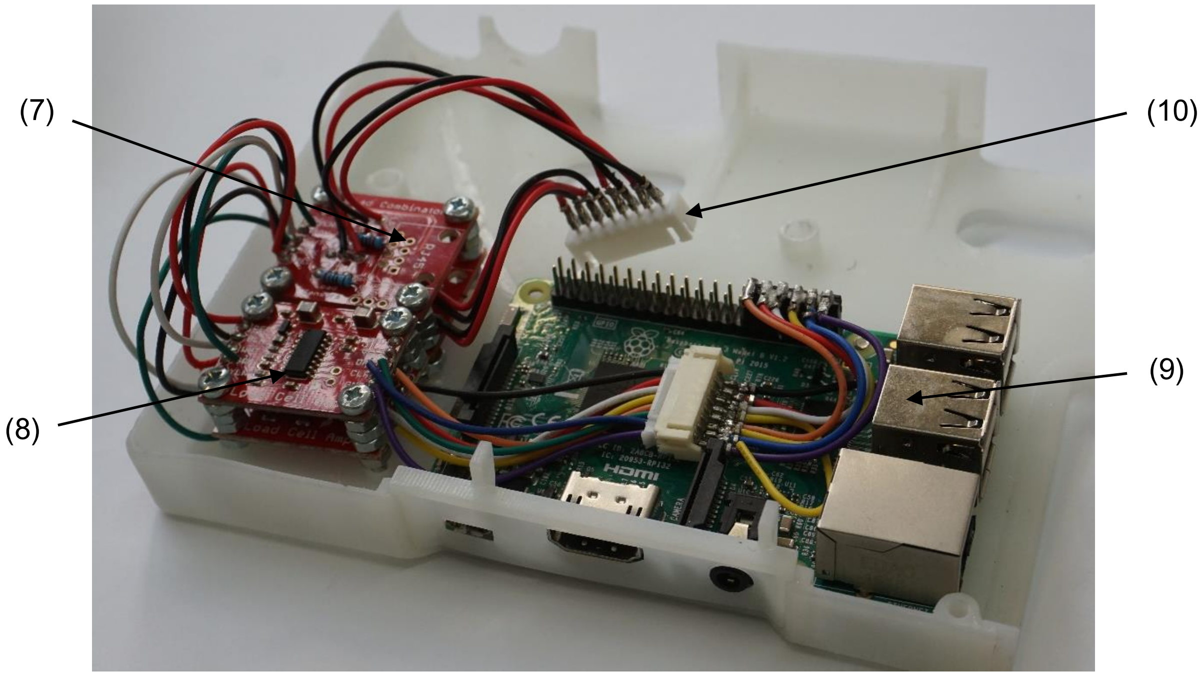


Figure 2-3 Electronic Parts

(7) Load cell combinator: The load cell combinator includes the Wheatstone bridge and is attached to the strain gauges and to the HX711

(8) HX711: This device combines an amplifier and an A/D-converter

(9) Raspberry Pi: single board computer to process the data and interface with the user

(10) Partition plug: These plugs keep parts of the electronic system separate

HOUSING PARTS

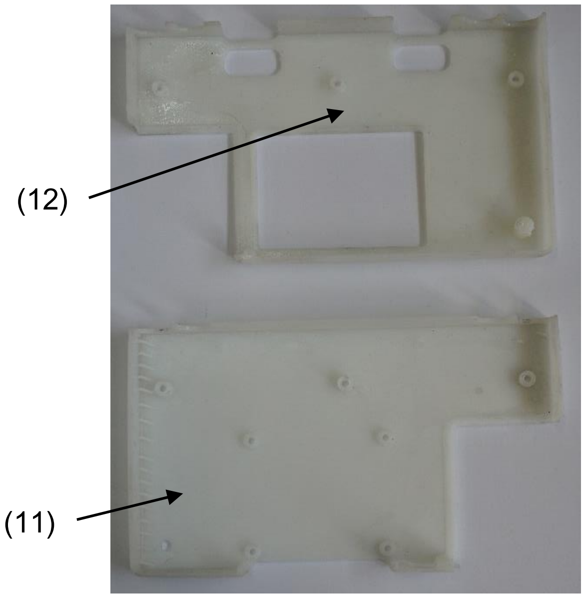


Figure 2-5 Front & Back

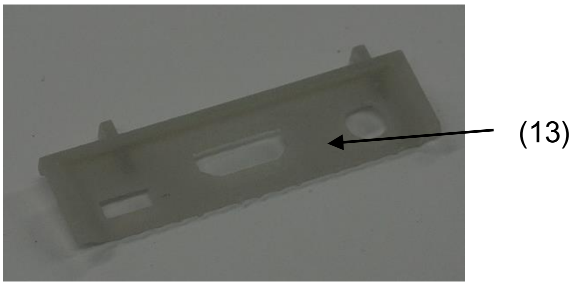


Figure 2-6 Port Cover

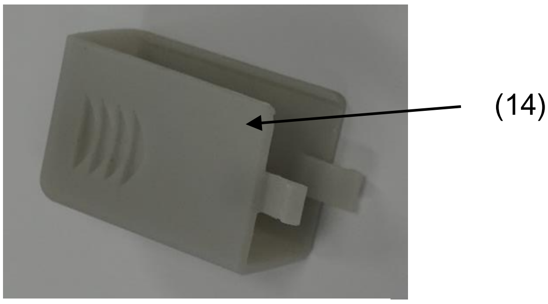


Figure 2-4 Cap

(11) Back: This housing part has special importance because all the electronic parts are mounted on it. The back defines the overall size of the housing.

(12) Front: The dimensions of the front housing part refers to the back. It mainly covers the parts inside and provides the frame for the LCD-display

(13) Port cover: The port cover offers access to the micro USB, HDMI & A/V-port of the Raspberry Pi

(14) Cap: covers the USB & network ports and gives access

(15) Spacer: defines the distance between the boards to prevent contact.

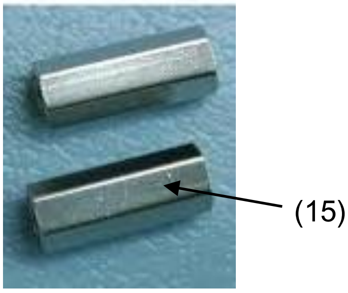


Figure 2-7 Spacer

EXTERNAL PARTS

(16)

Figure 2-8 Drill Guide

(16) Drill guide: Steel blade, clamped into the frame to guide the drill to reduce radial offset

(17) Arduino board: Improvised board to get a first reading in the testing phase to see the characteristic curve of the strain gauge

(18) Jig: Mechanic Construction to put a defined load on the bar for tests

(19) test bench: Combination of jig and Arduino board for testing measurement bars

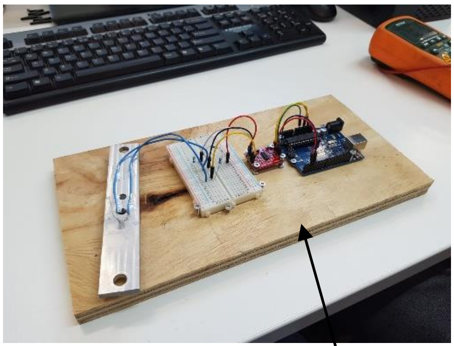
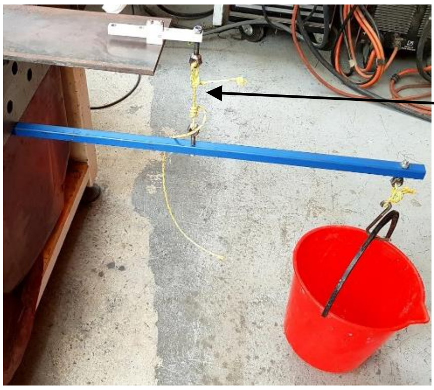


Figure 2-9 Arduino Board



(18)

(17)

(19)

Figure 2-10 Jig

(20) Patient: Person that needs their grip strength tested

2.3. GROUNDWORK

As already indicated in the introduction, we did not start the project from the very beginning. The first steps have already been taken and a first model has been built on the base of which the principle of operation has been explained to us. A basic idea of the device already existed, such as the rough shape of the handle and the frame and also the position of the bar. Therefore, we were limited in the design of the device and kept on developing from the previous status.

2.4. OBJECTIVES

In order to make the idea of getting a functional, calibrated prototype, that is ready for operation, real by the end of the semester, the developing process has been broken down into four smaller tasks to be focused on:

- Create a measurement system able to recognize the change of resistance of the strain gauges, convert and display the force a person is pulling with.
- Manufacturing the frame and the handle after improving their design, including shape, dimensions and material
- Design a housing on which the electronic parts of the measurement system are mounted on and that protects the measurement system, bar and strain gauges
- Define the Material and the dimensions of a bar able to elastically deform itself when a specified amount of force or rather a specified range of operation is applied

3. RESEARCH

This research topic is not dealing with all the research we had to do during the project, but it is dealing with the general topics. More specific research themes, like the electrical functionality of strain gauges will appear in the according topics in chapter 4. Design Phase and chapter 5: Testing Phase.

There were some main problems we had to deal with in the beginning of the semester. Because we are not only from another academical institute, but from a whole different continent, we took quite a time to get used to the work conditions at the Otago Polytechnic. To make sure we don't start and work into the wrong direction, we tried to specify the target product as good as possible. We also got in touch with a lot of staffs and students at the Polytech, who were meant to play an important role in the project later on.

At our university, we used Creo 4.0 for CAD and simulation work, which is very different to SolidWorks 2017. Therefore, we took a lot of time to get familiar with SolidWorks and the included simulation program, to be able to work with the program in a professional way. Most of this was done with learning by doing, online tutorials (e.g. on youtube.com) and support by William Early, a learned industrial designer and staff in the Epicentre workshop in A-block.

Another point was the working in the Epicentre workshop. There a several different machines, e.g. a lathe, a manual mill, a drilling machine, several 3D-printers, a chop saw we would have to use to build our prototype.

ATTACHMENT OF STRAIN GAUGES

The quality of the adhesive bond between strain gage and measurement object is of crucial importance for the accuracy of the measurement. In order to achieve a good bond it is recommended to proceed according to the following scheme:

- <u>Surface preparation</u>:

  define the position the strain gauge is glued on the measuring object. Remove dirt or other remains by grinding the surface with sandpaper. Clean the surface with a solvent to free it from any fat (acetone or isopropyl alcohol).

- <u>Mark the strain gauge position</u>:

  Mark the strain gauge position with a ruler and a pencil. Do not use a scribing needle or anything else that can scratch the measuring object. Do not touch the spot with your fingers.

- Gluing:

  Grab the strain gauge at the connection wire with a pair of tweezers and place it in the right position. Cover it with a piece of Sellotape. Fold the Sellotape together with the strain gauge upwards carefully and spread some glue on the marked position. Fold strain gauge and Sellotape back and press the strain gauge to the measuring object for one minute.

- Check the adhesive bond:

  Remove the Sellotape when as soon as the glue is hard and check the adhesive bond with the help of a magnifying glass. Check the position and check whether the strain gauge carrier is glued over the entire surface.

- Cover the strain gauge:

  Protect the strain gauge from environmental influences using special covering products that are optimally adapted to the conditions.

- Final inspection:

  At the end of the strain gauge installation, each measuring point must be checked once again for strain gage resistance and insulation resistance. For this purpose, the individual strain gage cables are connected in succession to an ohmmeter or a suitable strain gauge measuring device.

(Preusser Messtechnik, 2018)

ANTHROPOMETRIC DATA

To design, construct and test the measurement bar properly, the requirements for the bar must be known first. The force or the force range must be defined the bar is loaded with. The demand is that the bar should be suitable for measuring the grip strength but also for higher loads, for example loads that emerge when a deadlift is performed. However does the bar not have to be able to withstand world records but should be able to withstand the weight that a moderately trained person can lift. Hence, research is carried out on the internet for anthropometric data about people, grip strength and the force applied when deadlifting.

Definition of anthropometry:

Anthropometry is the science of the determination and the application of the dimensions of the human body. (Wikipedia, 2018)

Reading through numerous reports and studies dealing with measuring and gathering data from people about their grip strength, it can be said that the average grip strength of man is about 50 kg and the average grip strength of women about 25 kg. Therefore the bar must be constructed to get an accurate reading within a range from 10 kg to more than the average grip strength of man, namely up to 60 kg. According to get an idea what the amount of weight a person with a moderate fitness level can lift statistics about human body mass have been looked at. 50% of all men weigh 80 kg and 95 % of all men are weighing less than 96 kg. Furthermore research on fitness websites has been made to see how much weight people with the mentioned body mass attributes can lift. Men with these body mass attributes and a moderate level of fitness should indeed be able to lift up to 150 or 180 kg. A moderate lifter can be considered Stronger than 50% of all lifters. A moderate lifter has trained regularly in the technique for at least two years.

4. DESIGN PHASE

This section deals with the design phase of several sub-assemblies of the hand grip. In order to deal with all the aspects of the thematic design processes, we have divided this chapter into the following sub-themes:

- Measurement bar
- Electronic system
- Frame and handle
- Housing

4.1. MEASUREMENT BAR

There was one main requirement for the measurement bar: It has to be strong enough to withstand any force that will be put on the device (with ordinary usage) and on the same time deform enough to get a good reading out of the strain gauges. The more the measurement bar deforms elastic, the more the strain gauges deform and the more accurate will be the signal. In the same time, it has to be thinner than the frame to make sure it can't touch the housing and as low as possible to give enough space for the user's hand.

The first step in our construction process, was to figure out which strain range the strain gauge need to work properly. We found out that most of the strain gauges can easily withstand a strain of 2%, which is more than aluminium and steel can handle over time.

In the next step we had to define the dimensions given by the first model, to figure out in which range we can change the dimensions.

We created a CAD model in SolidWorks to go through simulation with different variants (thickness, width, length…). One big problem were the limited possibilities with SolidWorks simulation because we only have a student license for the program available on the computers we used.

We were not completely sure, whether the simulation, the way we set it up is realistic enough, so we created the same part again in Creo 4.0 simulate, an add-on for PTC Creo Parametric (Figure 4-1) to compare the results of both programs.

Figure 4-1 PTC Creo Parametric (ptc.com)

In order to define the Material and the dimensions of a bar able to elastically deform itself when a specified amount of force or rather a specified range of operation is applied, we reconstructed the bar from the first model.

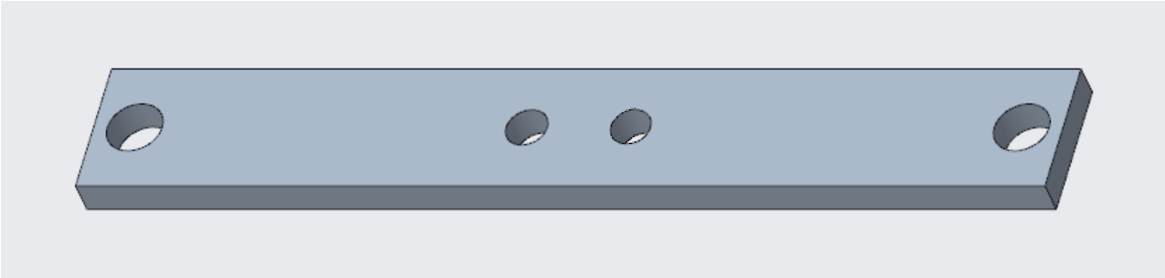


Figure 4-2 Measurement Bar Design 1

The simulation of the bar showed that the tension on the screw holes is too high. For mechanical optimization, we have thickened the middle of the bar and made a smooth transition to this thickening in the form of a radius to minimize the notching effect. This measure was taken to reduce the tension at the screw holes to virtually zero. Because the tension curve can't be represented mathematically, some attempts to estimate the tension curve were necessary, which is very time-consuming.

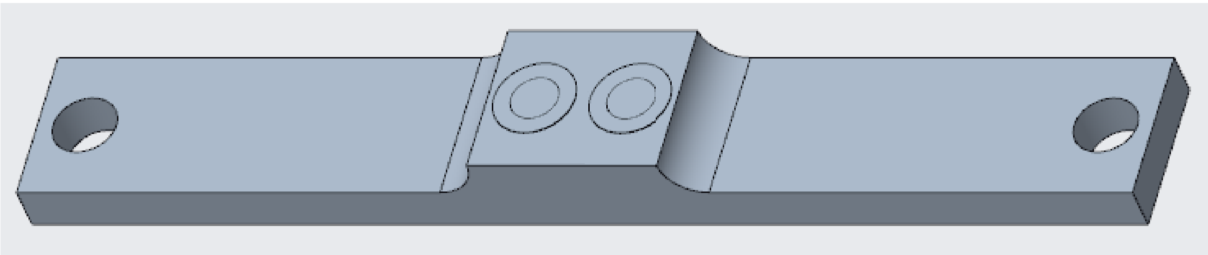


Figure 4-3 Measurement Bar Design 2

There is one problem with bar design 2. As we have figured out during the production of the bar, the manufacturing effort is way too high. Waterjet cutting the bar, drilling the holes and producing the thick middle part including the radius with the conventional mill is simply to intricate, which is why we had to resort to rod material. Also as we figured out during the testing phase, the accuracy of the bar is more than necessary. Nevertheless, the problem that the tension at the drill holes is too high must be solved. Our solution is to mount a separate plate of steel on top of the measurement bar using the same two screw holes to support the bar and to increase its stiffness. The same plate is needed on the bottom side of the bar to make the simulation and a testing realistic but is not needed in the hand grip since the construction of the frame takes that into account. Another challenge was to estimate the strain over the course of the beam so as to produce a sufficiently strong signal for the strain gauges, but also to have sufficient strength. As you can see later in the report in chapter 5: Testing Phase, the strain of all the bars, we tested was high enough for the strain gauges to detect.

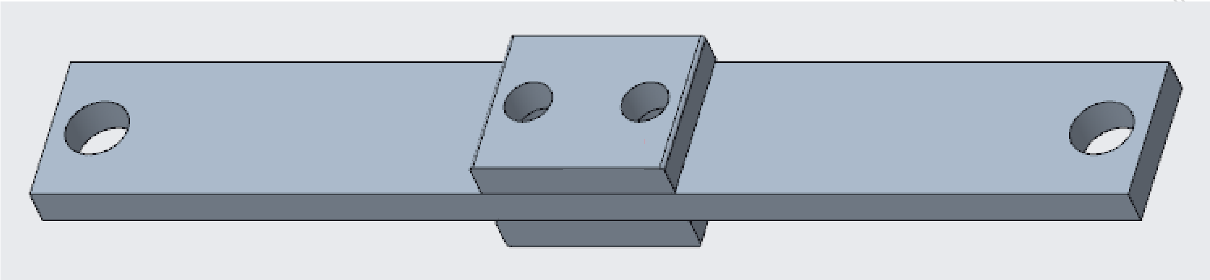


Figure 4-4 Measurement Bar Design 3

4.2. ELECTRONIC SYSTEM

In the beginning of the project a few specifications were given about the electronic system. Therefore, the force to be measured is transformed into mechanical strain (deformation of the measurement bar), the first specification was to use strain gauges to convert the measurement into an electric signal. To use a Raspberry Pi for digital signal processing and displaying a result was the second requirement. As additional requirement the device should have an independent power source included to increase the usability.

But before we were able to start designing the electronic system, we had to figure out the functionality, different characteristics of strain gauges and the problems we would have to deal with regarding the accuracy we want to achieve. Since the strain gauges wouldn't only affect the electronic system, but also the design of the bar and thus the dimensions of the whole device, we agreed on gathering as much information about strain gauges as needed, before we start any design step.

A strain gauge in general can be described as a variable resistor, so the output signal you get by putting strain on the strain gauge is a change in its electrical resistance. To convert the resistance change into a voltage change you use a Wheatstone bridge.

There are several characteristics you need to look at, choosing the right strain gauge for your application:

- Strain gauge material: The resistance change observed during mechanical loading of the strain gauge is caused by the geometric deformation of the measuring grid and by the change of the specific resistance of the measuring grid material. Different strain gauge materials give different values for the sensitivity of the strain gauge.
- The maximum extensibility of the strain gauge depends on the extensibility of the measuring grid material. Further dependencies exist due to the adhesive and the material of the carrier material. The values of the maximum extensibility are typically in the range of a few thousand µm/m up to 50,000 µm/m at room temperature.

- Strain gauge resistance: The nominal resistance of a strain gage is the resistance measured between the two ports without stressing the strain gage. Typical values are 120, 350, 700 and 1000 Ω. The right resistance: The choice of resistance depends on the conditions of the measurement task. 120 Ω strain gauges are relatively insensitive to variations in insulation resistance. The advantage of higher-resistance strain gauges is that they generate less self-heat. They are also less sensitive to ohmic resistances in the connecting cables. The disadvantage is that they can be more sensitive to receiving glitches.

The Wheatstone bridge is supplied with normally up to 5V and is made of two paths. The right path consists of two equal solid resistors, so the voltage in the middle drops to 50% of the supply voltage. The left path consists of a solid resistor and a variable resistor (in this case a strain gauge), who should have the same base resistance, so in unloaded situation the measured voltage between both paths is be zero. You call this structure a quarter bridge because of one variable resistor. If the strain gauge changes its resistance, the voltage measured between the paths changes proportionally. If you replace the one solid resistor by a second strain gauge, you call it a half bridge. A big advantage is the self-compensation if both strain gauges change their resistance in the same way. Another advantage is the higher resolution if the resistance changes inversely proportional.

One main thing we figured out during research, is that using one strain gauge wouldn't work. Because the device must be usable at any time and many different places, we need to compensate an effect, called thermal expansion, which is caused by changes in the ambient temperature and results in a displacement in the measurement bar according to the following formula:

$$\boxed{\Delta l = l_0 \cdot \alpha_k \cdot \Delta T}$$

To achieve the temperature compensation, we chose building a half bridge instead of a quarter bridge. The first strain gauge will be glued on top of the bar and the other one on the bottom surface.

A homogeneous thermal expansion will always point in direction of the bar, so the strain will be approximately the same on both sides of the bar → same change of resistance in both strain gauges.

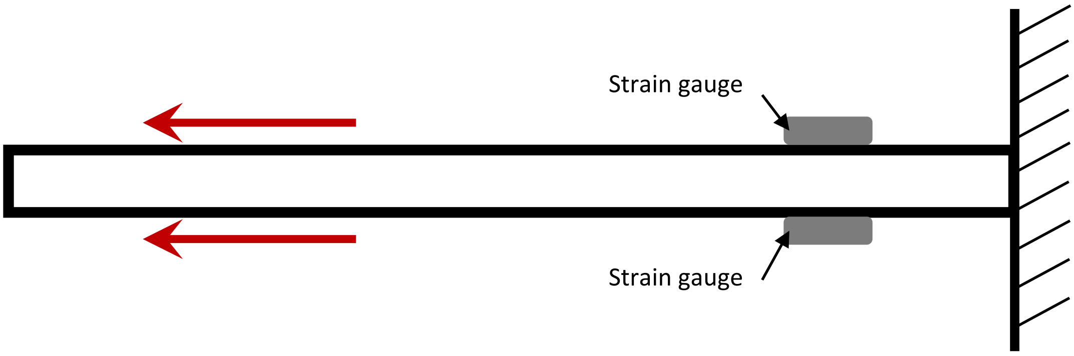


Figure 4-5 Thermal Expansion

When we put a perpendicular load on the end of the bar to either bend it down or upwards, the resistance of the strain gauge will change in different directions (Figure 4-6). This will cause an even bigger voltage change in the bridge, which will also increase the signal.

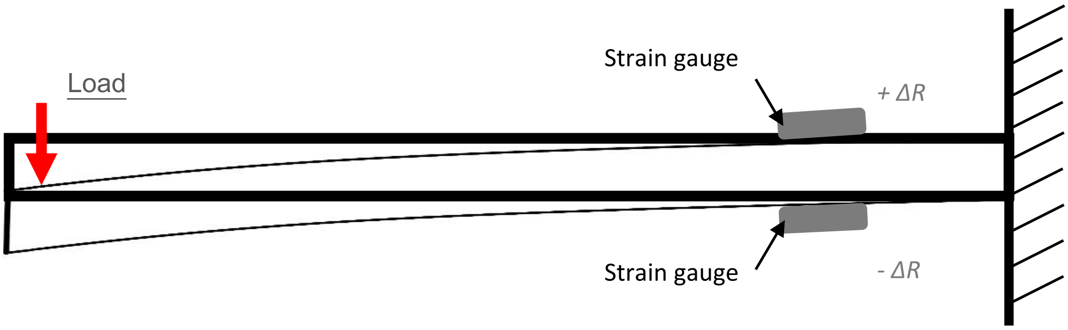


Figure 4-6 Load on Measurement Bar

After understanding the functionality of strain gauges and developing a system to create an electrical signal (1), that can be given to the Raspberry Pi (3), the next obstacle would be to amplify the signal given from the Wheatstone bridge into a processible size (2).

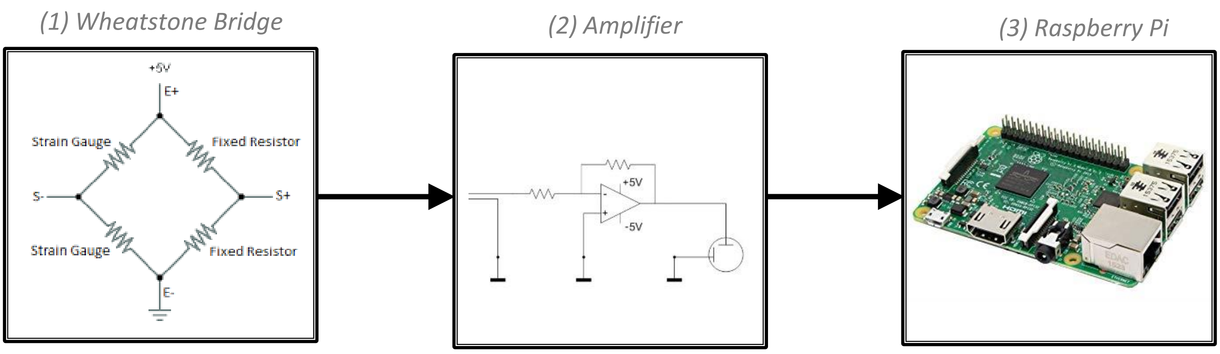


Figure 4-7 Electronic System 1

To safe space in the product and keep the production effort low we firstly chose an amplifier board (Figure 4-3), that already includes the Wheatstone bridge and the strain gauge, so we would only need to connect that one board to the Raspberry Pi.

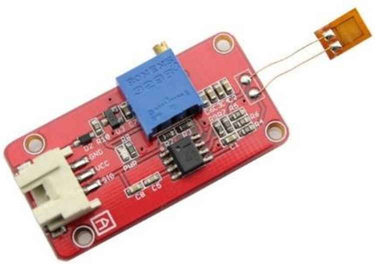


Figure 4-8 Elecrow Strain Gauge Module

In difference to similar devices as the Arduino Uno, a Raspberry Pi can only handle digital inputs, so we had to convert the analogous signal from the amplifier into a digital signal, so we added an analogous/digital-converter (A/D-C) between the amplifier and the Raspberry Pi [3]. Also, the existing system had the disadvantage that each Wheatstone bridge only includes one strain gauge and three solid resistors. As already shown in the section above, it is necessary to build a half bridge to increase the accuracy and to compensate temperature changes on the device. In consequence we decided to not use the chosen amplifier board and build the Wheatstone bridge on our own. Subsequently we had to find an amplifier and an A/D-C to transfer the signal from the Wheatstone bridge to the Raspberry Pi (4). We found the best solution in the HX711 (3), which includes the amplifier and the A/D-C and a therefor designed load cell combinator (2) to build the Wheatstone bridge. Normally the load cell combinator is meant to be used with prepared load cells. This load cells have three pins matching to the pins on the board and an internal wiring. The strain gauges we use for our system only have two wires, so we had to find a way to build the needed connections for the load cell combinator on our own. In the end we decided to connect the ports by soldering them together directly on the board. The exact wiring diagram will be shown in chapter 6.1.

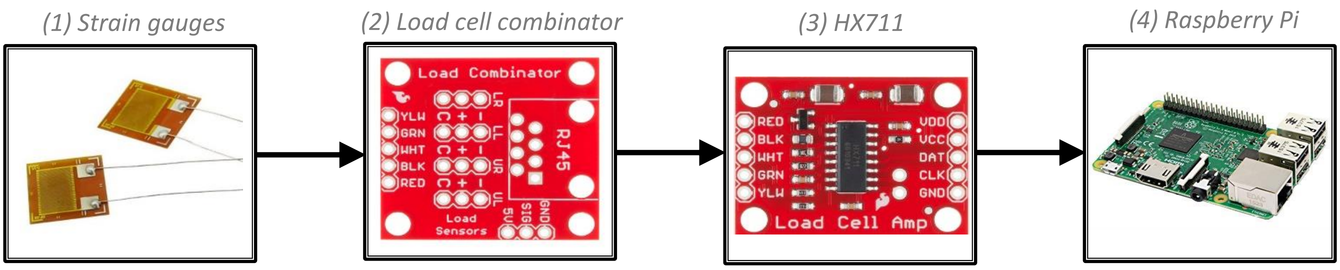


Figure 4-9 Electronic System 2

To ease both the assembly and the replacement of separate (groups of) parts in the device we decided to have partition plugs between the strain gauges and the load cell combinator as well as between the HX711 and the Raspberry Pi. With these connectors we can mount the bar with the strain gauges glued on to the frame and screw the frame to the back part of the housing afterwards. Also, if there are problems with single strain gauges, it is easier to get the bar out and replace the strain gauge. We are running the same system with the HX711 and the Raspberry Pi to get the boards out in case of malfunction without dismounting or replacing the Raspberry Pi. We saved a connection between the separate boards, because it would take too much space in the device and because it would be easier and cheaper to replace all the boards together instead of separating the boards.

4.3. FRAME & HANDLE

In order to design the most ergonomic handle possible that has a high-quality feel, a 3D scan (Figure 4-10) of the Jamar hydraulic handheld dynamometer has been made and imported into the cad system.

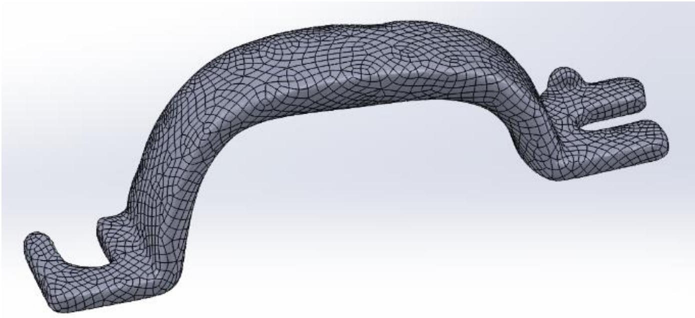


Figure 4-10 3D-scan of the handle

With the help of this scan an already previously designed handle was optimized, which yields the following result:

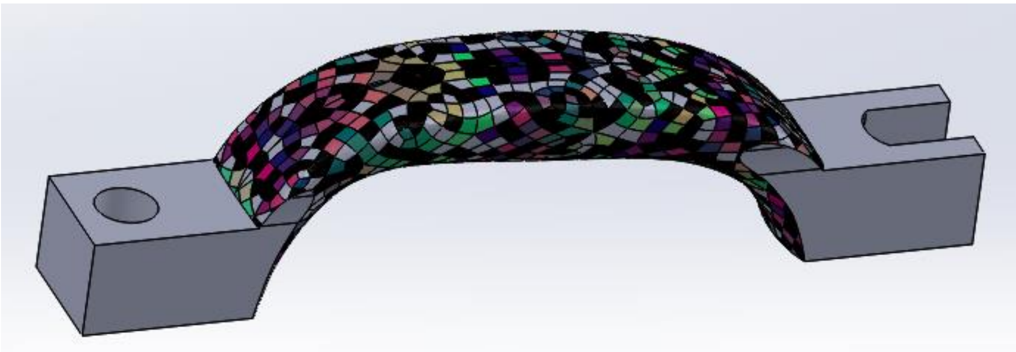


Figure 4-11 Handle Design

The design of the frame has also been optimized by making the top pleasantly ergonomic, so that the element fits comfortably in someone's hand. The bottom of the frame has been thickened compared to the rest of the frame. The underside of the frame has been thickened compared to the rest of the frame and has also been provided with three through holes with threads into which the two halves of the housing are bolted. As can also be seen, left and right of the middle material has been taken away, which means there is an increase or a base in the middle. The bar is screwed to this base so that it hangs in the air next to the base. This was done to allow the bar to bend in both directions and that the strain gauges attached on the bottom of the measurement bar are free accessible to cabling them.

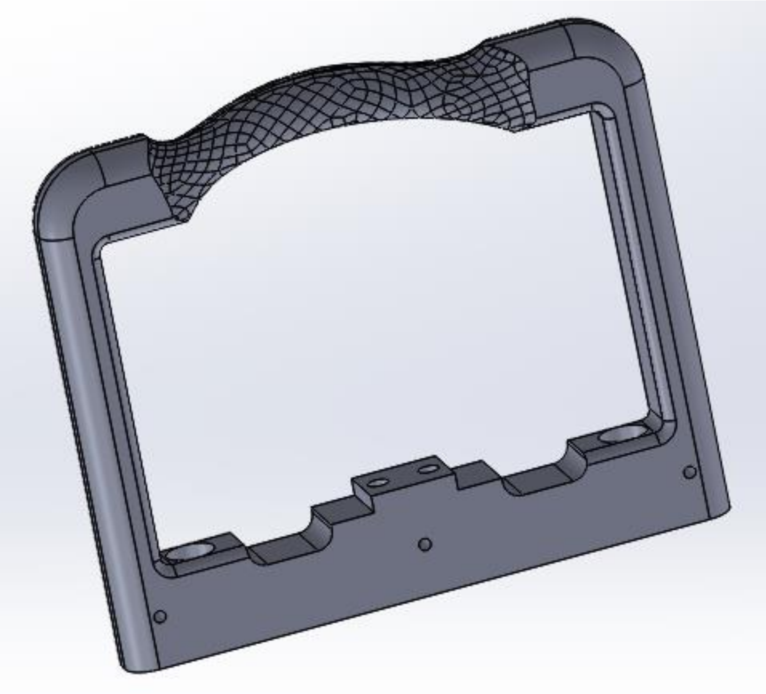


Figure 4-12 Frame

4.4. HOUSING

Although, the housing doesn't seem to be very important, there are several requirements given for it. The housing covers all the mechanical and electronical parts, not only for optical reasons, also to protect them from dirt, dust and wetness. It gives a solid connection between the frame and the electronical parts, it adjusts the position of the display and places most of the parts. In the same time it should be as light as possible and take as less room as possible to keep the device mobile and handy.

In the beginning we tried to figure out, how we can keep the device as small as possible, so we chose the width of the frame as maximum width and added the Raspberry Pi with the short side to the overall height. To keep the ports of the Raspberry Pi accessible we needed some kind of cut-out. We decided for the port cover on the lower side because the micro USB would be used more often for power supply and the cap for the USB and network ports. The next idea was to get all the other parts in the space that is left beside the Raspberry Pi. To keep the production costs low, we used the available 3D-printer in the workshop to print our housing parts.

VERSION 1

Version one was printed very early, before we knew the exact amount and sizes of parts. It was meant to be a first test, to see how the 3D-print works and what accuracy is possible.

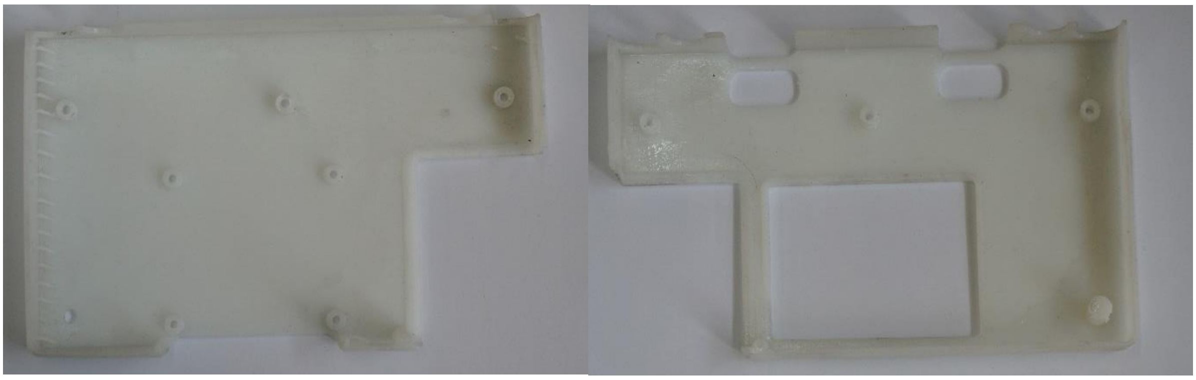


Figure 4-13 Front & Back V1

VERSION 2

This version was the first finished design, that was meant to be used for the prototype. The electronical parts we need fit perfect beside the Raspberry Pi. The screws for the parts would be insert from inside. We figured out that there was a lot of bending in the big parts, that made it impossible to fit them together. The back was very weak because of the low wall thickness, so we cracked it while working on it. Also the material around the holes was to less for drilling them to the right size. Furthermore, the guide rails, we designed for the cap were too thin for the 3D-printer. The little edge at the end, meant as resistance to lock the cap, didn't work because it was way too small.

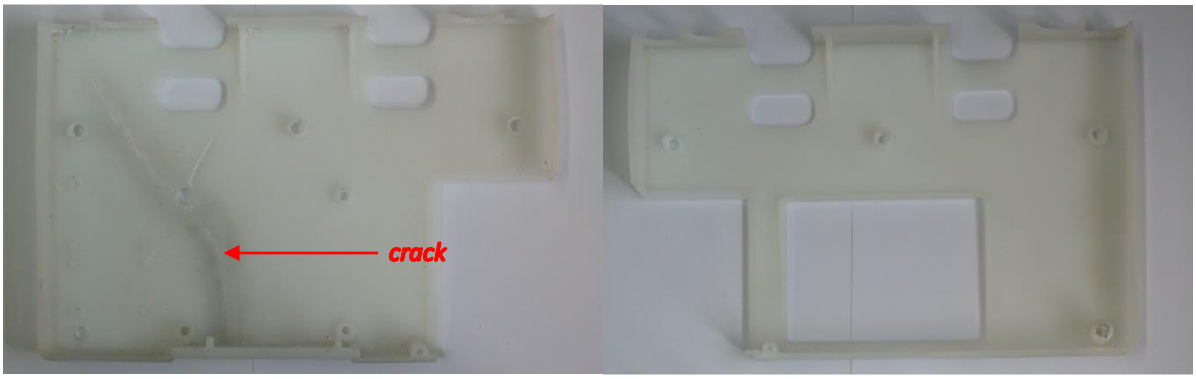


Figure 4-14 Front & Back V2

VERSION 3

First of all we changed the screws for the Raspberry Pi to be insert from the inside, same as for the electronic boards, to make them invisible from outside of the housing. Than we changed the thickness around all the holes, to have enough material for drilling the holes to the right size. Additionally we added ribs to the upper edge, to make them stronger and pretend them from bending during the 3D-print. Also, we added noses on the back, as well as matching gaps on the front to bring them into the right position during the assembly. Then we added an overlapping edge on the parts, to make sure the inside is covered even if they don't fit perfectly together. We increased the size of the guide rail of the cap and designed a new snap system to hold it in. In the end we increased the wall thickness to make the part stronger and provide it from bending. Both main parts are screwed to the frame three times (blue mark). Additionally they are screwed together in two positions (red mark). The current back print already has a third position, that will be added in the next version (orange mark). The violet marked positions are for the Raspberry Pi and the green marked ones are for the electronic boards.

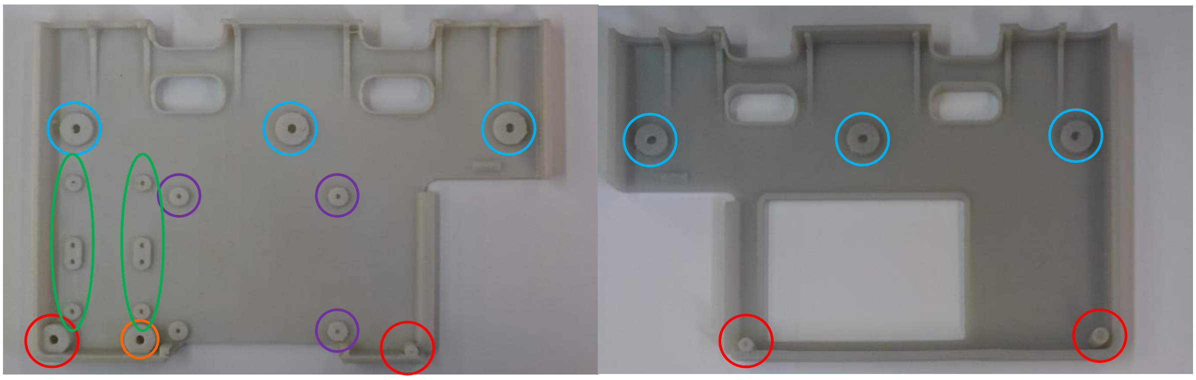


Figure 4-15 Front & Back V3

Another new feature is the visual protection at the top of the housing (Figure 4-16). With the second version, the problem was the visibility of strain gauges and measurement bar and the view into the housing. The visual protection makes sure, that the technique inside is protected and the strain gauges can't be reached.

The position of the cut-outs in the port cover slightly changed to fit better to the ports on the Raspberry Pi. We added little humps on the back and the front, where a little nose on the cap will slide in.

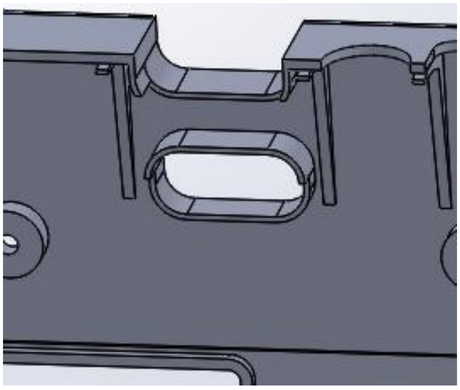


Figure 4-16 Visual Protection

Betraying the outcome of version 3 of our housing, we still found some possibilities to improve version 4. One problem are the flaps on the edge of the housing. These are to small for the 3D-printer and therefore their effect degreases. With version 3, we still had problems with bending in the cap, so we might have to add a bit of space in the guide rails, to keep them working.

After completing the hardware parts of our hand grip, a little change was made regarding the position of the electronic boards, so we had to improvise and create space for the parts (Figure 4-17).

Figure 4-17 Cut-Out for Electronic Parts

As result, we will have to design version 4 a bit longer to create enough space the new system.

For further development steps we planned to integrate the port cover into the back. In the current situation the port cover is a separate part, to ease the installation of the Raspberry Pi. The prototype showed us, that it is not necessary to have the port cover separately. The Raspberry Pi can be placed a little bit above the final position and moved downwards to place the ports into the for this provided cut-outs. That would save the logistic and production effort for one part and increase the strength of the back at the same time. Furthermore, you don't have to take care of the accuracy of fit between the two parts.

5. TESTING PHASE

The testing of different measurement bars was carried out with the help of a test bench specially built by us for this application. Furthermore, the calibration of the strain gauges should be possible on the test bench as well. Requirements the jig for the measurement bars has to fulfil are therefore as follows:

Different bars must be mounted on the Jig for testing in combination with different strain gauges. Therefor a fast mounting of the bars must be possible.

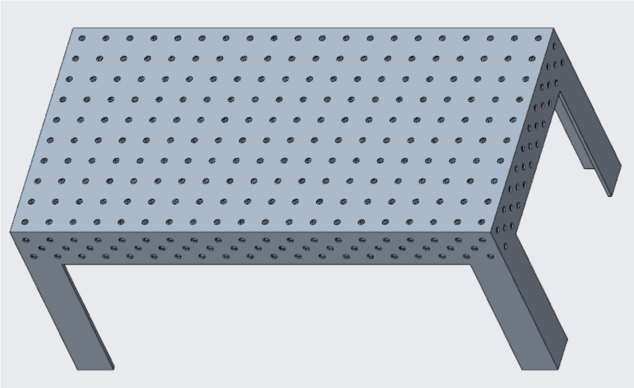
- The initiated force must be equally distributed on both sides of the strain bar.
- The initiated force needs to be adjustable between 0 and 180 kg over a few seconds.
- You should be able to set the force with an accuracy of 0.2 kg.
- The jig must be usable by only one person on its own.
- The strain gauges need to be accessible for gauges

For setting a specific force, there has to be an own measurement at the attack point of the force

The available expedient for building the test bench given to us by the workshop was a steel table (figure 5-1) with the size of 2000x1000x850 mm and with a pattern of threaded holes on its working surface and on its sides. So, the last requirement for the test bench is to build it using the table as its basement.

Figure 5-1 Steel table

Before we started with the construction of the jig itself, we rebuilt the table and some other parts that we thought of being useful for the jig in our CAD system.



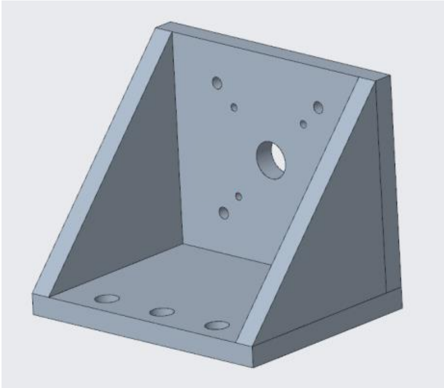


Figure 5-2 CAD-data of Table & additional tools

The fundamental idea of how the jig should like is this:

Knowing the amount of force applied on the bar as precise as possible the force shall be initiated through weights. Otherwise an additional measurement system will be needed to capture the force applied on the jig and the measurement system has to be calibrated from time to time. By using weights, the amount of force loading the bar is always exactly known and no extra calibration is needed. Due to the fact, that the measurement bar has to withstand a range from zero to 180 kg the weight or rather the weights that have to be used are very heavy and take up a lot of space as demonstrated in Figure 5-3 with a weight of 14kg attached to the measurement bar.

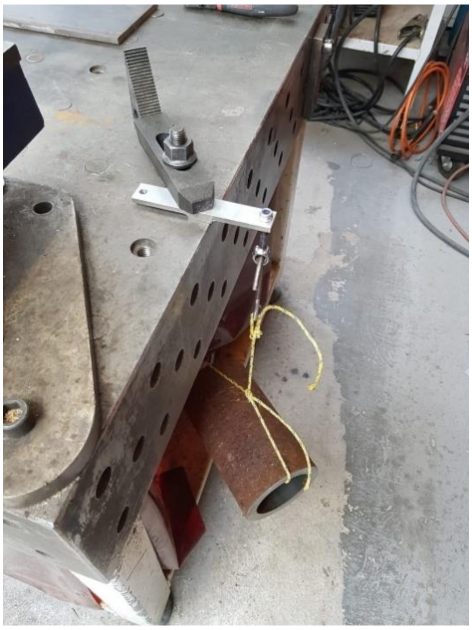


Figure 5-3 14 kg Weight on Measurement Bar

To counteract this, the lever principle is used to reduce the mass required to test the bar. A lever with a ratio of 5:1 is intended. In order to calibrate the bar in 0.5 kg increments, we need weights that can be increased by 0.2 kg at the other end of the lever. In order not to violate the so-called golden rule of measuring technology, a scale is required which provides an accuracy of 0.01 kg. The golden rule of measuring technology namely says that the ratio between measurement uncertainty and tolerance mustn't be higher than 1/10 of the measurement.

Having an idea in our minds knowing what the lever should look like we started constructing the jig. But after constructing some parts and making a few assemblies we noticed halfway that the construction effort is far too large for the application purpose. In addition to that it became clear that not only the workload building this jig would be very high but that is also a matter of costs producing all the parts, even on our own. Instead of continuing the designing and constructing the jig with the CAD programme we changed our plan and decided to find a faster and cheaper solution leading to the same goal by using the resources given to us by the workshop.

On the table, a heavy steel sheet is attached which stands a few centimetres above the table edge out making sure there is enough space for the weight. The measurement bar is bolted to this sheet. In order to make the bending process of the bar on the jig identical to the bending process in the handgrip itself, the bar is screwed to the steel sheet with two support plates, one in between and one on top auf the bar. The adjustment poles which initiate the power into the bar in the handgrip device are replaced by simple screws on which we have previously welded an eye.

The lever has been sawn from a square hollow profile, also made of steel, to a length, so that a ratio of 2:1 results. At one end the lever touches the lower edge of the tables working surface. This edge is the pivot point of the system. Holes have been drilled in the middle and at the other end of the profile to mount two more eyebolts of the same kind used for the measurement bar. Lever and measurement bar are now connected with each other by means of the two eyebolts and a rope which has the length to keep the lever in a horizontal position when unloaded. Through the last eyebolt a self-bent s-shaped hook is pushed, or rather another rope is linked to the eyebolt, that at the other end has a loop for the hook. On this hook various weights can be hung. We decided to hang buckets as weights on the hooks, which we can fill with water or other substances and weigh before each measurement to know exactly the amount of weight.

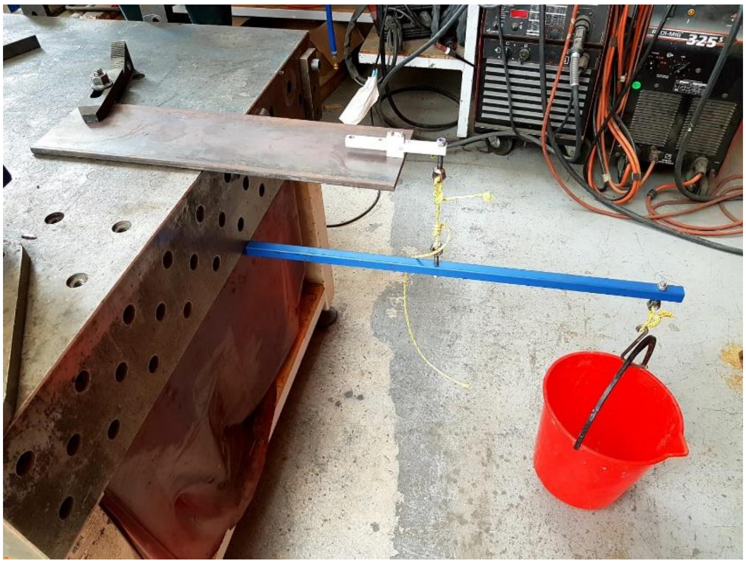


Figure 5-4 finished Jig

For a complete test bench, of course, a measuring system is needed. It must be easily accessible and portable to be able to connect to the measurement bar. The system can be seen as the precursor of the system installed in the finished hand grip. It generally consists of the same components that would be Wheatstone bridge the HX711 and an Arduino board as a minicomputer. The Wheatstone bridge was built on a board, it just has to be connected to the strain gauge to be complete. An Arduino board had to be used because the Raspberry Pi does not yet have the software needed for the measurement. Consequently, we have downloaded the right software for the Arduino and adapted an existing code for reading the change of resistance of the strain gauges for our needs. For a more detailed explanation of the function of the measuring system, please refer to chapter 2. Research and/or chapter 4.2. Electronic System.

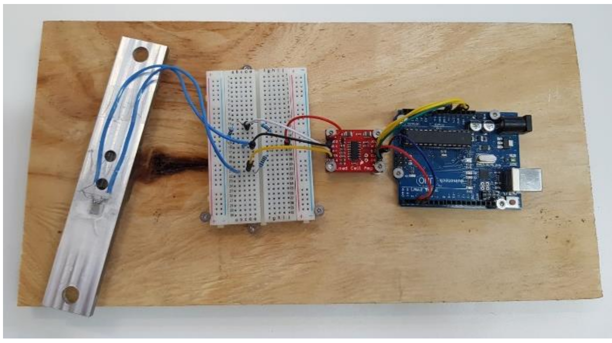


Figure 5-5 Arduino Board

Having finished building the test bench successfully testing the bars can finally be started. We tested 3 different aluminium bars.

- Bar 1: Designed by us with plinth and transition radius, 25mm wide and 6mm high without the plinth. The outcome as shown in points out, that the bar is more accurate than required. In order to save production costs we went on to a bar out of rod material
- Bar 2: Aluminium bar out of rod material with a squared cross-sectional area of (half inch) ² which is equivalent to (12,7 mm) ².
- Bar 3: The same aluminium profile used for bar 2 has been shrinked in its height to 7.4 mm.

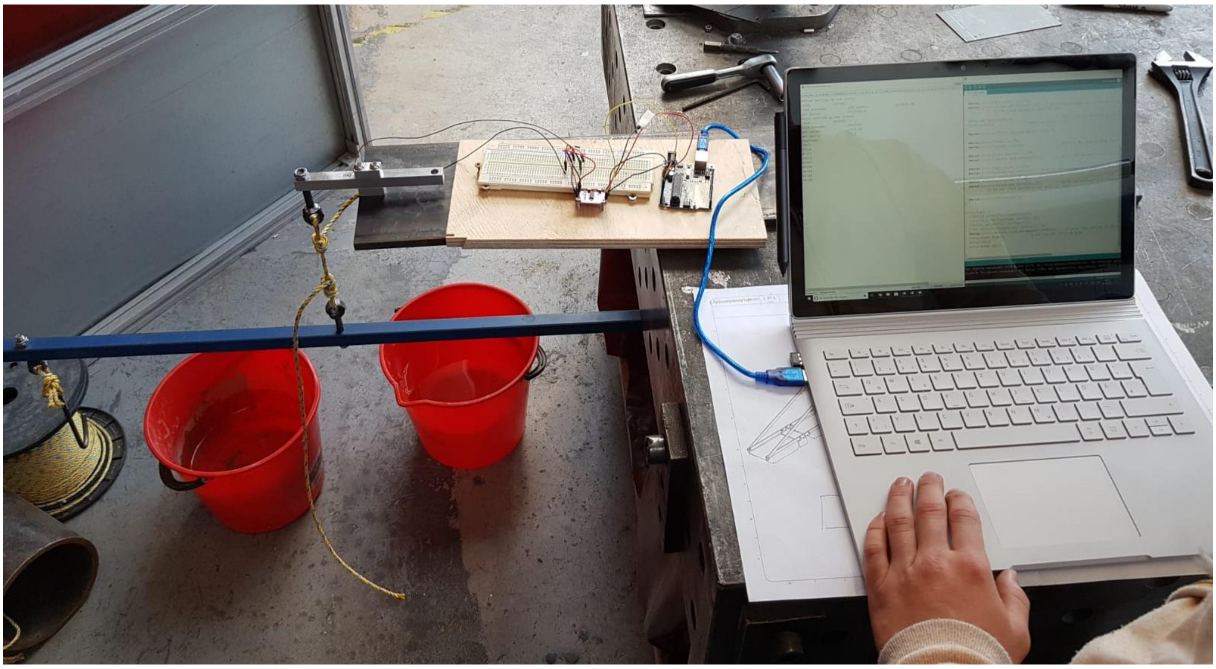


Figure 5-6 Bar Testing

We have tested all three bars and made a diagram with Microsoft Excel. Calculating the mean out of ten readings given by the Arduino within 20 seconds, we plotted the results in the diagram dependent on the weight hanging on the test bench. In Diagram 5-1 you can see the results of all three bars compared to each other.

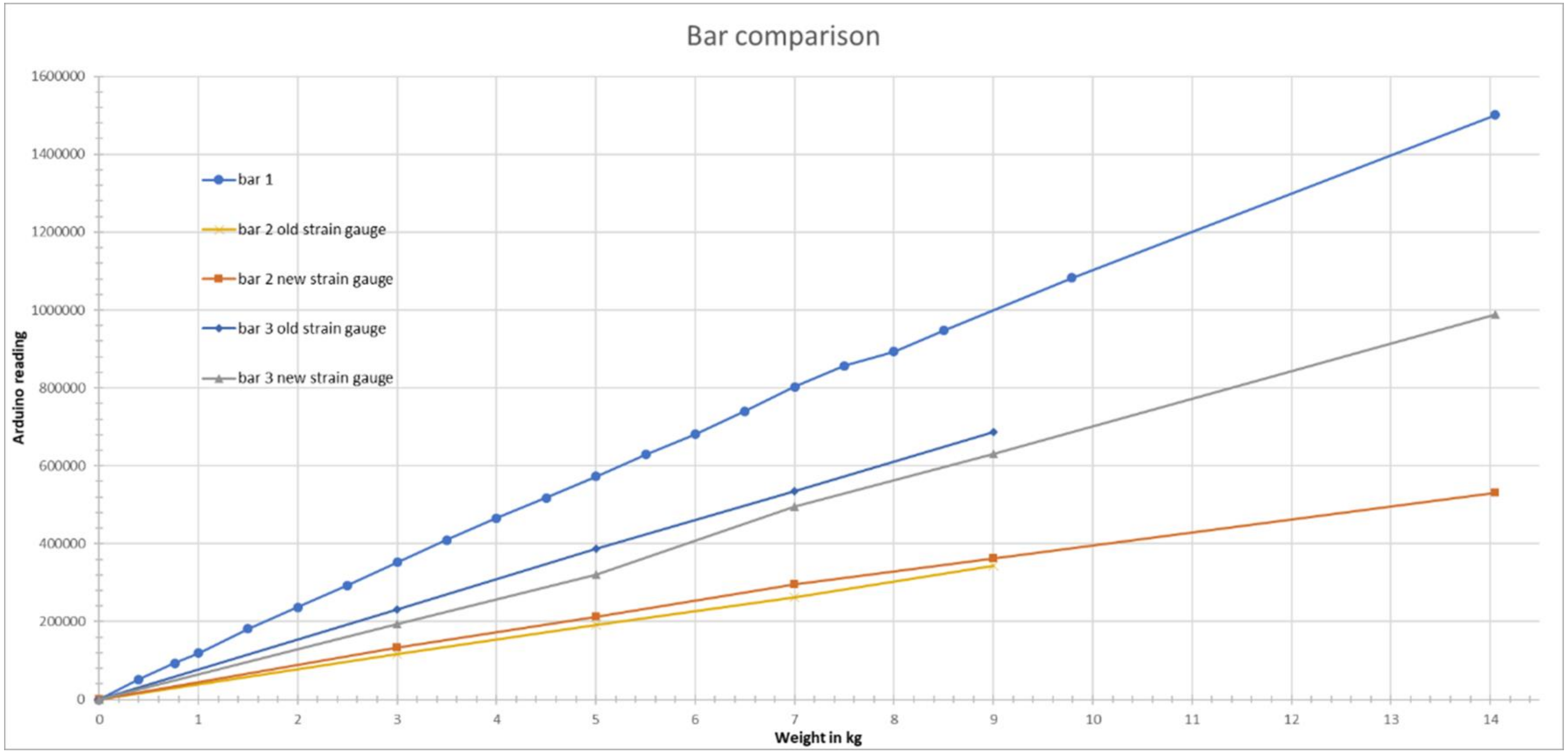


Diagram 5-1 Comparison of Bar Measurement Results

Bar 1 is loaded in 0.5 kg steps from 1 kg up to round about 14 kg. Between 0 kg and 1 kg two more weights have been measured, namely 0.4 kg and 0.76 kg. It shows linear characteristic except of one measuring point caused by a small displacement of the lever. Bar 2 and bar 3 are measured with a different step width and less steps than bar 1. We wanted to see if these two bars have a linear characteristic similar to bar 1 and because this is not the final calibration it is not necessary to measure the bar with the same increments bar 1 is tested. However, every bar shows indeed a linear characteristic. The bar increasing the steepest is bar 1 followed by bar 3 and at last bar 2. This is referable to the height of the cross-sectional area of the bars, due to it being used by the power of three in the formula to calculate the moment of resistance. Furthermore, you can see that bar 3 and bar 3 are measured two times. This is because we ran out of the strain gauges from a German company supplied to us by our supervisor. Alternative strain gauges with the same properties and the same amount of resistance that can be obtained faster have been provided to us then. The diagram shows that there is barely any difference of the two different strain gauges to recognize. As already indicated bar 3 is less accurate than the other two bars due to its height but in our opinion and in the opinion of our supervisor still accurate

6. PRODUCT MANUFACTURING

6.1. PRODUCTION PROCESSES

FRAME & HANDLE

The handle as well as the frame are mainly produced on a semi-automatic milling machine. The recommended process for mass production depends on the number of devices, that will be produced. For smaller amounts, we would recommend using CNC-milling machines. For the production of several thousand devices and upwards, we would recommend using a sand-casting process with cores for the adjustment pole holes and rework of the functional surfaces as well as thread tapping for the attachment of the measurement bar and the housing.

MEASUREMENT BAR

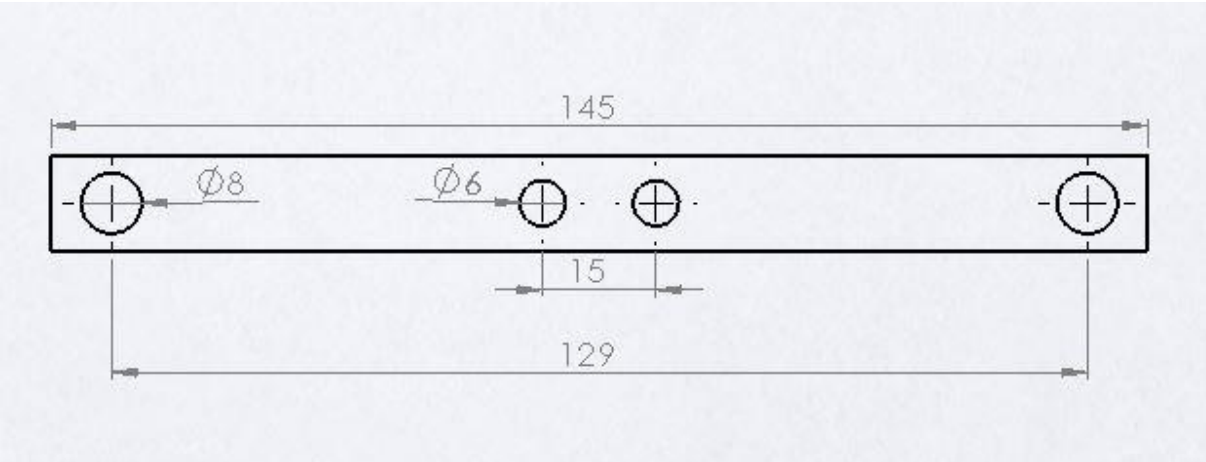


Figure 6-1 Measurement Bar Dimensions

The production of the measurement bar can stay the same for small or high production numbers. The rod material for the measurement bar has to be cut to the right length. The dimensions of the bar are given in Figure 6-1 above. The surface should be fine grinded to prevent scratches under the strain gauges. Afterwards the holes are drilled into the bar and the position of the strain gauges has to be marked as shown in following Figure 6-2 Strain Gauge Positioning.

Finally the strain gauges get glued on as already described in chapter 3: Research.

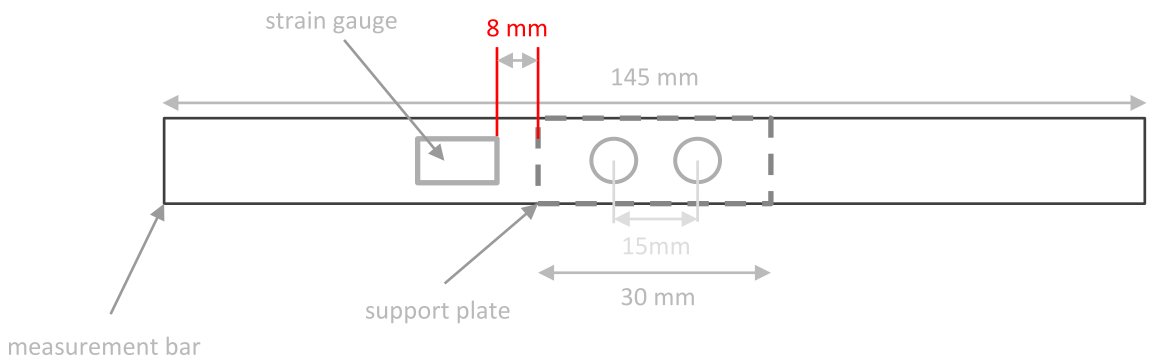


Figure 6-2 Strain Gauge Positioning

Belonging to the measurement bar, the support plate has to be produced. It has a length of 30mm, a height of 6mm and a width of 12,7mm. The holes are match-drilled to the bar and countersinked matching to the screw heads.

ELECTRONIC SYSTEM

Main part of the electronic system is soldering, beginning with the first wires being soldered to the strain gauges. Those eight wires and up in the female part of the first partition plug. Take care, that you make the wires long enough to get, starting at the bar around the frame. The male part of the partition plugs is soldered to another eight wires. Those wires separate to the two load cell combinator boards. Take care that both strain gauges of one side of the bar go to the same load cell combinator.

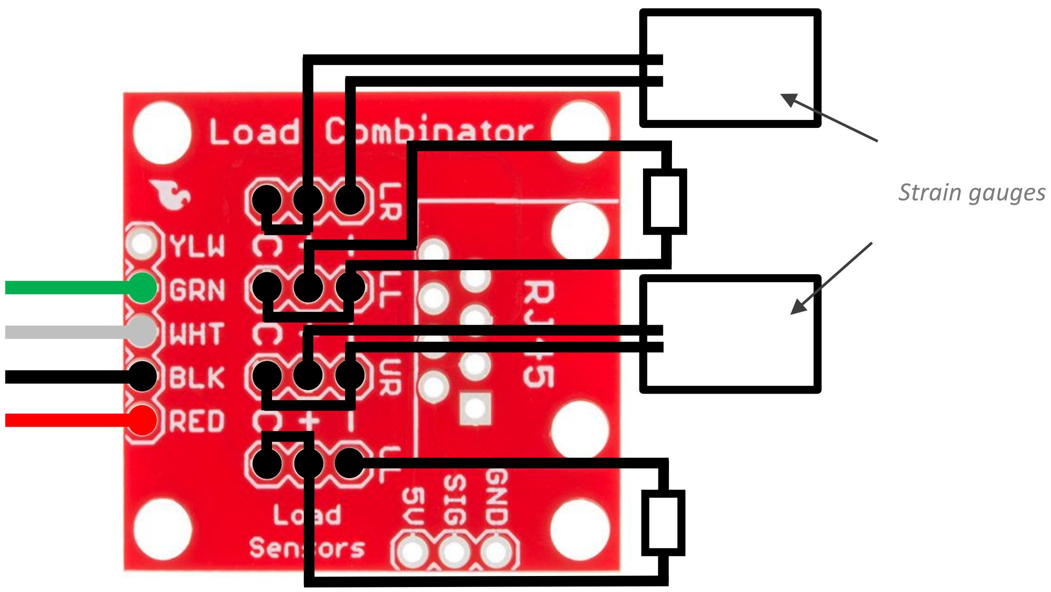


Figure 6-3 Load Cell Combinator Wiring

Each load cell combinator gets connected by four wires to one HX711. The colours named on the load cell combinator has to match the colours named on the HX711. The fifth (yellow) port stays free and is unused. On the other side of the HX711 connect the VCC and VDD port. Both are supplied with the same voltage. Connect the remaining 8 wires of both HX711 with the female part of the second partition plug. Connect the power supply and the ground of both HX711 on the male side of the partition plug. This reduces connections to the Raspberry Pi from eight to six. The male part of the partition plug gets soldered to the connector for the GPIO pins of the Raspberry Pi. The connector is plugged onto the six lower left pins of the Raspberry Pi. GND is already set. The power supply has to be programmed on the right pin and each two data and clock wires for both HX711 need to be arranged.

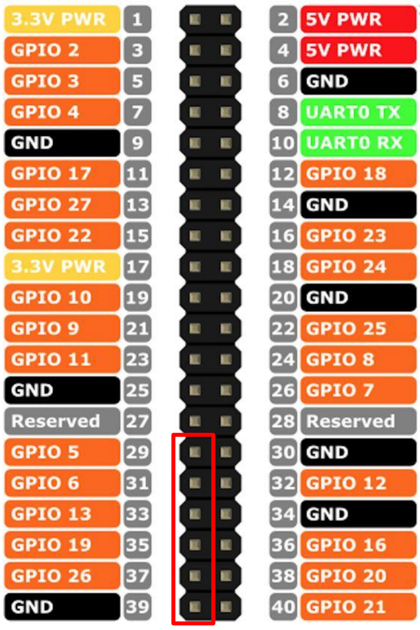


Figure 6-4 Raspberry Pi GPIOs

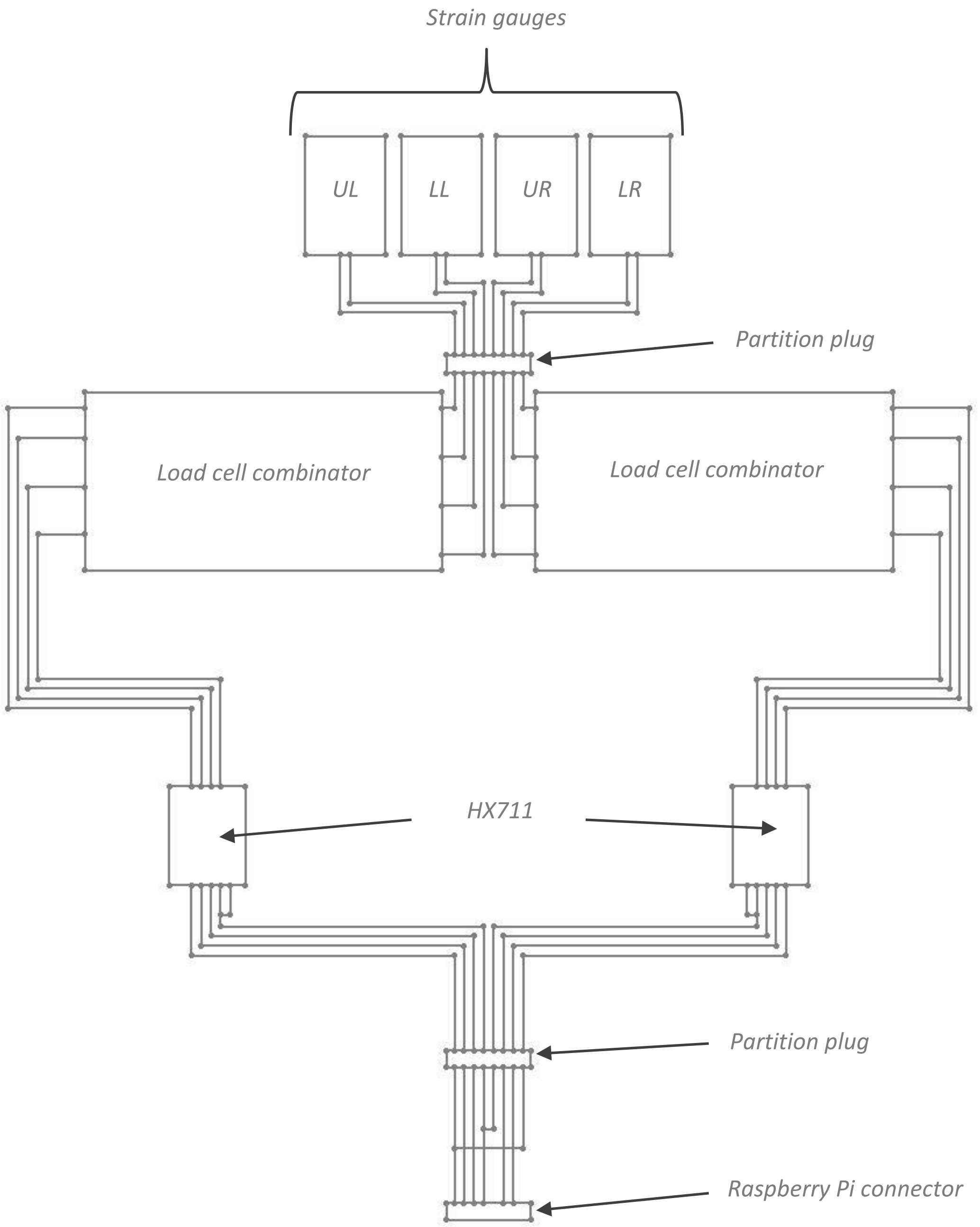


Figure 6-5 Wiring Plan

For mass production the load cell combinator can be replaced through specialized boards, to reduce soldering effort. Also the connection type between strain gauges and load cell combinator as well as between HX711 and Raspberry Pi can be improved.

HOUSING

The housing as it is right now, can only be produced on a 3D-printer. We recommend producing the parts by injection moulding for mass production. Therefore, a few changes need to be done. For example replacing the material around the holes through a cross instead of a round shape. This reduces the wall thickness and provides bending during cooling down after injection moulding. Depending on the type of 3D-printing it might be necessary to grind of the support points needed for the print. Independent of the first production step, the holes for frame, electronic parts and housing connection must be drilled to the right size (the outcome of a 3D-print or injection mould can be too rough).

Before starting the assembly, you need to check if the parts are fitting together, to prevent complication during the assembly.

6.2. ASSEMBLY MANUAL

Before you can start the assembly, realize that the holes in the Raspberry Pi are slightly too small for the used screws. Match-drill the holes, so the screws have enough space to fit through.

First of all, insert the prepared rubber bushings into the frame. As next step, the handle needs to be placed between the adjustment poles and insert the adjustment poles into the rubber bushings as shown in the picture underneath. Now carefully place the measurement bar between the adjustment poles and the frame. Take care, that the strain gauges and wires don’t get damaged. Insert the M8x20 screws through the holes of the frame and the bar to screw them into the adjustment poles. Put the two clips on the adjustment poles to fix their position. Slightly loosen the screws in the poles again to make sure the poles are easy rotatable. Finish the mechanical part by placing the support plate on the bar and screw both to the frame by using the M6x40 screws.

Take the Raspberry Pi and place it together with the port cover on the back of the housing. Once it is in the right position and all the ports are reachable through the cover, screw the Raspberry Pi to the back. After that, put the 8 screws into one of each board types, then put the spacers on the screws and add the two other boards. Screw the four boards to the back. Connect the back part of the housing to the frame, with the matching M4x10 screws. Carefully tighten the screws, because the plastic is likely to brake. Connect all the partition plugs and plug the 3,5” display on the Raspberry Pi. Put the front cover on and screw it to the frame, afterwards to the back part of the housing. Finally slide the cap onto the housing, until it clicks in.

7. CONCLUSION & DISSCUSION

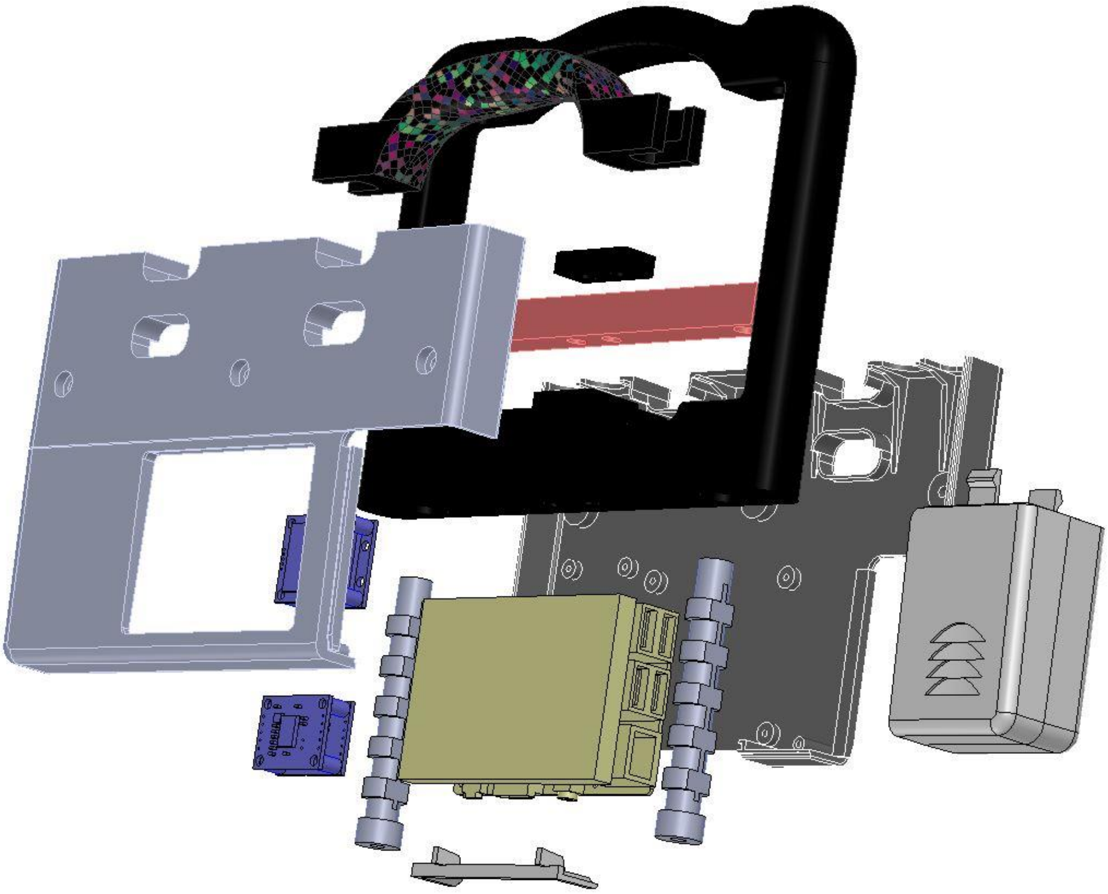


Figure 7-6-1 Exploded View – Hand Grip

It took us a certain amount of time to acclimatize and to get familiar with the local occurrences. While in Germany a lot of time is spent building up structures, schedules or planning processes, people here get straight to work and try to get something done. So we were expected to deliver results quickly shortly after the introduction to the project topic.

Of our four above mentioned goals we finished the production of the frame and the handle first. The main difficulty was the production with the semi-automatic milling machine, which we could not have operated without assistance. In addition, it requires some rework, because even the semi-automatic milling machine has not been able to make all the details. Nevertheless, we think it was well feasible and frame and handle have become quite respectable.

Second, we have dedicated our attention to the construction of the measurement bar. As it turned out later that our bar design was overqualified, we could have saved a lot of design work by starting tests with the bar earlier. That the current bar works can be seen from the tests. However, we do not know the fatigue strength of this aluminium bar and should therefore perform fatigue strength tests to ensure that the bar does not deform plastically even after prolonged use.

As we study mechanical engineering in Germany, we are not very familiar with electronic stuff. While we have basic knowledge in electronic engineering, we never worked with a Raspberry Pi or similar devices. Even less we know about hardware and dealing with it, e.g. soldering, choosing the right parts etc. Another problem we were struggling with, was the availability of the electronic parts, so we had to order them from another country which definitely takes more time. Hereby, we had to wait two weeks in between, until we were able to go on, because we had to wait for the electronic parts to arrive. Finally we got the system together and running as it was meant to be.

Sadly we weren't able to make the device mobile, because we had legal indifferences to get the battery-pack shipped to New Zealand and couldn't find a domestic company, which could deliver one.

The first two versions caused a lot of struggle for us, because the 3D-printer we could use couldn't produce with the accuracy we wanted. Also the prints take a lot of time (about 10 hours for a big housing part), so the production of the housing dragged on. A lot of design work was invested to create a proper, presentable model.

8. RECOMMENDATIONS

- Referring to chapter 7 we have some recommendations, as for example adding a battery-pack and the matching interface to the device to make it independent from an external power supply.
- Also there are long time tests needed to check the fatigue strength of the measurement bar.
- For the next prototype version, which is already in the planning, the material of the frame and the handle will be changed to polyvinylchloride (PVC) to reduce weight and production effort.
- In version 4 the housing needs to be a bit longer to make the new positions of the electronic boards possible.
- As already mentioned in chapter 4.4 Housing the port cover can be integrated into the back.
- For mass production the housing needs to be slightly changed to be compatible with injection moulding.
- For wide ranging usage the Raspberry Pi can get complemented with sequence programs, which run a complete measurement procedure, e.g. for strength endurance measuring.
- As prepared with the current device, a jig can be attached to the measurement bar in order to measure the force someone is exerting during deadlifting.

9. APPENDICES

9.1. COST ANALYSIS

The following cost analysis is based on the production of a single device with the machines we used, but with common prices for the work and machine time.

purchased parts	CPU in $	units	overall costs in $
1kΩ Strain gauge	3,60	4	14,40
Sparkfun Load cell combinator	1,95	2	3,90
Sparkfun HX711	9,95	2	19,90
Raspberry Pi 3 Model B+	69,00	1	69,00
3,5" LCD touchscreen	56,35	1	56,35
wire	0,09	32	2,88
partition plug	0,70	2	1,40
resistor	0,13	4	0,52
screw M8x20	0,73	2	1,46
screw M6x40	0,45	2	0,90
screw M4x10	2,26	6	13,56
screw M3x6	2,52	4	10,08
screw M3x16	2,46	8	19,68
spacer	0,33	8	2,64
8GB micro SD card	14,86	1	14,86
total part costs in $			231,53
machining time/work time	CPH in $	time in h	overall costs in $
3D-prints*			
back	-	-	59,47
front	-	-	54,51
port cover	-	-	5,00
clip	-	-	15,00
flap	-	-	25,50
lathe	80	1	80,00
soldering	75	2	150,00
frame & handle	150	7	1050,00
total machining costs in $			1439,48
raw material	CPU in $	amount	overall costs in $
rubber	2,5	1	2,50
aluminium for bar	4,6	1	4,60
aluminium for frame&handle	70	1	70,00
aluminium for adj. poles	7,2	2	14,40
steel for the support plate	5,5	1	5,50
total material costs in $			97,00
overall costs in $			1768,01

Table 9-1 Cost Analysis

*The costs for the 3D-print parts are based on the prices offered by shapeways.com

9.2. TIME SHEET

WEEK	HOURS	CONDUCTED WORK
1	35	Enrolment, project introduction, organization, planning, research
2	35	Specification, research, bar construction
3	35	Research, bar calculation/construction/simulation
4	35	Bar construction, manufacturing
5	35	Specification for the test bench, jig design/construction/build, strain gauge attaching
6	35	Soldering, project progress presentation, finishing the test bench, first tests
7	1	Discussion, planning
8	21	Ordering el. Parts, frame & adjustment pole manufacturing
9	35	Testing, measurement bar production
10	35	Discussion of the results, Construction of the housing
11	28	Construction & 3D printing of the housing, wiring of the measurement system
12	35	Construction & 3D printing of the housing, wiring of the measurement system
13	35	Construction & 3D printing of the housing, final report & presentation
14	35	Final report and presentation, Housing modifications

Table 9-2 Record of overall Work Hours

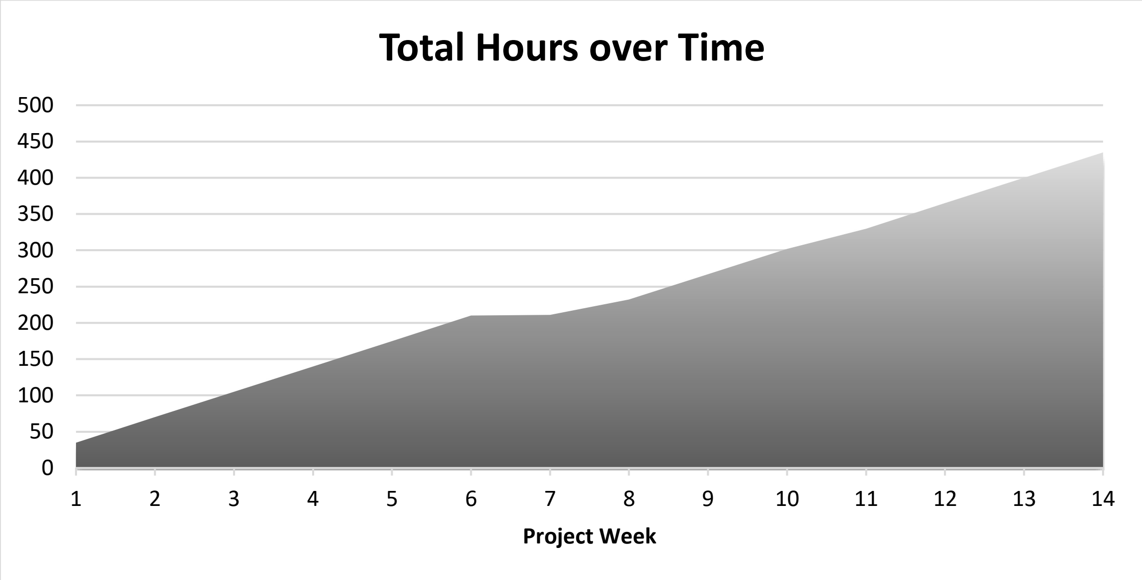


Diagram 9-1 Invested Work Hours per Week

9.3. REFERENCE LIST

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ORDERING INFORMATION FOR PURCHASED PARTS

Strain gauges:

https://de.aliexpress.com/item/BF1K-3AA-strainometer-hohe-pr-zision-draht-belastung-che-1000-ohmsche-dms-f-r-die-Druck/32858795167.html?spm=a2g0x.search0104.3.24.6739587eO3HveN&ws_ab_test=searchweb0_0%2Csearchweb201602_5_10065_10068_10547_319_317_10548_5728815_10696_10084_453_454_10083_10618_10307_537_536_5730020_5733215_5733315_328_10059_10884_5731015_10887_5733115_100031_5733415_321_322_10103_5733515_5733615%2Csearchweb201603_55%2CppcSwitch_0&algo_pvid=1d5edce0-106a-4a98-8ae0-5d3484dec277&algo_expid=1d5edce0-106a-4a98-8ae0-5d3484dec277-3

Elecrow load cell amplifier:

https://de.aliexpress.com/item/High-Quality-Crowtail-Strain-Gauge-Sensor-Module-DIY-Kit-Open-Source-With-3-Pin-Cable-

Free/32639329753.html?spm=a2g0x.search0104.3.1.208a617b8fJqgO&ws_ab_test=searchweb0_0,searchweb201602_5_10065_10068_10547_319_317_10548_5728815_10696_10084_453_454_10083_10618_10307_537_536_5733215_5733315_328_10059_10884_5731015_10887_5733115_100031_5733415_321_5730015_322_10103_5733515_5733615,searchweb201603_55,ppcSwitch_0&algo_expid=41f5d681-4f53-41fe-8189-4a38fc9d0b9d-0&algo_pvid=41f5d681-4f53-41fe-8189-4a38fc9d0b9d

HX711:

https://www.sparkfun.com/products/13879

Load cell combinator:

https://www.sparkfun.com/products/13878

3,5” Display:

https://pishop.nz/RPI-MON2/

Raspberry Pi 3 Model B+:

https://pishop.nz/Raspberry-Pi-3-Model-B-Plus/

Partition plug:

https://www.digikey.co.nz/product-detail/en/jst-sales-america-inc/SM08B-SRSS-TB-LF-SN/455-1808-2-ND/926714

Resistors:

https://nz.element14.com/2410737?CMP=KNC-GOO-SHOPPING-2410737&gross_price=true&CMP=KNC-GNZ-SHOPPING&mckv=sTw61JE5b_dc|pcrid|155921535509|pkw||pmt||slid||product|2410737|pgrid|34507434943|ptaid|pla-294680686006|&gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-ls_eaywuW7F-39Jpr-uGuXI8N204qRmUzRFYJgzWA_5lITreNCIcgaAoKCEALw_wcB

8GB micro SD card:

https://www.banggood.com/8GB-MicroSD-TF-Memory-Card-For-RC-Quadcopter-Camera-p-68888.html?gmcCountry=NZ&currency=NZD&createTmp=1&utm_source=googleshopping&utm_medium=cpc_elc&utm_content=2zou&utm_campaign=pla-all2-nz-pc&gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-ln5VGI53a1zSnJ3p7kse6CwtTOXjt_GF5glrItlEqVcJTx6gCoNZwaAqxhEALw_wcB&cur_warehouse=CN

Screw M4x10:

https://thcc.nz/products/kyosho-1-s34010ht-ttnm-hex-screw-m4x10-5pcs?variant=12521574727753&utm_campaign=gs-2018-08-30&utm_source=google&utm_medium=smart_campaign

Screw M3x6:

https://nz.element14.com/1420121?CMP=KNC-GOO-SHOPPING-1420121&gross_price=true&CMP=KNC-GNZ-SHOPPING&mckv=sTw61JE5b_dc|pcrid|155921535509|pkw||pmt||slid||product|1420121|pgrid|34507434943|ptaid|pla-294680686006|&gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-kRZmKdk82vqAZU-DdpZeU9Xw__PuHSFbWvbcQCP0AQTz_hEIQ7wUwaAjsCEALw_wcB

Screw M3x16:

https://nz.element14.com/1420393?CMP=KNC-GOO-SHOPPING-1420393&gross_price=true&CMP=KNC-GNZ-SHOPPING&mckv=sTw61JE5b_dc|pcrid|155921535509|pkw||pmt||slid||product|1420393|pgrid|34507434943|ptaid|pla-294680686006|&gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-nbscZ6QfWIJJKGeOgBHbxZl6mwIXSSqBKGovBPWE78YvvmfAq-MPYaApufEALw_wcB

Screw M8x20:

https://www.motardinn.com/motorcycle-equipment/rtech-screws-rounded-hex-head-8.8-m8x20-15pcs/136888044/p?utm_source=google_products&utm_medium=merchant&id_producte=7240391&country=nz&gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-lq3RkP6J0tZvRbn0wz1kFz5TbxacjosN6AcXd8hckZSh0lLAnLWVsaAghvEALw_wcB&gclsrc=aw.ds

9.4. REGISTER OF ILLUSTRATIONS