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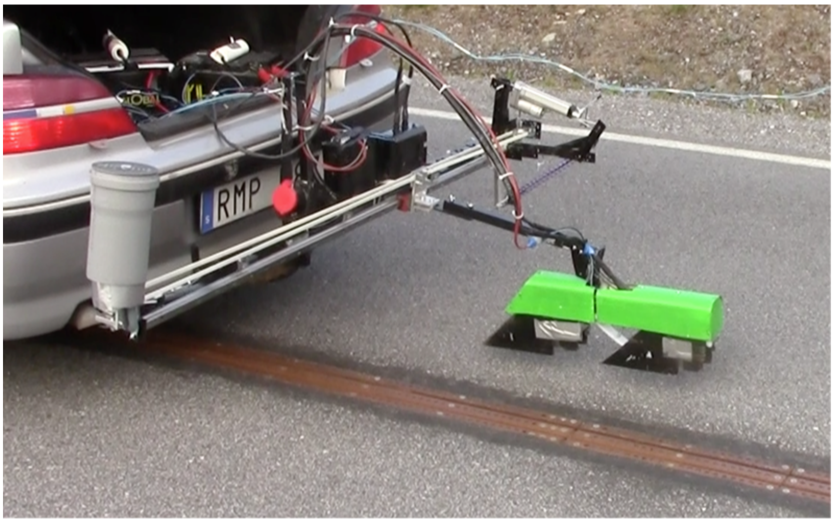

Developing, Constructing and Testing of a Contact System to the Elways Track

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Department of Energy and Environment
Division of Electric Power Engineering
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Cover:
A picture of the contact system developed and built in this thesis

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Abstract

Elways AB has developed an electric track road that can charge electric vehicles while traveling forward on the road. The solution taken forth by Elways is a conductive transfer of energy via a track built into the road. The technology requires the electric vehicle to have a contact mounted on it, which can be connected and disconnected to the track. The power is transferred from the track to the vehicle through the contact. This thesis includes the development, design, building and testing of a prototype for a contact system associated with the Elways technology. The contact is mounted on the electric vehicle, and set on a rail and can move the contact in the vertical direction as well as the horizontal direction. A number of sensors are included in the system in order to get an appropriate control of the contact. The contact moves by two electric DC motor, one for the vertical movement, and a linear motor for the horizontal movement.

The thesis includes the development of this contact system where different options are evaluated and analyzed for the different parts of the system, including control of the two motors and reading of the signals from the sensors. The overall control is performed by using a microprocessor and the code is written in Arduino.

The system was designed and built during the thesis work. Continuous tests were performed on each part of the system and developments and adjustments were performed as in a regular design process. When the system finally was assembled and built, the contact system was tested at a test track installed and built by Elways AB. These tests were evaluated and the results are presented in this thesis. The contact system worked as intended on the tests, but it is a prototype for a final product and is an ongoing project.

Keywords: Electric roads, motor control

Acknowledgements

Firstly I would like to express great thanks to my supervisor at Elways, Gunnar Asplund, for all irreplaceable help, encouragement and expertise on the subject. Without that help, this thesis would not have gotten far. I also thank Henric Dahlstrom and Johan Brandstrom, staff at Elways, for much help and support with everything in the project and especially the mechanical design. I would also like to thank Konstantinos Bourchas for the support in the Arduino code and to Mats Leksell for the information. Finally I would like to thank my supervisor at Chalmers, Ola Carlson.

Cecilia Karlsson
Gothenburg, Sweden, July 11, 2015

Nomenclature

Symbol	Quantity	Unit
ω	Angular velocity	rad/s
f	Frequency	Hz
T	Torque	N m
μ	Relative permeability	H/ m
L	Inductance	H
C	Capacitance	F
R	Resistance	Ω
i	Current	A

Contents

1 Introduction

The environmental issues existing in the world today is partly originating from the transportation sector including both private cars and trucks. One way of decreasing the pollution from these vehicles is to use electric motors instead of the conventional combustion engine. By doing this, a few new issues arises that has to be solved, and among these is the limiting battery capacity, especially for trucks which require a larger amount of power than small cars. A battery has a lower energy density than fuel, leading to a required larger volume if the same range is to be reached. If using the energy density of the most common batteries today, the volume would become too large to be functional for a transportation vehicle. If the battery instead was charged during driving, the possible driving range could be significantly increased [1].

1.1 Background

Since an electric vehicle usually has some amount of battery capacity, it would be sufficient to only have a grid of larger roadways where the vehicles could charge the battery or use the power for the drive. The battery range would be enough to be used on the smaller roadways in between this net. There are two main techniques for charging the battery whilst driving on a roadway; inductive charging and conductive charging. The conductive charging could be done in a number of ways, for example connecting to an overhead line above the vehicle, or connecting to a grid installed in the roadway under the vehicle. The inductive charging uses wire coils where the energy is transfered to the charger by varying the electromagnetic fields. This is an already proven technology. However, the technique has low efficiency, and due to that it is very expensive to build it is not a suitable choice for large-scale implementation. Conductive charging through a connection to an overhead line above the vehicle is also possible, but not very practical due to the difference in height between private cars and trucks. As the solution preferably should be applicable on all transportation vehicles, that option is not suitable. According to Elways [2], an option with connection to a grid installed in the roadways seems to be the most suitable way of charging. The charging would be possible for all types of vehicles and it would not be as expensive as inductive charging.

The conductive charging through the roadway comprise two major parts. One conducting rail installed into the roadway, and one contact connecting the rail to the electric motor or charging of the battery. Both parts can be designed in a number of ways, and Elways has developed one kind of rail that is both safe and can withstand tough weather conditions. The Elways rail consists of two tracks lowered into the ground, isolating the conductive parts from humans and animals. A picture of the rail from Elways homepage is presented in Figure 1.1 [2]. Elways is also developing the contact to connect the rail to the motor or battery charger [2]. The contact will be placed on an arm attached to the vehicle. The contact should be connected to the track without any interaction from the driver. Accordingly, the arm that the contact will be placed on has to be controlled, for instance by small electric motors and sensors. The system should be able to know when the rail is present and where the rail is positioned beneath the vehicle. The arm will drive the contact to the correct position and then connect it to the rail. When the contact is connected, the driver should not be forced to drive precisely along the rail, but must be allowed to sway a bit to not cause any dangerous situation. These are just a few of the requirements that will be put on the contact system. In this thesis, all requirements will first be developed, then realized with the aim that a fully working arm with all required properties will be built and tested.

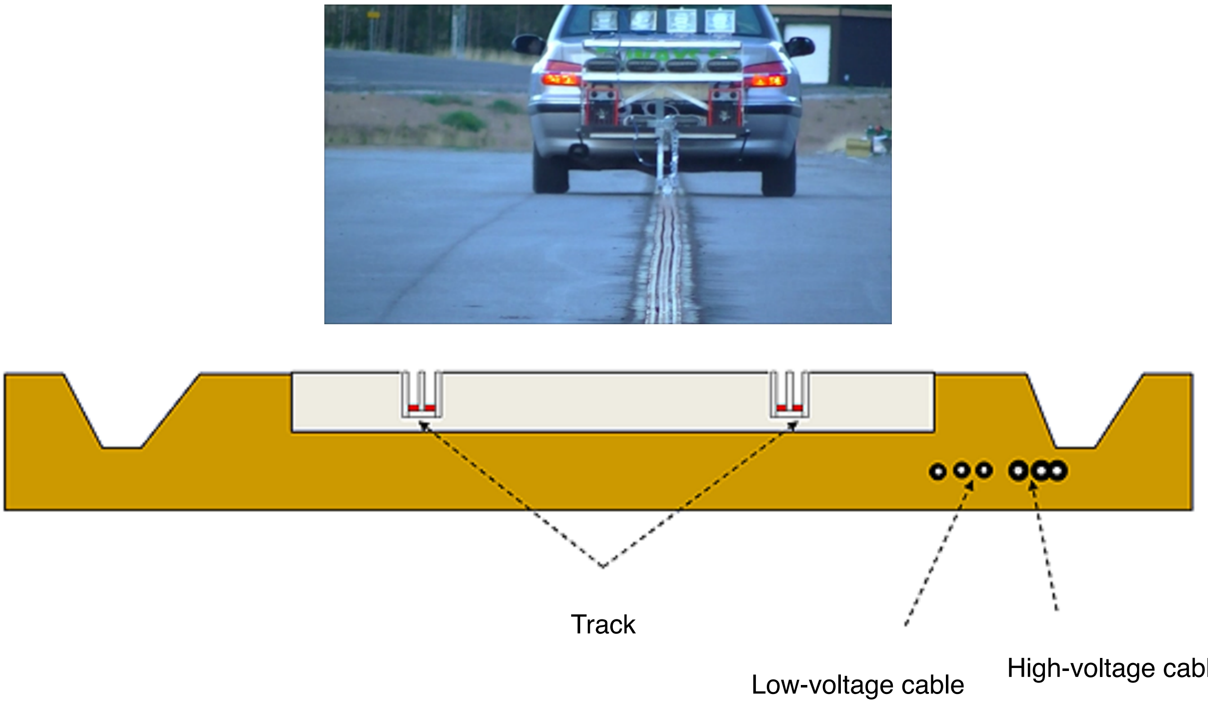

Figure 1.1: The track developed by Elways [2].

1.2 Aim

The main aim of this thesis is to develop, design, build and test a prototype of a contact system that transfers power from a track to an electric vehicle. The contact system consists of an arm moving the contact in vertical and horizontal direction, sensors for controlling the system and specifically a track detector system detecting the position of the track under the vehicle.

1.3 Tasks

As this thesis is built on a design process, a great part consists of practical work, such as building, soldering and testing different solutions and circuits. Considerable focus is on the functionality of the system, so that the contact system is applicable to the intended application.

The tasks in this thesis were divided up in three stages;

1. Design evaluation
    (i) Motors

   (ii) Sensors
   (iii) Controller
2. Developing
   (i) Ordering of components
   (ii) Building the system
3. Testing
   (i) Adjustments
   (ii) Testing on test track

In the design evaluation stage, analyze and evaluation of the different parts of the system have been performed in order to find the most suitable solution for this application. Each part of the system was investigated and a search on the market for existing solutions were performed and the results discussed. If no existing solution was found, appropriate to this application, a new solution have been developed. A design specification was taken forth from this investigation and evaluation, and have been included in the final report.

The developing stage first consisted of ordering the components specified in the design specification. Next step was to build the different parts in the lab for testing. The developing for each part continued until that part worked as intended. When all parts had been tested, they were assembled together. This included some mechanical parts as well as mounting the motors, sensors and arm. One critical part when assembling the system was disturbances between the different parts, which had to be considered. Whilst building the system, tests were performed continuously and adjustments and developments were made when needed.

When the tests in the lab were performed and the results were evaluated, adjustments were made to the system if it was needed. Further testing was performed until the system ran in a satisfactory way. The last step was to test the system on the outdoor test track in a realistic environment, and the final results were analyzed and evaluated as well.

1.4 Scope

The safety issues with this system will not be investigated in this thesis. This could for example consider fast turns made when driving a private car due to an emergency or block in the roadway. In case of an emergency situation, the contact has to be disconnected fast enough to not endanger the situation further by among other things keep the vehicle from turning. This is of course an important design aspect, but since this can be added as a feature in the future, this is left out of the scope.

Since the Elways-system still is in a testing phase to make the system work, the designed system will also be just a prototype suitable for future development. The system will be updated and adjusted for the final product, ready for the market. Because of this, specific parts of the system can be developed more and others left to future work. The only limit for this system is the time, and the development will continue as long as possible.

The mechanical parts of the system will of course be of great importance in this system. For these parts, guidance from the supervisor and staff at Elways will be utilized, since the main focus of the thesis will be on the electric motors, the control of the motors and the detectors.

1.5 Report structure

First, a design evaluation of the different design choices for the system available is presented. The chosen design specification is given in the next chapter. The development of the different solutions are presented including the control system and the track detector. The tests are then described together with the implemented adjustments. Finally, the results are analyzed and some conclusions about the functionality of the system is made.

2 Design evaluation

First, a short description of the whole system is presented to get a clear overview of the project. An evaluation of the different design choices is made in this chapter. Different solutions to each issue is presented and its suitability to this application is analyzed.

2.1 Description of the system

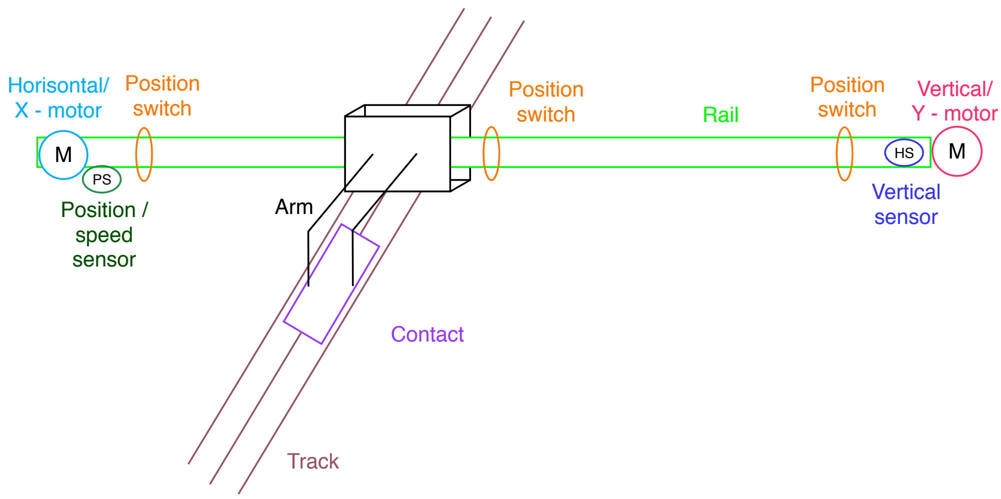

Figure 2.1: The nomenclature of the whole system to be developed, built and designed.

A figure of the system with its nomenclature is presented in Figure 2.1. The contact system can be attached to an electric vehicle, both cars and trucks, and should electrically connect the battery of the vehicle to the electric track in the road. The contact should connect without any interaction of the driver, i.e. automatically when a track is present in the road. For this prototype the contact will, when given a start signal from a manual switch, lower the contact to be a bit above the road, so that the sensor finding the track is close to the road. The arm should then move from side to side along the back of the vehicle and then stop when the sensor gives the signal that the track is found. After stopping, the contact should be lowered a bit further down on the road. If the contact is not lowered directly into the track, it should be dragged on the asphalt until the contact is connected to the track. The contact might not connect directly as the vehicle is in motion while connecting, and the vertical movement would have to be very fast for it to be possible. To drag the contact on the asphalt is a first version of the solution to connect the contact. This will be no problem for the contact, as it is designed to handle to be dragged without being worn. When the contact finally is in the track, the arm should lower the contact completely to press the contact into the track and hold it steady. This should all be performed while the vehicle is moving.

The arm with the contact should be able to move in the linear horisontal direction. One motor (X-motor) should steer the arm to the correct position on the rail. It should also be able to be decoupled when the contact is lowered onto the roadway and properly connected. It should be decoupled so that the contact can move freely along the rail so that the vehicle is allowed to sway and not follow the track along precisely. One horizontal motor (Y-motor) should lift and lower the contact from the vehicle to the roadway and the track. This could be done in different ways which will be investigated in this thesis.

In order to control the system in an efficient way, a number of sensors are required. The sensors included in the system are; a detector to detect the position of the track under the vehicle, a position detector to know where the arm is positioned in horisontal direction together with position switches for calibration, a speed sensor to get information of the speed in horisontal direction, position sensor in horisontal direction and a sensor for knowing when the contact is in the track. These all have requirements which will be developed and a search on the market together with discussions will be made to find alternatives and possible solutions.

2.2 Horisontal movement

The horisontal movement can be achieved in a number of ways. The most common types are screw-nut systems, linear motors and cog wheels. These three alternatives will be evaluated from the requirements below.

2.2.1 Mechanical system

The requirements for the horisontal system is important to consider when choosing design. The list of requirements for the system is presented below. The three alternatives are then described and evaluated. The chosen system together with the motivation is presented in the design specification.

- Environment: the system has to be robust and withstand hard strains such as dirt and fast changes in movement, as it will be placed on a driving vehicle in all sorts of weather.
- Design: the movement will be limited to around 1,5 m. It should be as small, flexible and run as smooth as possible. It should be easy to enclose to protect from dirt and weather. The system should preferably in this stage be easy to alter and adapt.
- Mechanical requirements: the system has to handle a certain amount of force as the contact will be dragged on the asphalt for a short while before the connection is made. The system has to be able to decouple the arm at signal, and also re-connect from stationary or moving.

2.2.2 Screw-nut system

This system consists of a screw, a nut and a motor turning the screw, leading to a movement in the nut. The distance between the threads can be adjusted to set the precision. The system is very robust, and a very accurate positioning can be achieved. However, the system is not suitable for longer distances and 1,5 m may be at the limit. The decoupling can be arranged by dis-connecting the nut from the screw. However, re-connecting the nut could be difficult.

2.2.3 Linear motor system

This is a system that is common for shorter distances. Instead of rotating, the movement is linear. This can be achieved as the poles of the motor are placed after each other instead of in a circle [3]. Drawbacks for this system is limitations in speed combined with force, and the fact that decoupling may be difficult. There are a number of already built linear systems, ready to use, on the market, but these are mainly intended for industrial applications such as robots for precise positioning and placing. They may be difficult to alter, so the required qualities has to be built in the system. It is not common with decoupling in such applications. The advantages are that the systems are robust and capable, and it would be an easy solution to use an already built system.

2.2.4 Cog wheel system

By using a cog belt connected to a cog and a motor, a movement in the horisontal direction can be achieved. This system is very simple, easy to alter and can easily be decoupled if a electromagnetic clutch is used. Accurate positioning can be hard to achieve, as the cog belt is never completely stiff. This is the system used in the already existing system.

2.2.5 Motors

The motor moving the contact along the rail in the horisontal direction is called the X-motor, or the horisontal motor. The X-motor is a DC-motor as the available power source is a 12 V battery. The size of the motor depend on the amount of force it should be able to handle. Preferably, the motor should work with 12 V as the power source is 12 V.

The control of the motor can be performed in a number of ways. Two methods were chosen to be tested and evaluated carefully. The first system is based on a ready-made control board from Velleman called ”K8004”. It takes a DC signal and gives a pulse-width-modulated (PWM) signal between 8-35 V, of maximum 6.5 A, with adjustable frequency of 50 Hz - 70 kHz [3]. This requires a controlled DC signal to the board, that should be controlled from the microprocessor. A simplified block diagram over this method is presented in Figure 2.2.

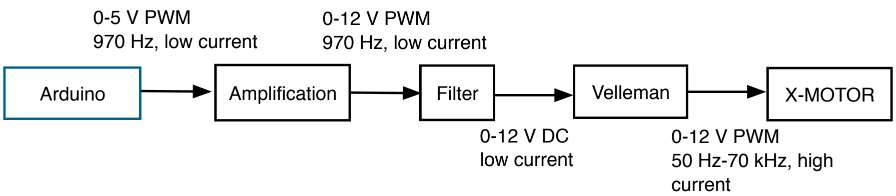

Figure 2.2: Block diagram over the first evaluated method of X-motor control.

The Arduino can only produce a PWM signal between 0-5 V with a frequency of 500 Hz or 970 Hz. The signal needs to be converted to a DC signal. The maximum output of 5 V also needs to be increased to 12 V from the battery. This can be realized using the circuit presented in Figure 2.3. The circuit is build in two steps. The first step increases the 5 V to 12 V, and the second step is a filter to transform the PWM signal to a DC signal. The first step is realized by using an PNP bipolar transistor. The PNP stands for which type of doped material is used, and in which order. The circuit could be made simpler if using an NPN transistor. However, at that time, only a PNP transistor was available for building. The bipolar transistor can among other things work as a switch or an amplifier. In this case the transistor works as a switch. A simplified explanation could be as follows; when the PNP transistor is forward biased over the collector and base, the transistor will work as a closed switch and collector current will run from the collector to the emitter. When collector and base is not forward biased, the PNP transistor works as an open switch from collector to emitter [4]. The PWM signal is transferred through the transistor by switching the voltage from the battery on and off with the same frequency and duty cycle.

The circuit works according to the following. The base point of the transistor is limited to 12 V plus the forward voltage of the diode, which is negligible in this case. When the Arduino gives 5 V output, the base point of the transistor will accordingly have 12 V, and the diode is forward biased. The transistor blocks as the voltage over the collector and base is reverse biased. When the transistor blocks, the voltage at the output will be grounded, i.e. 0 V. When the Arduino changes value to 0 V in the PWM, the voltage at the base point sinks to 7 V (12-5 V) and the diode gets blocked. Since the voltage over the collector and base now is forward biased, the transistor will be active. This will give the output voltage 12 V, as it is connected to the battery. The 0-5 PWM duty-cycle will be transformed to an inversed 0-12 PWM duty cycle.

By using this circuit a 12 V PWM signal is attained. However, the motor board requires a DC signal to in turn give a PWM with much higher frequency. The filter connected to the output is a simple low-pass RC filter, taking away the PWM signal and giving a DC voltage out between 0-12 V instead. The filter is designed to have a cut off frequency of

$$f_c = \frac{1}{RC2\pi} = \frac{1}{1 \cdot 10^3 \cdot 47 \cdot 10^-6 \cdot 2\pi} = 3,4Hz \qquad (2.1)$$

only leaving the DC level of the signal.

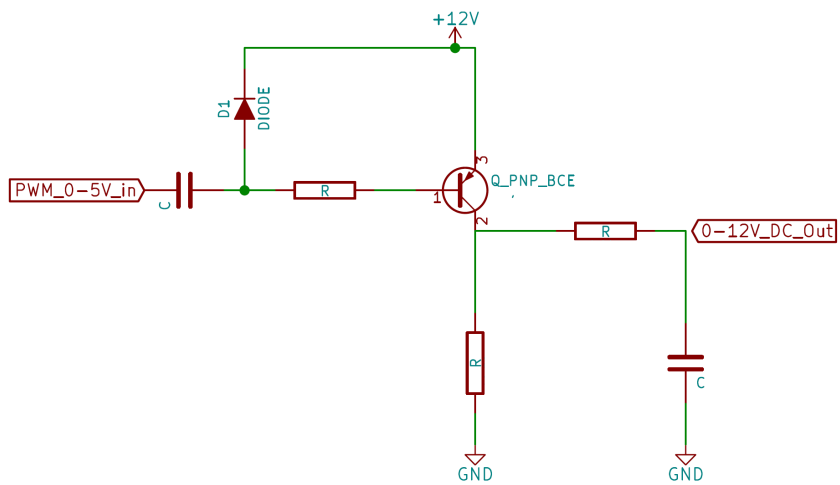

Figure 2.3: The circuit taking a 0-5 V PWM voltage and giving a 0-12 V DC voltage.

The other motor control method tested uses the PWM voltage with a frequency of 970 Hz from the Arduino and simply amplifies the signal. A simplified block diagram over this method is presented in Figure 2.4. This can be done by using transistors connected to the battery in a similar way as for the previous method. The circuit used for this evaluation is presented in Figure 2.5. The first part increases the voltage level from 0-5 V, to 0-12 V. The next part amplifies this signal and the configuration allows a high current directly from the battery. By using this configuration as shown in Figure 2.5, the current going to the motor will pass through the transistors. Therefore, the transistors has to be able to handle high currents. Transistors that can handle up to 20 Ampere are used.

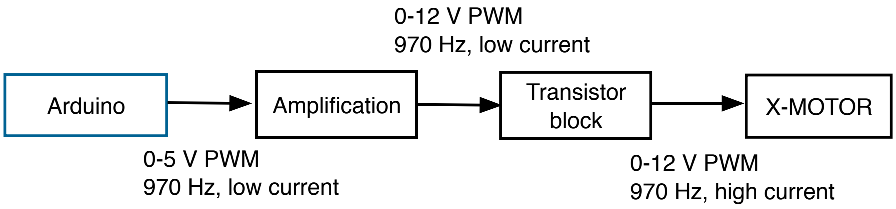

Figure 2.4: Block diagram of the second method evaluated for X-motor control.

In this circuit, the transistors work as switches. When the signal from the Arduino PWM is high, i.e. 5 V, the transistor T_1 is forward biased and current flows from the collector to the emitter. This will sink the voltage V_1, connected to the base of both transistors in the next step. When the signal from the Arduino is low, i.e. 0 V, the transistor blocks and V_1 is connected to the battery through the resistor of 50 Ohm.

The voltage V_1 controls if the transistors in the next step will be open or closed between collector and emitter. When V_1 is 0 V, the PNP-transistor, T_3, will be closed, giving the voltage V_2 ground potential, 0 V. At the same time the transistor T_2 is open. When the signal at V_1 is high, the NPN transistor will be closed and give V_2 12 V from the battery. Transistor T_2 is open. The diodes are there to protect the transistors as the load is a motor which is inductive and will discharge when the voltage is dropped.

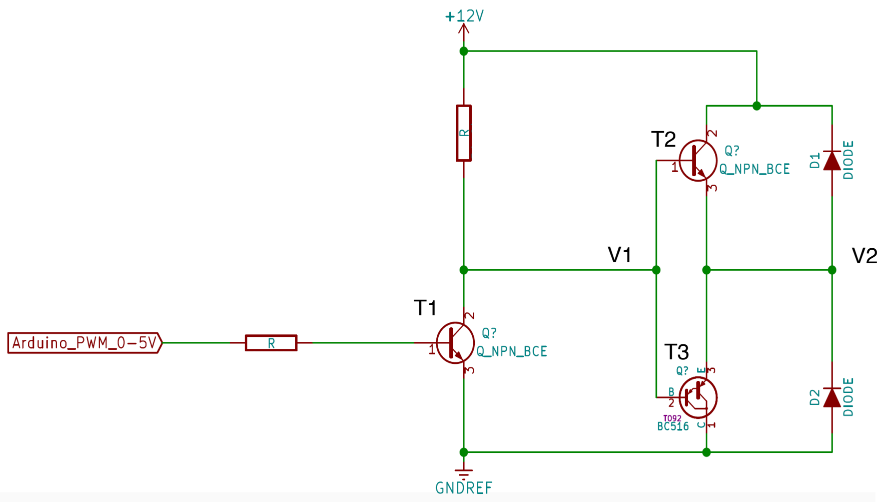

Figure 2.5: The circuit used to amplify the PWM signal from the Arduino.

These two systems only give positive voltage to the motor, i.e. moves the motor in one direction. As the motor should be controlled in both directions, both positive and negative voltage is required. This can be solved by connecting relays and control the relays as well. This has the disadvantage of more components, and the risk of relays breaking. It could also be solved by using two boards, or two output signals. This can be configured in different ways and two were evaluated here.

One way to control the motor in both directions is to connect the two signals with reversed polarities. As the signals both give 0-12 V the signals can simply be controlled one at a time. The disadvantage with this system is that it is easily short-circuited which could damage the system. The signals could also be a bit noisy, which could lead to problems around applying zero voltage.

Another way of using two signals to control the motor in both directions is to connect one to each pole of the motor and have both give 6 V for a total of zero applied voltage. If the signals are applied in opposite to each other, giving a resulting voltage of -12 V to +12 V. If a sinus-shaped voltage was applied when increasing of decreasing from maximum and zero, around 6 V, a smooth control can be achieved. Both signals and the resulting applied voltage for this method is presented in Figure 2.6. As the applied voltage is sinus-shaped, it results in an even movement of the motor.

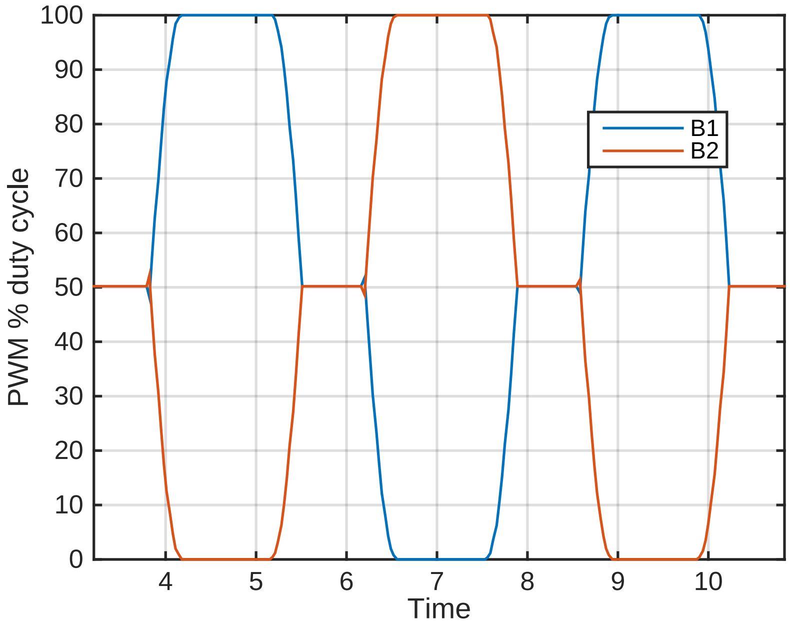

Figure 2.6: Resulting signal over motor by applying one signal to each pole of the motor.

2.2.6 Decoupling

As described in previous sections, the horisontal motor should be able to de-couple the arm at a signal. A search was made to find possible decoupling methods. The decoupling could be made mechanically. This could however be complicated to perform, as the decoupling should be made at a given signal. An alternative to using a mechanical solution would be to use an electromagnetic clutch. It consists of a coupling that is connected and disconnected when voltage is applied and taken away from it. The coupling is made via magnets that gets activated when voltage is applied. The magnets connect the clutch to the system.

There are a number of companies making these kinds of clutches, of various sizes and prices. The requirements on the clutch is the following.

- Environment: the system has to be robust and withstand hard strains such as dirt and fast changes in movement, as it will be placed on a driving vehicle in all sorts of weather.
- Design: it should be as small, flexible and run as smooth as possible. It should be easy to install to the system.
- Mechanical requirements: the coupling must be strong enough to be able to move the arm when connected. It has to run freely when decoupled to not cause any resistance when the arm is connected to the track. It has to be able to re-connect from standing still, but also from when the arm is moving, to be able to have complete control over the arm. The re-connection should be made fast and preferably quietly.

2.2.7 Sensors

A number of sensors are required to make the system work as intended. Switches are required to get feedback information of the position. A position sensor and speed sensor are also necessary to get complete control of the system.

Breakers

Some kind of breakers should be placed at both sides to not have the arm smash into the side of the rail if something goes wrong in the control. The end breakers should be placed at a short distance from the very end of the rail, so that the signal is given before the end point. The appropriate distance will be tested and will depend on the speed of the motor and the mechanical system.

Mechanical breakers are used on the already existing arm, which are a bit fragile, noisy and unnecessarily complicated to place. If instead magnetic hall effect switches were used, the breakers would be robust, insensitive to dirt, and silent. Hall effect sensors are mounted on the desired number of places on the track for switching, and magnets will be installed on the arm. When the magnet is in the vicinity, the switch will give a signal. A market scan was performed for suitable sensors and a number of alternatives were found. The switch should be easy to mount, have a reasonable required distance to the magnets and withstand dirt. It should preferably give an digital output signal of 5 V, and use a supply voltage of either 5 or 12 V, as these are the DC voltages easily available.

Position sensor

In order to perform control of the system, the position of the arm needs to be known. A number of position sensors can be found on the market, and they were evaluated for this system. The requirements for the position sensor is the following.

- Environment: the sensor has to be robust and withstand hard strains such as dirt and fast changes in movement, as it will be placed on a driving vehicle in all sorts of weather.

- Design: it should be as small, insensitive and flexible as possible. It should be applicable to the existing system.
- Mechanical requirements: the sensor should be able to measure around 1,5 meters. The accuracy is not required to be very high, around 5 mm is enough.

A good alternative as a position sensor would be a potentiometer. The value of the potentiometer is decided by the position of the arm. This could be used, but a market scan showed that most existing systems are not applicable for such long distances, or gets very expensive for those distances. A simple resistive thread could instead be mounted along the rail and used with the same principle as a potentiometer. The arm would then be connected to the thread and give different resistance values depending on the position. This would however be very fragile and not suitable for the tough environment.

Another alternative is a wire sensor. A wire sensor consists of a wire that simply follows the arm movement and the drawn out length of wire is measured. This is a robust system, however it is sensitive to dirt, and is limited in speed.

Next evaluated method was an angle sensor that could be placed on the horisontal motor, measuring angle and number of turns. The angle would be transformed to distance in horisontal direction.This is very robust and applicable to the system.

If a proper speed sensor was used, the speed signal could be integrated in the software and the position attained. This would be preferable as fewer sensors are required and integration is relatively easy to perform in the software.

Calibration would be recommended for positioning to increase the accuracy. This could be performed by using one, or a number of switches mounted at specific places along the rail that resets the positioning to a specific value.

Speed sensor

In order to get a complete control of the movement in the horisontal direction, a speed feedback would be necessary. This can be achieved in a number of ways, but is not trivial in this system. If a good position sensor can be achieved, a derivation of the position would give the speed. This is however not trivial to perform in reality. As the movement is controlled by a DC-motor, the current can instead be measured, the EMC can be estimated and the speed calculated. This gives a lot of uncertainty to the measurement.

Another way of getting information of the speed is to attach a small DC generator on the motor shaft, acting as a generator. As the speed increases, the voltage from the generator increase. If a calibration is performed for voltages against speed, the speed can be measured. If information is available about the speed, an integration would give the position, which is a lot easier than performing derivation.

2.3 Vertical movement

The vertical movement has to be able to move the whole system with arm up and down. It will have three positions; up, searching for the track, pressed and connected. The requirements and different parts of the system are presented below.

2.3.1 Mechanical system

The mechanical system has a number of requirements which all have been considered when evaluating the system.

- Environment: the system has to be robust and withstand hard strains such as dirt as it will be placed on a driving vehicle in all sorts of weather.
- Design: the system should be easy to enclose to protect from dirt and weather. The system should preferably in this stage be easy to alter and adapt.
- Mechanical requirements: the system has to move the contact in the vertical direction, and be able to press the contact to the track to have a constant connection. It should be strong enough to lift the whole system and to stop and start at different pre-determined positions. It should preferably stop and be strong enough to hold the arm when no voltage is given to the motor.

When the signal is given that the vehicle is driving on an electric road with the track present, the system should start to search for the track. The arm should be lowered to around a decimeter above the road, the distance will be depending on how sensitive the track detector is and what is a safe distance. These distances should be easy to alter as the most suitable distance will be discovered during testing. The arm should be stopped and preferably stay in a lifted position by just the motor. A mechanical system with for example a spring could also be used.

There are a number of ways to move the contact in the vertical direction. Either the whole arm and vertical movement system is placed on a hinge and the motor moves the whole system. The other alternative is to only connect the arm to the motor. To use a hinge would be easy to install and stable as the motor is placed stationary. If only the arm is lifted, the vertical motor has to be moving along with the arm, which also would increase the force required from the horisontal motor.

The contact will not be connected to the track immediately, but will move on the asphalt for a while before connecting. The system should be lightly pressed against the asphalt to be able to connect to the track when passing it. When the contact is in the track, the motor should lower the arm to maximum to connect.

2.3.2 Motors

One motor is required to move the system. The motor moving the contact along the rail in the vertical direction is called the Y-motor, or the vertical motor.This has to be very strong and relatively fast to move the whole system. It should be as fast as possible to connect to the track quickly. It should preferably be able to hold the arm in a lifted position when turned off, i.e. no voltage applied.

Two kind of motors were available for evaluation. The first one is a motor used for a windshield wiper in a car. It provides a rotational movement and is very strong and also fast. However, the motor cannot hold the arm at lifted positions as it gets too heavy. Some kind of voltage control could be used to solve this problem, and hold the arm still at positions. A spring could also be attached to the arm that the motor stretched when pushing the arm down. The problem with a spring is that a number of positions is required for the arm; uplifted, searching and connected. The spring would only keep the arm uplifted when the motor is turned off.

The other motor is a linear motor that provides linear movement. This motor is relatively slow but rather strong. It is strong enough to hold the arm still in lifted positions. The biggest disadvantage is that the motor is slow. If a faster linear motor would be used, this problem is solved.

If an overtaking is performed by the driver of the vehicle, or an emergency situation would occur, the arm has to be lifted immediately from the track. This is an important design aspect that needs to be included in the system. A mechanical system could be built to make this possible. This will not be included in this prototype of the arm for this project, because of the time limitation. This is however discussed in future work in the end of the report.

The horizontal movement does not require any speed control. The movement will only consist of on and off, but in both directions, and stops at suitable places. The control of the motor can be performed by using relays. As the speed is not controlled, and just an on and off signal should be given to the motor in both directions. Relays exist in numerous ways, and can be connected in different configurations. A few examples of connections are presented in 2.7.

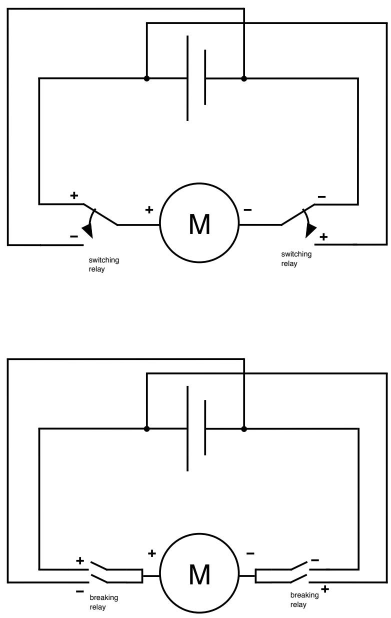

Figure 2.7: Suggestions for control connection of the vertical movement using relays.

2.3.3 Sensors

In order to get the motor to stop at three different positions, some kind of sensor is required to get information about the position. This could be done by using an angle sensor, if the sensor is placed on the same axis as the hinge. Another way to do this is to use breakers placed at the positions where the motor should stop. If using an angle sensor, very accurate positioning can be performed, and adjustments can easily be made in the software. If using the switches the positions can easily be altered at the testing spot by physically moving them. The advantage of switches is that no calculation or tests is required to know where the arm will stop. The advantage of the sensor is that it is easy to alter in the software and accurate positioning is available. Both methods require tests and calibration to get the correct positions.

A sensor is also required to get a signal for when the contact is connected, i.e. the track has been found correctly and the contact is in the track. This could also be attained from an angle sensor, as the arm will be lowered to a new position when the contact is lowered into the track. A mechanical or magnetic switch could also be used.

2.4 Track detector

The track detector is designed similar to a metal detector. The basic principle is to use coils which changes impedance as the nearby material changes. The total magnetic flux through a coil is given by

$$\phi = \frac{\mu_0 \mu_r N i A}{l} \tag{2.2}$$

where μ_0 is the relative permeability of vacuum, μ_r is the relative permeability of the material within the coil, N is number of turns, i is the current, A is the cross-section area and l is the length of the coil. The inductance can be calculated from

$$i \cdot L = \phi \cdot N \tag{2.3}$$

by using the equation

$$L = \frac{\mu_0 \mu_r N^2 A}{l} \tag{2.4}$$

which depends on the material in the vicinity. If the coil is approached with for example a metal object, the permeability will change and the impedance changes as the inductance will be different. This can be utilized in a number of different ways. Two alternatives are analyzed in this project, to compare sensitivity. In order to be able to measure a change in impedance, voltage needs to be applied to the coil. As it is a coil, an AC voltage is required for the system. The only voltage source available is a 12 V battery, so a circuit is required to give an oscillating signal. The oscillator should give out a sufficiently strong signal to be put on a coil, and it should be simple and efficient. The first evaluated system for track detection uses three coils in total. The other system uses only one coil, and both are presented in more detail below.

2.4.1 Three coil detector

In this system, an AC voltage is applied to one larger coil, in order to create a altering magnetic field around it. Two smaller coils are placed as close as possible to the coil, at a symmetric distance from it. The altering magnetic field from the larger coil will by induction cause voltage over the smaller coils, as

$$U = \frac{d\phi}{dt} \cdot N \tag{2.5}$$

If the coils are placed exactly symmetric and they have the same inductance, the resulting induced voltage measured over each coil will be the same. Consequently, if the voltage across both of the coils are measured, and the coils are placed opposite each other, the measured voltage will be zero. The magnetic field will change if the material in the vicinity changes, as the inductance changes according to equation (2.4). When iron approaches the coils, the voltage across each smaller coil will no longer be the same, and the voltage across both will not be zero. This signal can be measured and amplified, and will signal when iron is close.

The three coil detector circuit is shown in Figure 2.8. The oscillating signal is put on the larger coil L1, resulting in the altering magnetic field. The smaller coils, L2 and L3, is placed very close to L1, and a voltage is induced because of the changing magnetic field. The voltage is measured over both coils. The voltage from the coils are rectified simply by placing diodes in series with the signal. The rectification of the signal is made to get a positive signal out only for the amplification in the later stages. The signals from the coils is kept to a stable level by a capacitor, placed over the measurement points. A resistor is placed in parallel with the capacitors for discharging. The output should be amplified and sent to a comparator to get a digital signal for the microprocessor. This is explained further in section 4.3.

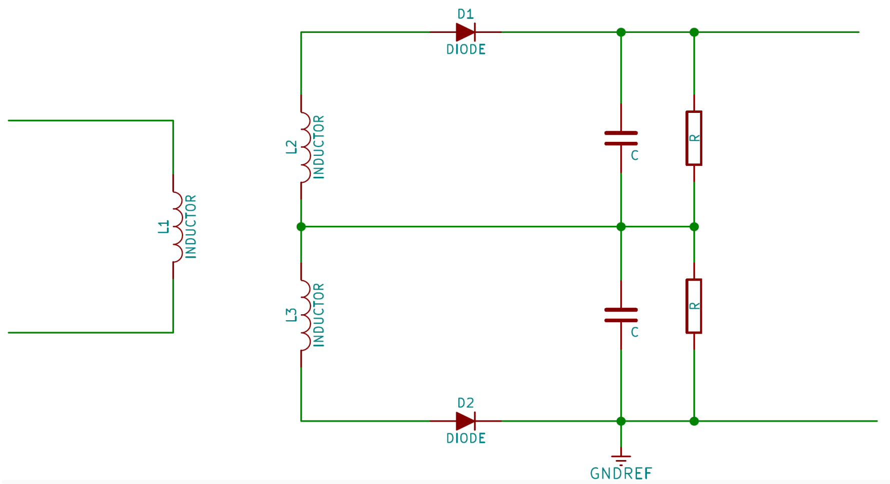

Figure 2.8: The circuit of the track detector using three coils.

The two smaller coils, L2 and L3, will never in practice be exactly the same, and the magnetic field could never in practice give the same values for both coils. This is solved by having a high pass filter, filtering out the DC-component. By doing this, only changes in the signal is detected, which is enough for this application.

2.4.2 One coil detector

This system is also built on the principle that the inductance of a coil changes when the material in the vicinity changes. For the one coil system, the oscillating signal is placed upon one coil connected to a capacitor in series. The capacitor is added in order to decrease the total impedance. A resistor is also connected in series to the circuit in order to limit the current in the circuit, as the impedance of the coil together with the capacitor could get to zero, i.e. in resonance. The circuit is shown in Figure 2.9. These three components are connected to the oscillator giving a AC voltage.

The measurement is performed over the coil and the capacitor, as can be seen in Figure 2.9. By setting the value of the capacitor, the total impedance over the measurement can be adjusted.

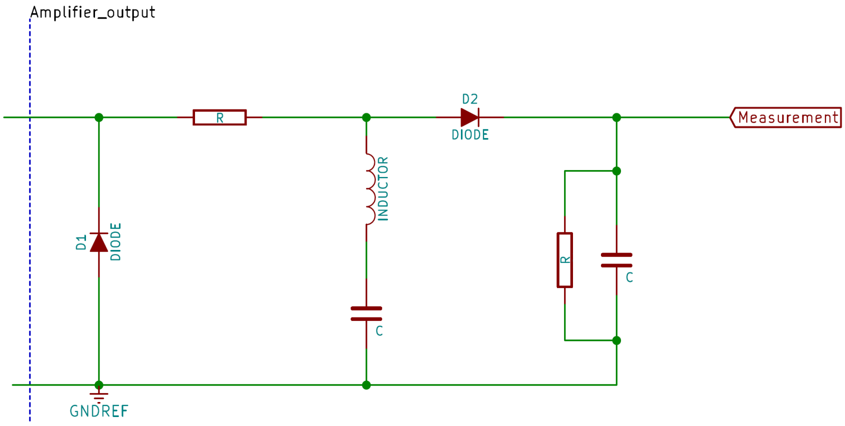

Figure 2.9: The circuit of the track detector using one coil.

If setting this total impedance low, a small change in the inductance of the coil can be detected. When the coil is approached by iron, its impedance will change, and consequently, the measured signal will change.

The capacitance was chosen to be a bit lower than the impedance of the coil, in order to get a low value of the total impedance of both components. If the total impedance is low, a small change in the impedance of the coil will be more noticeable, consequently making the detector more sensitive than without the capacitor. The impedance of the coil was estimated by calculating the current from the measured voltage and frequency over the capacitor, together with the capacitance. The voltage and frequency over the coil is also measured and the inductance can be calculated. Different values of the resistor and capacitor were tested, and the resulting chosen values can be seen in Figure 2.9.

The signal is rectified by a diode and held up by a capacitor with a resistor in parallel. The signal is, as for the three coil system, sent through a high pass filter, where the DC-component is filtered out. The signal is amplified and then sent into a comparator to get a digital signal for the microprocessor. This is explained further in section 4.3.

The output from the oscillator which is applied to the circuit includes a capacitor. By adding the diode D2, reciftying the signal, the capacitor made the signal negative. This could be solved by placing another diode D1 as in Figure 2.9, to keep the signal positive. The rectifying diode makes it necessary to include another diode to keep the voltage above zero voltage.

2.4.3 Tests

Both systems were built and tested. Both principles worked as intended but a few differences exist. First of all, the system with three coils obviously require more components and have a bit more complicated system. The advantage with the three coil system is that if developed further, one can attain information about from which direction the track is approaching. This could be an advantage for the control of the motors. However, the one coils system proved to be a bit more sensitive than the three coil system. This is an advantage as a distinct signal is wanted, and the detector should be as far away from the ground as possible to increase security.

3 Design specification

This chapter includes the design specification for the system. All chosen methods and designs are presented that are evaluated in the precious chapter. A picture of the finished system can be found in Figure 3.1.

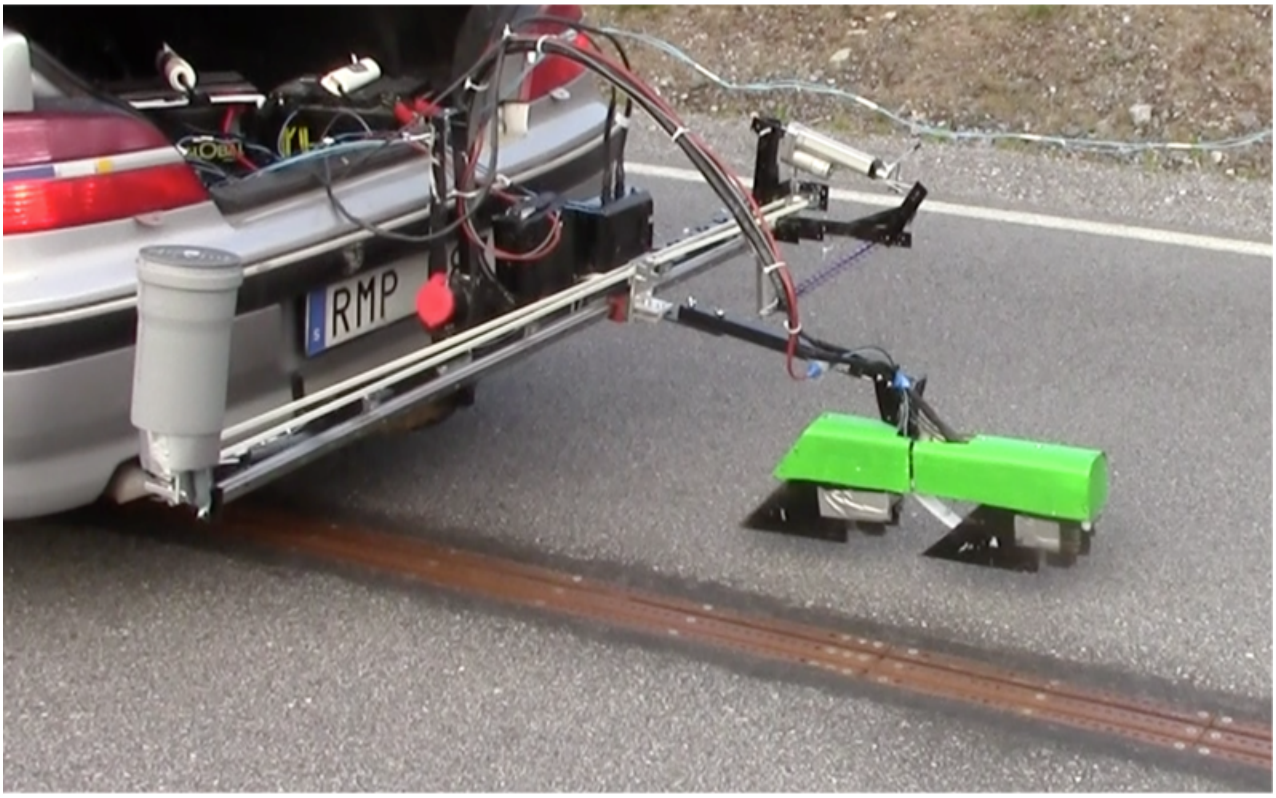

Figure 3.1: A picture of the finished system with all parts installed. The X-motor is covered to the left, and the linear Y-motor can be seen to the right.

3.1 Horisontal movement

The choosen designs for the horisontal movement are presented below. This is used when building the system, but alterations may be performed as the test results are analyzed.

3.1.1 Mechanical system

The horisontal movement is performed by having a cog wheel and a DC motor controlling it. The mechanical system is built by staff at Elways.

3.1.2 Motor

The choosen DC motor is a 12 V motor that was already available at Elways.

3.1.3 Control

The control of the motors will be performed by using the amplifying system from the Arduino PWM. The frequency of the PWM from the Arduino is normally 500 Hz, but it can be set to around 900 Hz at most. A simple speed control will be included in the code. The contact should in a normal state move in a sinus form, and the voltage will be set for this. This will be possible as the speed is given as a feedback to the system. Also, the force from the motor will be different depending on the different situations. When the contact is dragged on the asphalt, the speed should still be kept, resulting in a higher voltage.

3.1.4 Decoupling

The decoupling is made by using an electromagnetic clutch, that is attached to the system when a signal is given. When the signal is low, the arm is decoupled and can run freely on the cog wheel.

3.1.5 Sensors

As the speed is required for the speed controller, the position can be attained by the same system. If the signal is simply integrated in the control code, the position can be calculated. The speed is attained by attaching a small DC generator to the motor axis. The integrator will be reset at one or more selected positions. These positions will be decided from tests.

The breakers used for the horisontal system is chosen to be magnetic switches, as it puts least mechanical stresses on the system, and is very simple. A number of magnets are placed on the moving arm, and switches are put on decided places along the rail. Signals for the end of the rail, the middle and perhaps in between for positioning will be set.

3.2 Vertical movement

The chosen designs for the vertical movement are presented below. This is used when building the system, and alterations may be performed as the test results are analyzed.

3.2.1 Mechanical system

The vertical movement is achieved by placing the whole system on a hinge and have a motor move it. The position is decided from an angle sensor placed on the axis of the motor. When the arm is lowered onto the ground for connection, a light pressure is present by installing a spring to the system.

3.2.2 Motor

The motor used has to be strong and fast. A strong linear motor is used that takes 12 V. This one is chosen as it is able to stop and hold the arm at specific positions without any mechanical arrangements. The motor used may be too slow for the final product, but is able for this version.

3.2.3 Control

The control is performed by using two switching relays. The connection is presented in Figure 3.2. This requires least amount of components, and has least risk of short-circuiting.

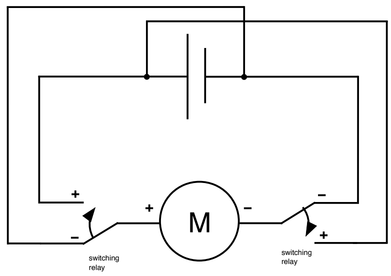

Figure 3.2: The relay connection used for control of the vertical movement.

3.2.4 Sensors

An angle sensor is used to decide the position of the arm in the vertical direction. Four fixed positions will be used; up and waiting, down around 10 cm above the ground searching for the track, down for dragging the arm to the track and max low when connected to the track.

A sensor is also required to get information about if the contact is connected to the track. For this, the angle sensor will be used as the arm will lower when the contact connect to the track.

3.3 Track detector system

The one coil system is used as it is more sensitive, requires less components and is less complicated.

4 Developing

The development of the system from the design specification is presented in this chapter. There are two systems that require more development for this thesis; the control of the motors and the track detector. The control is made in Arduino and the track detector is build from the chosen system in the design specification.

4.1 Building the system

For the testing in the lab, and later on the test track, the system was constructed and built. The system was built using all parts decided in the design specification.

4.1.1 Horisontal movement

The horisontal movement is achieved by using a cog wheel and a cog belt. The cog is placed on an electromagnetic clutch that can be de-coupled at signal. The motor is connected to the clutch and the small DC generator used as a speed sensor is mounted on the axis.

4.1.2 Vertical movement

The vertical movement is achieved by mounting the arm on a hinge that is controlled by a DC motor. According to the specification, the linear motor should be used and mounted on the axis of the hinge to move the arm up and down in the vertical direction. This was mounted and worked well in moving the arm and holding it still in lifted positions.

4.1.3 Control box and cables

All circuit boards built for the different parts of the system along with the Arduino microprocessor is mounted in a plastic box, from here on called control box. To avoid disturbances, the track detector is mounted in a separate metal box with a separate supply battery voltage. The angle sensor is also mounted in the track box, to decrease the disturbances from the other parts of the system.

One important practical issue is connecting the cables from the control box to the arm. Suitable contacts should be used to easy move and connect the system after moving. The cables from and to the control box were divided into two groups; signals and motor supply. The different cable groups are presented in Figure 4.1.

4.1.4 Track detector

The circuit boards for the track detector were as previously mentioned mounted in a separate metal box to avoid disturbances. The coil needs to be installed in or on the contact in some

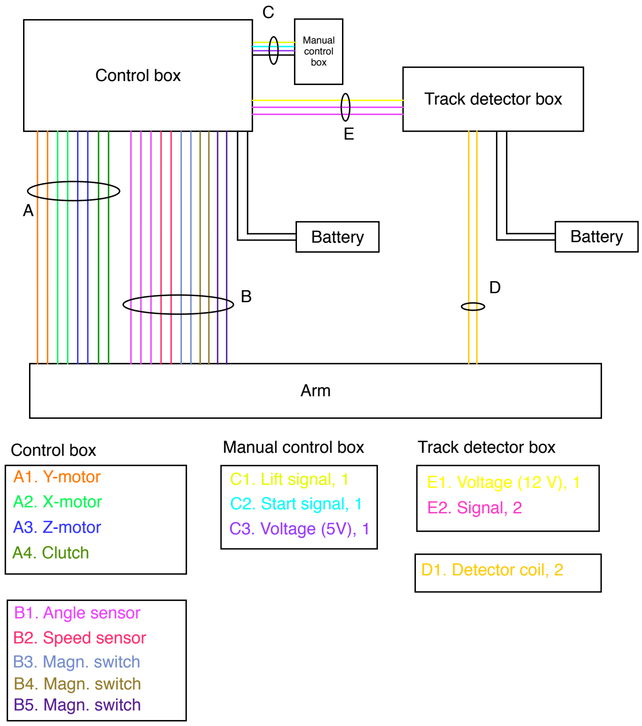

Figure 4.1: The configuration of the cables and parts of the whole designed system.

way to get as close to the ground as possible, to get a distinct signal. The coil is milled into one of the ”legs” of the contact, making the coil protected but still close to the ground. This introduces some safety issues if the contact for some reason would break and the coil would get contact with the track. By using an isolating transformator for the signal given to the coil, this problem is solved.

4.2 Control of the motors

The control of the motors are developed in the Arduino software, using an Arduino board called MEGA 2560, based on a microprocessor called ATmega2560. There are 54 digital input/output pins and 16 analog inputs. It is powered from a DC voltage between 7-12 V. The preferable voltage lies in between these values so a converter is used to get 9.5 V from the 12 V battery [5].

4.2.1 X-motor control

The chosen control amplifies the PWM output from the Arduino by two steps of transistors. Two boards are used and connected to each pole of the motor. The connection is presented in Figure 4.2. The PWM from the Arduino controls two transistors but are connected as an H-bridge, as can be seen in Figure 4.2. The resulting voltage over the motor together with the configuration of the transistor switches is shown in Figure 4.3. When positive voltage is applied over the motor, i.e. the motor is moving ”forward”, the current moves according to the red arrow in Figure 4.3. When negative voltage is applied over the motor, i.e. the motor is moving ”backward”, the current flows according to the blue arrow. The resulting voltage over the motor is a PWM signal, meaning that it is either +-12 V, or 0 V. When 0 V is applied the two top transistors, or the two lower transistors in Figure 4.3 is active, while the other two are open.

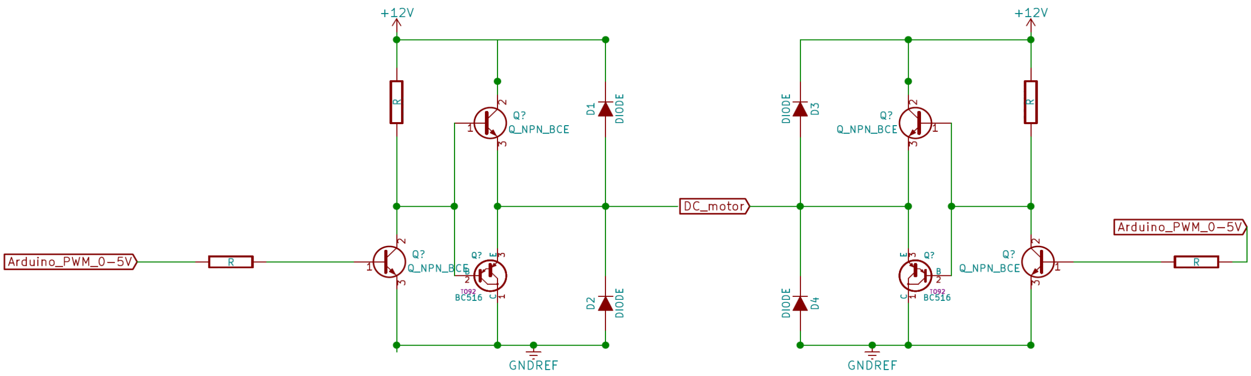

Figure 4.2: The circuit of the X-motor control with the connections to the two control boards.

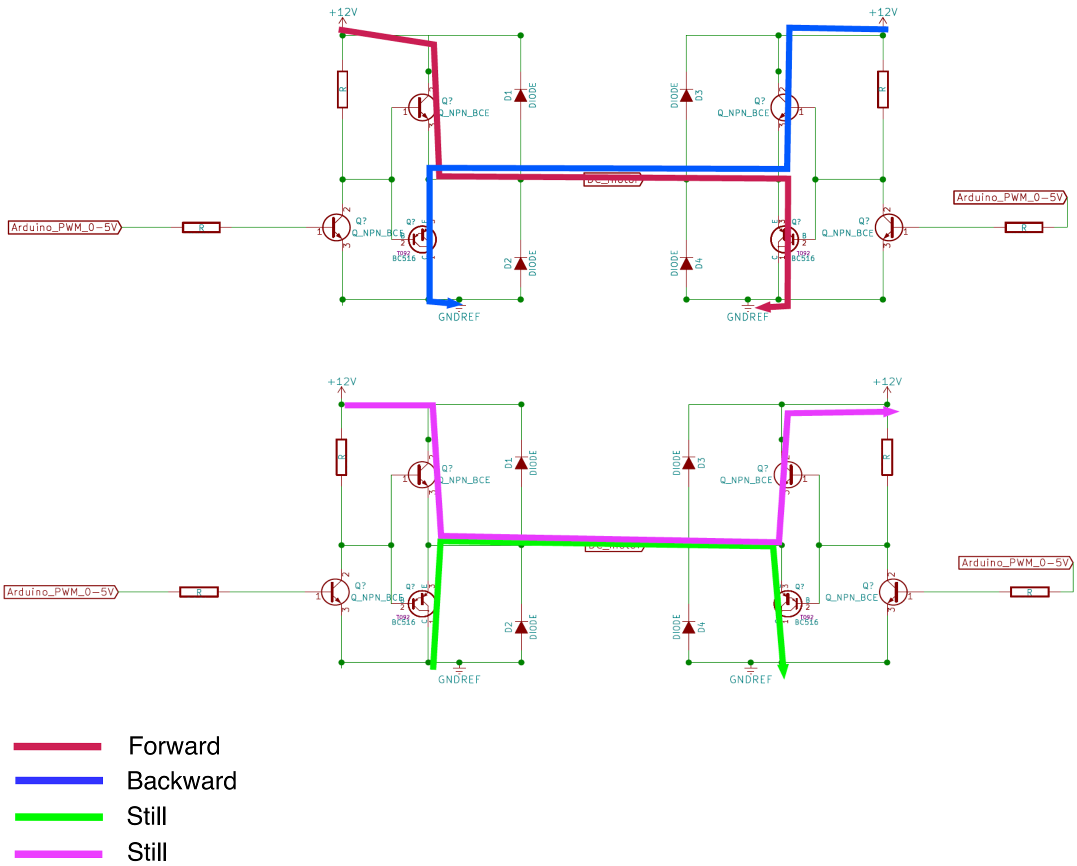

Figure 4.3: The current paths in the X-motor control circuit.

When testing the setup, the voltage over the motor was significantly lower than the expected 12 V. From an analysis of the circuit, the problem was found to be that the transistors have a voltage drop of around 1-3 V, giving less than 12 V to the motor which makes it weaker.

From the data sheet of the transistors used it can be read that the voltage V_CE of the NPN transistor is 1-3 V depending on collector and base current. This voltage drop will lower the voltage from the battery of 12 V. The PNP transistor voltage drop is 1.1-8 V depending on collector and base current. This will cause the voltage to not be drawn to ground when the PNP is switched off, but have a voltage instead. This leads to even lower voltage over the motor.

The solution seems to be to increase the voltage applied to the transistors. If 15 V is applied instead, the voltage over the motor would increase. The voltage over the motor will for each of the states (forward and backwards) is

$$V_{motor} = V_{supply} - V_{NPN} - V_{PNP} \tag{4.1}$$

From the formula it is clear that if the supplied voltage would be increased, the voltage over the motor would increase. One way to increase the voltage would be to use an extra battery and connect the batteries in series. Also, a boost converter could be used to increase the voltage level. A DCDC converter could also be used to convert the 12 V to 3 and connect those in series. The chosen solution was to use a converter that boosts the 12 V voltage from the battery to voltages between 15-24 V, with a maximum current of 6-8.5 A.

The speed sensor was installed on the high speed shaft of the X-motor, i.e. the shaft before the downshift that the arm is connected to. The speed sensor consists of a small generator giving a voltage output when the X-motor is moving. The voltage is positive for moving the arm in one direction, and negative for the opposite direction. The Arduino can only read a positive value between 0-5 V. A voltage divider was installed to transform the negative and positive voltage to a positive voltage between 0-5 V. The maximum voltage was estimated to be +-8 V from the generator for maximum speed. The voltage divider was designed from these values. The voltage divider along with the resistor values are presented in Figure 4.4 [6].

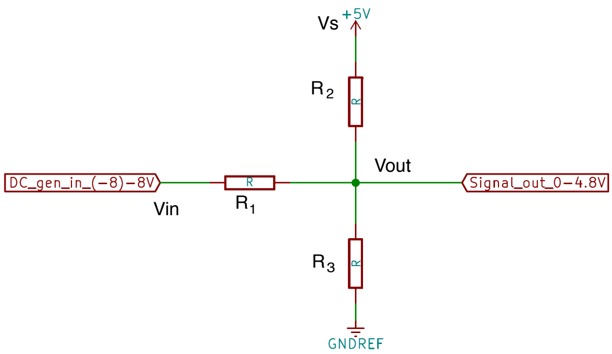

Figure 4.4: The voltage divider circuit for reading the speed sensor voltage in the Arduino.

A simple node analysis of the circuit gives

$$\frac{V_{out} - V_{in}}{R_1} + \frac{V_{out} - V_s}{R_2} + \frac{V_{out}}{R_3} = \frac{V_{out} - V_{in}}{1800} + \frac{V_{out} - 5}{1000} + \frac{V_{out}}{2200} = 0 \tag{4.2}$$

and the output voltage is given by

$$V_{out} = 0.2764V_{in} + 2.4874 \tag{4.3}$$

giving the input voltage to be

$$V_{in} = \frac{1}{0.2764} V_{out} - \frac{2.4874}{0.2764} \tag{4.4}$$

for the circuit. This equation is used in the software to calculate the actual voltage from the generator. This voltage is converted to speed by estimating the maximum speed and reading the maximum voltage, and then just assume a linear conversion. The speed signal is also integrated over time to get the position of the arm. This is easily made in the software and the information is used to control the movement of the arm. A magnetic switch is placed in the middle of the rail, which resets the integration.

The control is set to slow down the X-motor sinusoidally when a certain position is reached of the arm. The read speed and the calculated position during searching, i.e. when arm is moving back and forth along the rail, is saved and plotted in MATLAB, and the result is shown in Figure 4.5. From the plot it can be seen that the signal is smooth, but that the calibration is necessary to get the correct position.

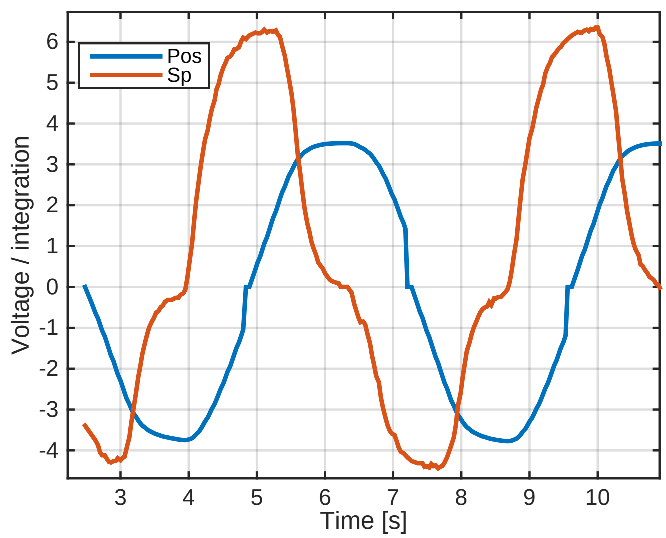

Figure 4.5: The speed and position of the arm during searching.

The figure is plotted again in Figure 4.6, with points showing data at specific points. From the data is can be read that maximum speed gives different voltage for the different directions, i.e. around 4 V for negative values, and around 6 V for positive values. This is easily fixed in the software, and not investigated further. The position is slightly different maximum values as well, but this is an acceptable error.

4.2.2 Y-motor control

The horizontal motor was controlled by simply using relays as shown in the design specification. A digital signal was given from the Arduino of 5 V and lifted to 12 V by connecting it to an emitter follower working as a pull up transistor [6]. This signal of 12 V is sent to the relay that changes state. When the relays get no signal, both poles of the motor is connected to ground, and the motor is off. When relay number 1 is given a signal, the motor is getting positive

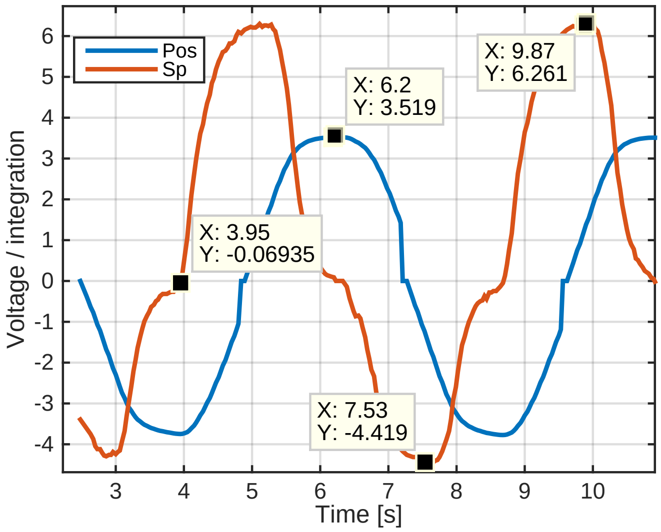

Figure 4.6: The speed and position of the arm during searching, with datapoints.

voltage and moving forward, i.e. moving the arm down. When relay number one is given no signal, and relay number two is given a signal, the motor is getting a negative voltage, moving backwards, i.e. lifting the arm up.

The angle sensor is connected to the same axis as the hinge on which the arm and X-motor is placed. When the arm is moving in the horizontal direction, the angle sensor turns along with it, and gives a voltage for different angle values. The angle sensor has three connections, one for supply voltage of 5 V, one ground and the last is the signal.

As noticed from the first tests of the sensor, the signal was very noisy and gave an uncertain value. The reason for this turned out to be disturbances from the other parts of the system, mostly the Y-motor. To minimize the noise, the angle sensor was connected to the other battery, along with the track detector. A low pass filter was also added to decrease the impact from the disturbances. As the angle sensor is placed upon the arm, a bit away from the control box, the supply voltage could get disturbed as well. By installing a capacitor holding the voltage, the signal was more stable.

4.2.3 Control modes

The nomenclature of the positions in the horizontal direction is presented in table 4.1. The different control modes for the system is presented in table 4.2. There are 6 different modes, and the table present which situations these modes represent, the position and function of the X- and Y-motor, corresponding to movement in horisontal and vertical direction. The last column present which possible modes could come next after the present mode. The control is presented for each mode, and what conditions are set to move between the different modes.

MOD 0, Parked position

The parked position is the position the arm should have when the track is not present, i.e. the vehicle is not driving on an electric road. It could also be if the arm for some reason should not connect to the track. Both motors are turned off and the position of the arm should be on end

Table 4.1: Positions in vertical directions

Name	Position
High	Top position
Pos 1	Search position
Pos 2	Lightly pressed against asphalt
Low	Max down position

Table 4.2: Different control modes

Control mode	Situation	X-motor	Y-motor	Next
MOD 0	No track	Start position	High	MOD 1
MOD 1	Track	Going to search	High -> Pos 1	MOD 2
MOD 2	Track	Searching	Pos 1	MOD 3
MOD 3	Track found	Still	Pos 1 -> Pos 2	MOD 4
MOD 4	Into track	Servo	Pos 2	MOD 5
MOD 5	Connecting	Still	Pos 2 -> Low	MOD 6, MOD 7
MOD 6	Connected	Decoupled	Low	MOD 7
MOD 7	End	Still	Low -> High	MOD 0, MOD 1

side. The arm should be held up at a high position. This is an area of possible improvements, especially on the mechanical part, as the arm could have a certain position in a protected place where the parking could be.

MOD 1, Going to search

This is just a step between parked and search, where the Y-motor moves the contact in the horizontal direction down to the search position. The X-motor is just still and coupled.

MOD 2, Searching

When searching for the track, the X-motor should sweep over the rail until the detector signal is high. The sweeping movement should be made as efficient as possible, whilst not exceeding the current limit, since finding the track and connecting to it should be made quick and easy. The control for the searching mode, MOD 1, is based on a speed regulator, keeping the speed at a pre-determined value, depending on the position on the rail.

The actual speed of the arm in the horisontal direction is measured and fed back to the control, to the speed controller. The speed is measured by measuring the voltage of a small DC-generator, connected to the axis of the X-motor. The voltage output from the generator will be proportional to the speed of the X-motor.

The speed control is made with a PID-regulator. A PID-regulator library can be found among the Arduino software downloads. This could be used, and the problem to be solved is which speed the arm should hold. This will depend on the position of the arm, and have a sinusoidal shape over the rail. The position of the arm is given by integrating the speed.

MOD 3, Track found

When the track has been found, the arm should stop and hold still in the horisontal direction until the arm is lowered. The arm should move from the searching position in vertical direction to the lowered position, where the arm is pressed against the asphalt, tensioning a spring. This mode is only active for a short while, as MOD 4 will be active as soon as the arm is lowered.

MOD 4, Sliding into track

When the arm is lowered, the goal is to connect the contact, and to get the arm lowered all the way down into the track. The arm is from MOD 2 lowered onto the asphalt, and dragged on it. It is crucial that the contact gets connected to the track as fast as possible, to not apply to much strain on the contact and on the system.

As an initial method, the motor will drag the arm in the opposite direction from what it had before the stop. This is used since it is most likely that the arm has passed the track before stopping. This method is not close to exact, but it is a start for easy implementation in the control.

A next step would be to increase the accuracy of the connection position. The movement of the X-motor could be adjusted to get to the track faster. An even more accurate, and probably the final implementation would be to have several track detectors placed along the rail in order to know the exact position of the track the whole time. That way, exact positioning could be performed.

The next MOD after MOD 3, would preferably be MOD4, when the contact is connected to the track successfully. However, if the contact for some reason is not connected to the track, the next MOD should be MOD 1, where the arm is searching for the track again. The arm should try to connect the arm during a certain amount of time, and if the contact is not connected during that time, the arm is lifted and goes back to searching for the track again. The duration of time that is suitable will be tested out and set when a good time is found.

MOD 5, Connecting

This is just a step between the contact being dragged on the asphalt and found the track, and connecting to the track by lowering the arm completely into the track.

MOD 6, Connected

When the contact is connected, a signal should be given from the vertical movement system that the arm has been lowered all the way down into the track, and the X-motor should be decoupled from the system. The decoupling lets the arm run freely on the cog wheel, disconnected from the motor. This way the vehicle can sway when driving along the track, and the arm stays connected. The arm should stay connected for as long as possible, until a signal is given that is should dis-connect, when the system goes into MOD 7.

MOD 7, Lifting the arm from track

When the arm for any reason should be lifted from the track and disconnect, the X-motor should reconnect, and the control should be set in again. The de-coupling should be coupled back fast for the X-motor to be controlled, but the fastest movement needs to be from the Y-motor.

4.2.4 Control code

The control code was developed from these different modes using if-statements. A simplified flow scheme of the code is presented in Figure 4.7. The code is built so that if the "lift" button is pressed, it restarts the system and holds until "start" is pressed again. The "lift" and "start" button is a switch and can never be high at the same time.

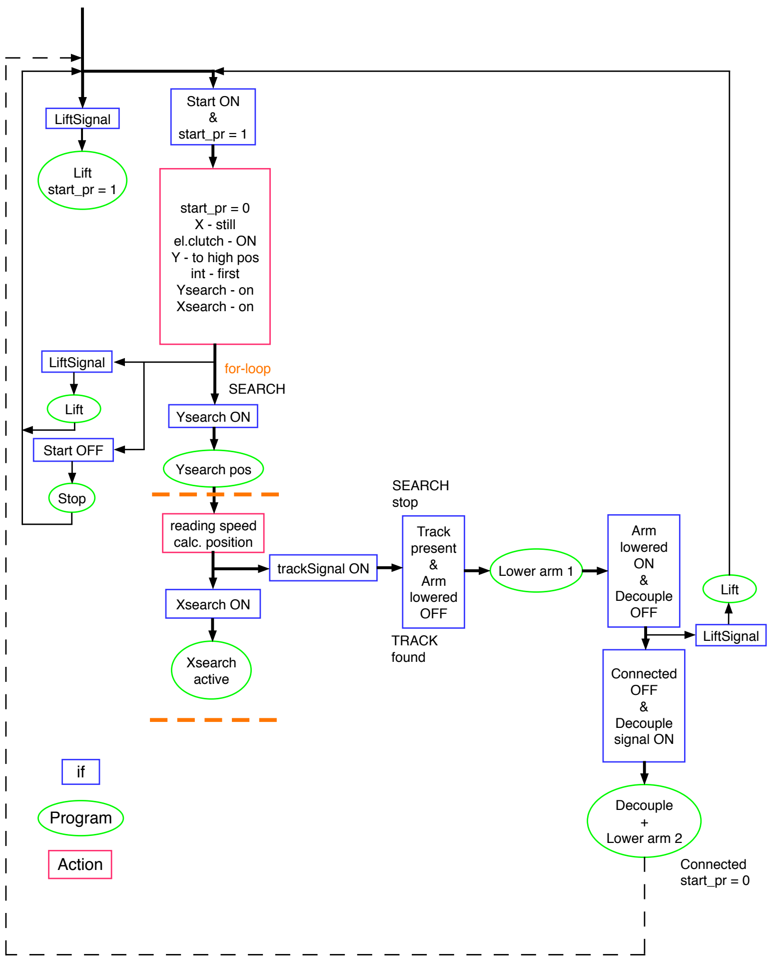

Figure 4.7: Flow scheme of the control.

When the system starts up, the first actions are to lift the Y-motor to a start position while the X-motor is held still. The electromagnetic clutch is set high, i.e. the arm is connected to the X-motor. All variables are reset and search variables are set high. The system is now at MOD 0.

When moving to next part of the control, MOD 1, the arm is lowered into search position.

This position is set so that the arm and most importantly the track detector coil is close to the ground and can find the track. The Y-motor is now in ”Pos 1”.

Moving along the flow scheme, the next step is the X-motor search. The Y-motor is held still at ”Pos 1”, but the X-motor moves the arm back and forth along the rail. This is held by a for-loop and the voltage sent to the X-motor is calculated from a sinus. When the calculation reaches maximum voltage in either direction, it is held at maximum until a certain position is reached. The position is as previously explained calculated from the speed sensor and calibrated when the arm passes the middle switch.

When the signal from the track detector gets high, and the contact is moving over the track, the X-motor is set to stop and hold still, while the Y-motor lowered to ”Pos 2”, pressed position. MOD 3 is now reached. The angle that the Y-motor should reach is determined by a set variable.

When MOD 4 starts, the arm is dragged along the ground towards the track. The direction of the arm before lowering is saved in a variable, and the arm is set to be dragged in the opposite direction. The dragging of the arm is an important part of the functionality of the system. The contact should not be dragged too fast, so that it passes the track without connecting. It should not be too slow, but reach the track as fast as possible. As the speed of the arm can be attained from the speed sensor, this is used to get a very trivial speed controller. If the speed is higher than a certain value, the voltage to the X-motor is decreased a bit. If the motor is moving to slow, the voltage is increased.

The contact is dragged until the signal for connection is given, or until the end switches are reached. If the end switches are reached, the contact is on the side of the vehicle and have probably missed the track. The contact is lifted and the search is restarted.

When the contact is connected to the track, i.e. the signal for connection is read, the X-motor immediately disconnects through the electromagnetic clutch. The signal sent to the relay controlling the clutch is set to low, and the clutch is disconnected. The X-motor is also set to be off when the signal for connecting is read.

At any time when the contact has been connected the ”lift”-button can be pressed and the contact is lifted from the track. The system can now restart.

4.2.5 Electromagnetic clutch

The electromagnetic clutch should get a signal to connect and disconnect the motor. The ordered clutch takes a signal of 24 V, so a converter is required from the 12 V battery. The clutch is connected by getting a signal from the Arduino, which can give a maximum voltage of 5 V output. The signal is given to a relay which works as a switch for giving the 24 V from the converter to the clutch.

4.3 Track detector

The track detector is developed in this chapter. The signal from the track detector should be amplified and detected. The sensitivity is adjusted to fit the application. A simplified blockdiagram over the track detector is presented in Figure 4.8.

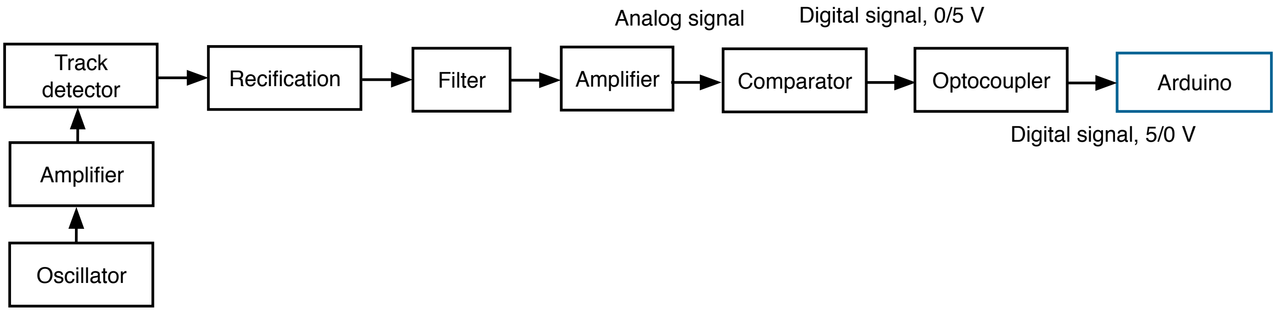

Figure 4.8: Blockdiagram over the track detector.

4.3.1 Detector circuit

The system used for the detector circuit was chosen to be the one described in section 2.4.2, based on one single coil. As the circuit was built for the testing, it can easily be implemented into the system. This system was chosen since it is more sensitive and require less components.

The issues arising with connecting such a detector to the system are disturbances from the other parts of the system. This is solved by placing the track detector in a separate box from the control box. To decrease disturbances further, the track detector box takes the voltage from a separate battery. An optocoupler is installed to transfer the digital signal from the track detector box to the control box where the microprocessor is placed. The circuit with the comparator output coupled via the optocoupler to the microprocessor is shown in Figure 4.9.

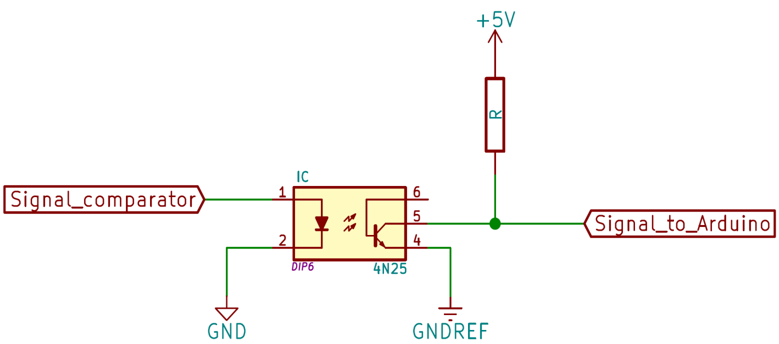

Figure 4.9: The circuit of the optocoupler.

4.3.2 Oscillator

As only a battery is available with a constant DC voltage of 12 V, an oscillating circuit is required to be able to apply an AC voltage. A simple oscillating circuit can be built by using operational amplifiers [7]. The simple circuit used is presented in Figure 4.10. The frequency is usually between 3-100 kHz for metal detectors [8]. The values of the resistors and capactitors were chosen to achieve a frequency of around 70 kHz, as this is a suitable value for the detector.

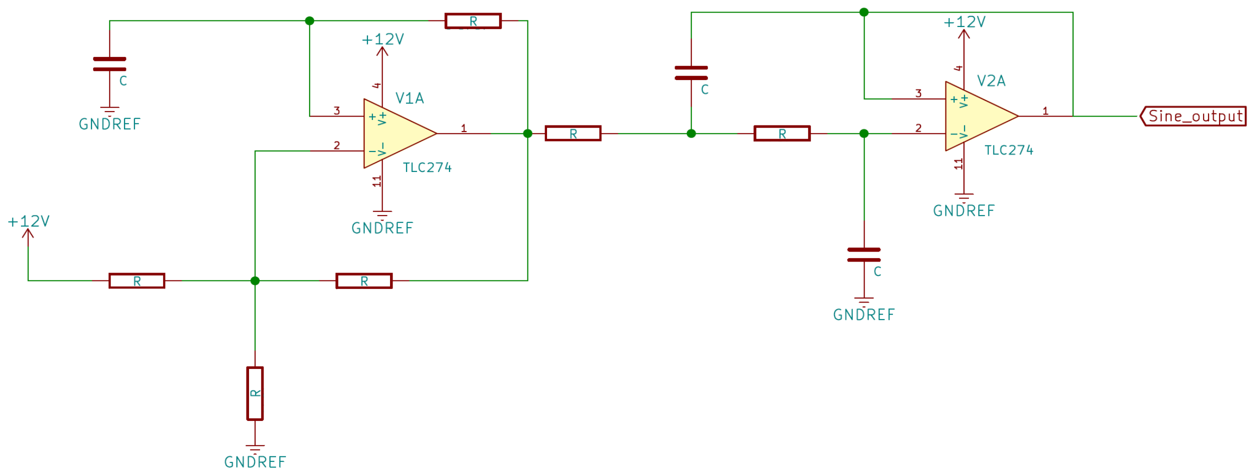

Figure 4.10: The sine wave circuit used for the oscillating signal to the track detector.

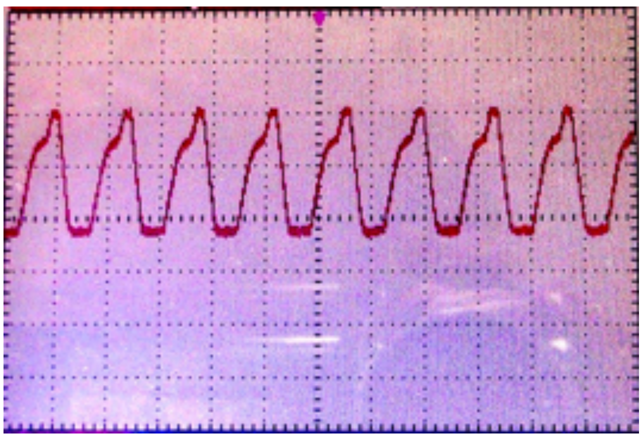

Figure 4.11: The resulting signal output from the oscillator.

The resulting signal is not a perfect sinus, but it is an oscillating AC-signal as intended. The resulting voltage output from the generator is shown in Figure 4.11. This signal has the shape that is required, but it is not very strong. An amplifier is therefore required to make the signal stronger. This amplification is built with a transistor circuit, shown in Figure 4.12. The electrolytic capacitor is placed to hold the input voltage from the battery stable.

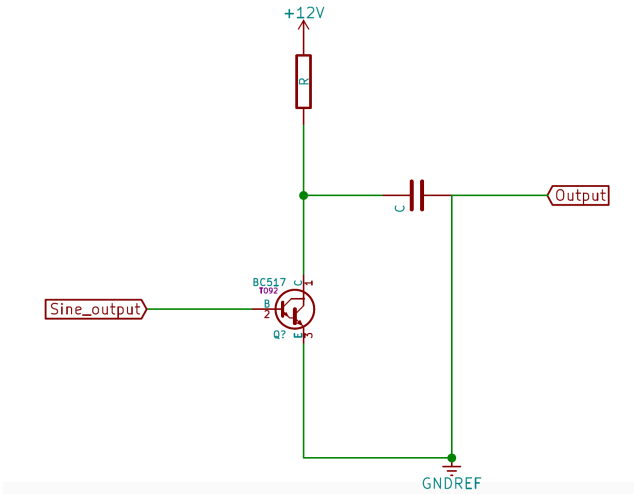

Figure 4.12: The amplification of the oscillating signal sent to the track detector.

Detector coil

The coil should be installed onto the contact to be as close to the ground as possible. This may be altered in future versions of the system where the coil could be on a separate arm. The coil is simply made by winding copper wire around a material with a permeability that is close to the permeability of air. This is then mounted into the contact and the coil is connected through the cable to the track detector control box.

4.3.3 Amplification of the detected signal

The amplification of the signal will have some requirements. It is crucial that the amplifier do not amplify the noise, but only the actual detected signal. The frequency of the detected signal will be the same as for the frequency of the oscillator that apply the signal to the reference coil. Consequently, the amplification will be adjusted to the correct frequency of the detected signal.

As the arm will be moving when approaching the track, the detector could be designed to only detect changes in the signal. This will remove the noise and the DC level of the voltage from the track detector will be filtered out. A schematic of the amplifier and the comparator is presented in figure 4.13. Two amplifiers are used to amplify the signal 10 x 10 = 100 times.

A high pass filter is put on both inputs to remove the DC voltage of the signal. Instead, only changes in the signal will pass through and get amplified. As a battery of 12 V is used as the power source, the operational amplifiers are powered by this and the other side to ground. Because of this, the voltage is lifted to 6 V on one of the inputs to the amplifier. If the DC voltage changes or drifts with for example temperature changes, those changes will be filtered out as they will be very slow.

The output from the amplifiers are connected to a comparator, comparing the voltage to a steady DC level. The compared voltage can be adjusted with help of the potentiometer. A hysteresis was also required to get a distinct signal and not jump between on and off. This was added as a feedback from the output, giving a different DC-level depending on if the output signal from the comparator is high or low (0 or 5 V). When no change is detected, the output will be 5 V, and when a change is detected, i.e. the track is present, the output will be 0 V. As the circuit only detects changes, the signal will only be LOW until the arm stops, since if the track is in the same position, there will be no change and the signal gets HIGH again. This is important when considering the control later on.

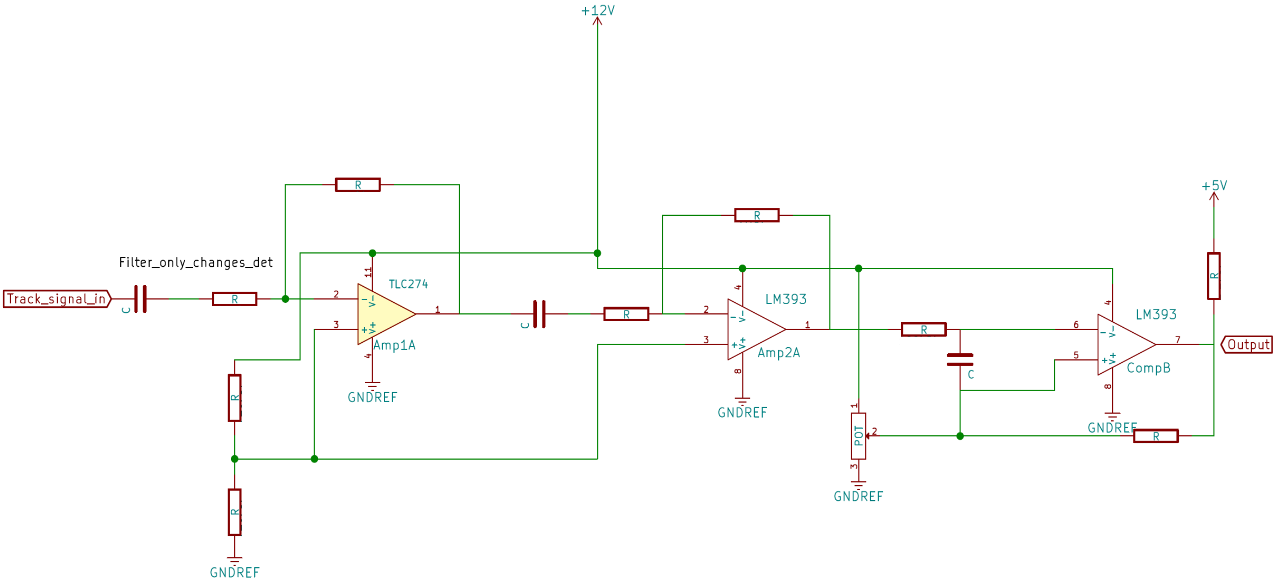

Figure 4.13: Circuit scheme of the amplification and comparation of the track detector signal.

5 Testing

The testing of the system is presented in this chapter. The first testing is made in the lab and the results are analyzed. Adjustments are made to the system after testing in order to improve it in the best way. The final tests are made on the installed test track.

As the system is only a prototype, and not the finished product to be used, a few manual control adjustments are necessary. When the track is ending, the arm should be lifted. This should in the future version be sensed by some outside signal, giving information about that the track is ending. For now, a manual switch is used that needs to be pressed to lift the arm. A button is also installed for starting the system up, in order to handle the startup in a simple way, and also to reset the system easily. The manual switch has a number of button for replacing parts that are not completely finished for the first tests.

5.1 First test, 6th of may

For the first test on the test track, the design was not completely finished. Instead of all sensors, the manual switch buttons were used. This meant that a button was used for stopping the arm above the track, and for decoupling the system. The searching movement in the horisontal direction was simply controlled by a pre-set time, and the same was used for the vertical movement. The track detector coil was not installed, so a manual button was used for giving a signal of when the arm was close to the track. When the contact was in the track, another manual button was used for knowing that it was connected and should lower to max down.

The system was tested even with the lack of sensors, just to get a view of the system in the real environment. The results were good, and the arm was actually successfully connected more than once. There was however problem with the code and the arm went from MOD 3 to MOD 6 directly, and the vertical motor went from search position to low position directly.

After analyzing the problem with the code in the lab, it was easily solved and the system worked fine again. The sensors were installed to the system part by part. The angle sensor and track detector were both installed and the speed sensor with the position sensors were further tested. All cables were renewed with connections that can be disconnected from both the arm and the control boxes, in order to easily move the system for the outdoor tests.

5.2 Second test, 20th of may

For this test, the track detector and the angle sensor were installed. The speed sensor, and consequently the position sensor was not connected, as the position switches were not working properly. The X-motor was as for the last test controlled by time. However, as the track detector turned out to work very well, the searching was short and the contact stopped at the first cross over the track.

The angle sensor had some noise in the signal, even though it was separated from the other parts of the system to a separate battery. The sensor worked rather well anyway and was used for positioning in the vertical direction.

However, the code did not work perfectly. When the code reached MOD 5, the system broke down and lifted the contact instead. This could unfortunately not be solved on spot so the test was aborted.

After the second test, the code was developed further to get rid of the problem. The MODes were gone through each at a time to make sure that the code works properly for the next test. The position switches were also fixed to have a proper positioning of the arm in search mode.

5.3 Third test, 28th of may

For this test, all sensors specified in the design specification are installed. The system fulfilled the requirements that were set, and worked as intended. Some adjustments and calibration were required specifically for the angle sensor and delay time.

In order to make sure that the track is passed when detected, as the program is set to drag back the contact in opposite direction, a short delay was installed. The delay made sure that the track is passed by moving the arm a bit longer than needed when a signal from the track detector was attained. This delay time was adjusted and tested to fit the application during this test.

As the test setup in the lab is not at the exact same distance as when the system is placed on the vehicle for outdoor testing, the angle sensor values for the different position in vertical direction had to be calibrated. As the mechanical part of the system was not as robust as perhaps would be desired, the angle value also changed a bit as the whole mechanical system was not completely stiff. This made it necessary to adjust the angle value between tests to make sure that right angles were reached.

Apart from the adjustments that had to be performed, the system worked as intended. The first test was performed in slow speed while the system was monitored from behind the vehicle, and the manual switch was used from this position. As this test showed good result, the next test was to increase the speed of the vehicle, and control the manual switch from inside the car, without close monitoring from outside the vehicle. This test also proved to work, and the contact was connected without issues. The speed and position of the contact during this test were attained and the values are plotted in Figure 5.1. As can be seen in the figure, the system works as intended. In Figure 5.2, the same plot is shown again, but with numbers for specific events in the process. The system starts up at number 1. The angle will increase for lowering the arm in the beginning, i.e. the contact is moving to search position. Which angle the contact should reach was calibrated before start. When the angle is reached, as indicated by number 2, the system starts to move the arm in the horisontal direction, and the position is changed. The code is written to only interpret the track signal as high, when the signal has been high for a number of times, so that noise does not cause disturbance to the system. When the track signal is distinctly high, at number 3, the contact should stop and the angle increase again as the contact is lowered onto the ground. As can be seen in the plot, this takes a relatively long time. When the contact is lowered onto the ground, at number 4, the system should drag it in the opposite direction until the angle increases further, giving the signal for that the contact has slipped into the track. This signal is attained at number 5. Then the arm should be stopped, and kept low.

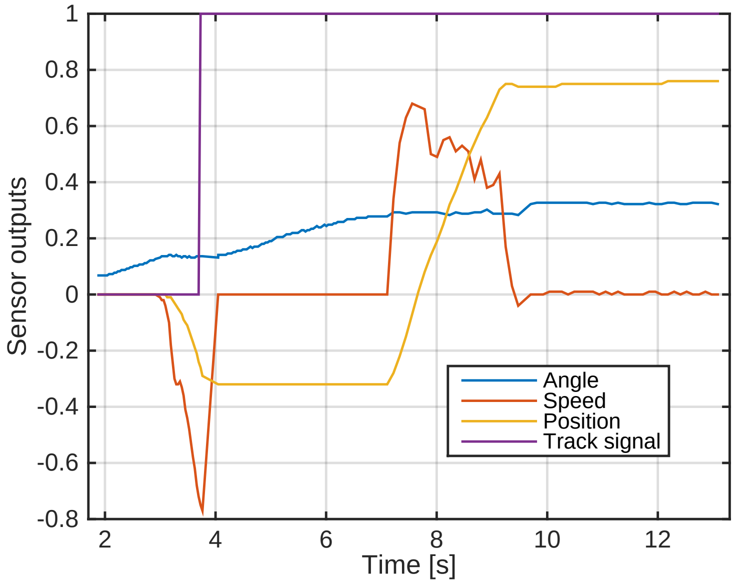

Figure 5.1: A plot over the different sensor outputs in the system. The position in vertical direction is given from the angle sensor, and the "Speed" and "Position" gives information of the contact in the horisontal direction.

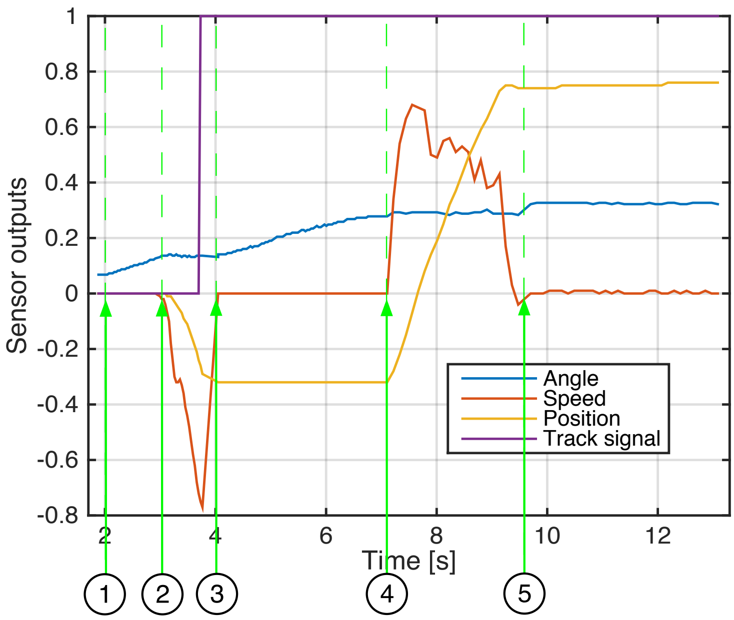

Figure 5.2: A plot over the different sensor outputs in the system, with numbers indicating different specific events.

6 Discussion and future work

In this chapter, a discussion is held about the results. As the built system is a prototype, the future development is an important part of the project. This is presented and discussed further in this chapter.

During the first part of the project's process the different parts of the contact system were designed and tested. At the same time, adjustments were made to the tested parts in order to get the best results. As there was limited amount of time, the design specification had to exclude some parts of the system to be able to finish in time. A development of probably all parts of the system will be required before the product is commercially ready. However, the design specification that was developed in this project was met when the project was finished.

The control of the X-motor was performed using a number of BJT transistors. One alternative to these transistors would be to use the more modern MOSFET transistors. However, as the supervisor of the project had a lot of knowledge about BJTs, and those were available at Elways, these were used. For future development, MOSFETs could be used. As the contact system is only a prototype, the BJTs seemed as the best choice. From the tests, the use of these transistors were not a limitation for the performance.

The generator used for the speed sensor was a simple and cheap motor, which could contribute to the quite uncertain output voltage. From the tests, it was clear that the voltage reached different maximum values for maximum speed in the different directions. This was solved for this version in the code, by using different conversion variables for the different directions. For the future versions, this generator could be replaced with a more accurate one.

The track detector worked very well during the tests. The biggest concern was thought to be that the detector would not be sensitive enough, and that the contact had to be very close to the ground for the detector to work properly. The contact could however be at an acceptable height over the ground when searching, and still find the track. For this version, the contact stops when the signal from the track detector gets high. This will mean that the contact does not stop precisely above the track, but will continue a short bit passed the track. For this version, the control code considered this and used the assumption that this is always the case, and when lowered onto the ground, the contact was always dragged back in the opposite direction. For the future versions of the track detector, a larger number of coils could be used and placed along the rail, directly knowing exactly where the track is located. The arm could be controlled to that position directly and lowered into the track.

From the tests, it was noticed that the resistors in the X-motor control board got a bit higher power than they were designed for. The resistors used can handle up to 2 W, which is a bit low in this application. If they were simply replaced by resistors that can handle higher power, this problem would be solved. The resistors could however handle the current, so apart from that they got very warm, there was no problem.

The results from the tests on the outdoor test track were in the end very good. The first two tests were performed with the system not completely finished, and the result was not perfect from these tests, as expected. However, at the final test when every part was properly installed and working, the system worked as intended, and the set requirements were fulfilled. However, this version is only a prototype, and a number of improvements are definitely required for the system to be a finished product.

The most distinct problem that was noticed during tests was that the Y-motor was too slow. As could be seen from the test result plot, the lowering of the arm was slow and took relatively long time. This is not critical, but should definitely not take that amount of time. When the vehicle is driving on the road with the track, it should be connected to the system as soon as possible. This problem could easily be solved by using a faster motor, or some kind of mechanical arrangement with tensioning of springs that handle the fast movements.

Another aspect to consider is the safety of the system. This is out of the scope for this project, but is definitely something to consider for next version. If the vehicle for some reason turns sharply from the road, and needs to be disconnected from the track, this has to be performed very quickly and safe to not cause a safety issue.

7 Conclusions

The goal of this thesis work was to develop, design, test and build a contact arm to work on the Elways track. This was successfully achieved and the contact system was tested both in the lab and on the outdoor test track. However, the contact system developed in this thesis is only a prototype that needs further development before it can be considered as a finished product.

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