Sensor based system for train detection

Master thesis for MTR in Mechatronics

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Sammanfattning

Tunnelbanan i Stockholm består av tre linjer, som omfattar 100 stationer med 108 km spår. Resenärer gör 1,1 miljoner resor varje dag. Beroende av tid på dygnet kan antalet tågvagnar variera, vilket kan leda till att föraren av misstag stoppar tåget med en vagn kvar i tunneln eller utanför plattformen. För att förhindra detta behövs ett sensorbaserat fristående system som indikerar till föraren att hela tåget är vid plattformen.

Först beskriver denna avhandling de befintliga tekniker och metoder som används för tågdetektering idag. Två typer av teknik jämförs för denna applikation, optiska och induktiva. Det optiska systemet är dyrare och är känslig för en stökig och smutsig miljö, men är enkelt applicerbart på denna applikation. Den induktiva sensorn är billig och kräver inget underhåll. Utmaningen är det korta avkänningsavståndet på 50 mm.

De båda typerna av sensorerna testas i ett system, i laboratoriemiljö och vid Hjulsta tågstationen. Olika typer av konfigurationer testas och utvärderas. De två konfigurationer som jämförs i slutet, är ett lasersensor system som indikerar för föraren när laserstrålen är blockerad. Den andra konfigurationen använder två induktiva sensorer som räknar tågets axlar på två olika platser längs spåret.

Ett schema för det slutliga kretskortet och kod för logiken presenteras avslutningsvis.

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Approved	Examiner Lei Feng	Supervisor Baha Alhaj Hasan
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Abstract

The metro system in Stockholm consists of three lines, covering 100 stations with 108 km of track. Boarding passengers take 1.1 million journeys every day. Depending on the time of day, the number of cars varies, which can cause drivers to inadvertently stop trains with one car still in the tunnel or off the platform. To prevent this, there is a need for a sensor-based stand-alone system to alert drivers that the whole train, including all cars, is at the platform.

First, the thesis describes the existing technologies and methods for train positioning. Two types of technology are compared for this application, optical and inductive. The optical system is more expensive and more sensitive to a messy environment but is more straightforward. The inductive sensor is cheap and does not need any maintenance. The challenge is the 50 mm sensing range.

Both types of sensors were tested in a system, in laboratory environment and at Hjulsta train station. Different approaches were tested and evaluated. The two configurations that are compared in the end are a laser sensor system that indicates to the driver when the laser beam is blocked. The second configuration uses two inductive sensors that count the axles in two different locations along the track.

Schematics for the final PCB and code for the logic are also presented.

ACKNOWLEDGMENTS

I would like to thank all the people who contributed in some way to the work described in this thesis. First and foremost, I thank my supervisor at KTH, Ph.D. student Baha Alhaj Hasan for who provided me with insightful advice, guidance and support and my examiner, Assistant Professor Lei Feng for all guidance and valuable critique. I would like to thank my supervisor at MTR, Zeki Rida for making this work possible.

I also would like to extend my thanks to my friends and family for all invaluable support and help, with special thanks to Anna K, Bryce E and Michelle W.

At last but not least, I would like to thank my companion through life Tobias Douhan for always believing in me, for giving me strength and for always being by my side.

Michael Raun
Stockholm, December 2014

TABLE OF CONTENTS

1 INTRODUCTION

This chapter describes the background for this master thesis. There is a short introduction to the MTR Stockholm company and the Stockholm underground. Then the purpose and method for the project is presented.

1.1 Background

This master thesis project is carried out in cooperation with the MTR company. The external supervisor is Zeki Rida, head of Infrastructure at MTR. The supervisor at KTH is Ph.D. student Baha Alhaj Hasan and the examiner is Assistant Professor Lei Feng. The title for the thesis is Sensor based system for train detection.

1.1.1 MTR (Mass Transit Railway Corporation)

MTR Stockholm is since 2009 and for at least eight years has been the subcontractor with responsibility for operation, maintenance and planning of the subway in Stockholm. MTR Stockholm is a subsidiary of MTR Europe in London and employs around 2.800 persons.

1.1.2 Stockholm underground

The metro system in Stockholm consists of three lines, covering 100 stations with 108 km of track. Passengers make 1.1 million journeys on it every day. The oldest line is the green line, inaugurated by the Swedish king in 1951. The newest line is the blue and is the deepest below Stockholm. Of the 100 stations, 53 are located above ground.

1.2 Problem description

Depending on the time of day the number of cars on the train varies, which can cause driver to inadvertently stop the train set with one car still in the tunnel or off the platform. This mistake could have fatal consequences if a passenger falls out in the tunnel. It also affects the time schedule for the whole line because cars left off the platforms needs to be carefully examined before the train can move again. This happens to all different kinds of drivers, of all ages, with long work histories and short ones.

1.3 Purpose and definitions

MTR is in need of an indication system that will alert the driver that all train cars are at the platform, so that they can know if it is safe to stop the train.

1.3.1 Sensor based system for train detection

To prevent drivers from stopping trains at any time other than when all train cars are aligned on the platform, there is a need for a sensor-based stand-alone system alerting the driver that the whole set is at the platform. The indication can be a signal light or another suitable indication by the platform. The system will have to be accurate and have a high level of security classification. It cannot be interfere with or be linked to the existing signalling system. Sensors must be adapted to operate with high precision in the intended environment. The system will primarily be designed and adapted for the Hjulsta station but will later possibly be adapted to other stations in the Stockholm subway system (though this is outside this thesis scope). The system will not be installed on the train, but is intended to be established as a permanent installation at the station.

The system will, in other words, detect if there is a car in the tunnel and indicate to the driver if it is safe or not to stop the train.

1.3.2 Research question

Two different types of sensors will be examined and compared; optical (laser) and inductive. The thesis will investigate which sensor would be the most suitable to place near the platform in order to indicate, in time, to the driver where to stop the train. In other words, threats to the timeliness of the system are the primary focus of the investigation. Threats by environmental factors in both the indoor and a Swedish outdoor environment will also be investigated in the area of Stockholm. Additionally, the timeliness of the system will be examined to work under different kind of natural disturbances, including electromagnetic interferences (EMI).

1.4 Delimitations

This project has been carried out at KTH and not at the company (because of a lack of allocated space for the project). The contact has because of that been limited. The supervision from the company has also been of a non-technical art.

This type of solution is normally, when studying the frame of reference, involves attachment of the technology on the train. That was not permitted for this project.

I do not have a permit to enter the rail area without supervision from someone with a special license to bring someone with him or her. It also takes a lot of planning to enter the rail area because of the traffic. The occasions the system was tested were because of that limited to three times and performed late at night. The number of train at that late hour is also very limited (one train every half hour). Because of its nature, the system makes it impossible to collect data in LabVIEW at the same time the whole system is tested (because of different software) so the collected data is very limited. As a result of that, some conclusions are based more on observation.

1.5 Methodology

A profound study will be made of train positioning, the technology behind it and the both chosen sensors. This study will be the base for setting up and tuning the prototype that will be constructed in the best manner for this kind of application. The prototype will be constructed in a manner that allows both kinds of sensors to be used separately. This allows the possibility of finding the different parameters and behaviours for the sensors during test cases. The test cases and evaluation will be performed primarily in laboratory environments so the sensors can be exposed for disturbances and be monitored in a correct way. Because it might be difficult to build something that is equal to the real train in a laboratory environment, real field study must be part of the conclusion.

1.5.1 Requirements for the sensors

These are the requirements for the sensors regarding this application:

- They must make it possible to detect all types of commercial trains that are in used in the Stockholm underground.
- They must have the right EMC for the environment.

- They must be able to work between -20°C to 30°C.
- The degree of protection against solid foreign object must be IP6X.
- The degree of protection against water must be IPX5 or higher.
- They must be able to operate in direct sunlight.
- They must be able to handle 10% ripple.
- They must operate on a frequency of 70 Hz or higher.
- They must be able to work continuously for 3 days without change of performance.

1.6 Disposition of the report

The disposition of the report is a breakdown of four parts (see Figure 1) in more or less equal sizes, except for the first one that will be about 1/4 of the other ones. The first part presents the introduction, background, purpose and definitions. The second part describes relevant facts, existing theory in the field and a profound study in the chosen sensors. The third part describes implementations and why and how the prototype and the laboratory environment are constructed. How and why the field study was performed, is also included in this part. The fourth and the last part is divided in to two sections: result/analysis and conclusion/discussion. The result/analysis section presents the result from the test cases. Furthermore, the result is compared to the existing theory and facts given in the second part of the report. The second section of the fourth part presents conclusion and discussion. This is based on the first section, the result and the analysis, in relation to the definition of the thesis in the first part. The discussion gives suggestions as to how to proceed with the work.

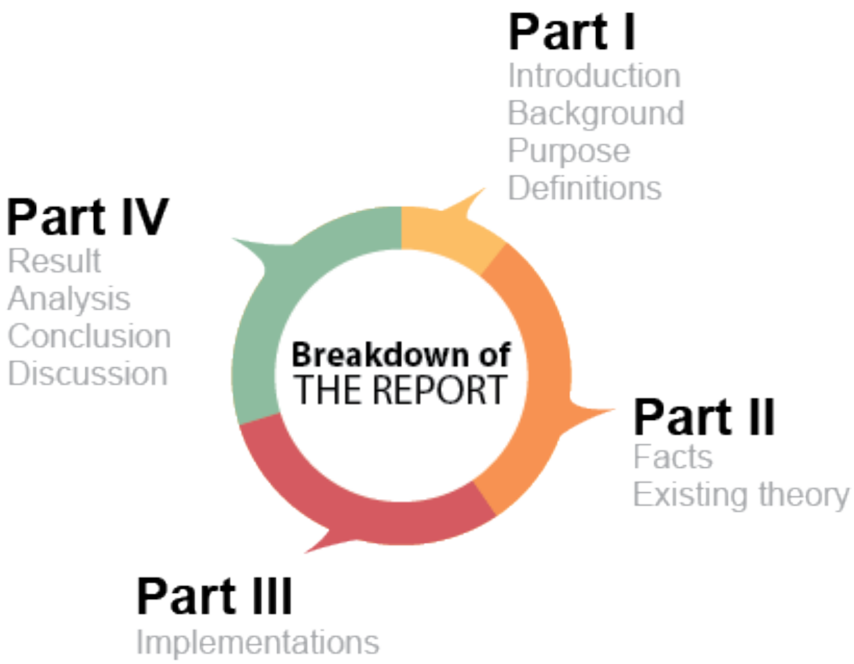


Figure 1. Breakdown of the report

2 FRAME OF REFERENCE

This section first describes the existing literature regarding the field of this project. After that the parameters for the trains and the environments that need to be considered for setting up of the system are described.

2.1 Train Positioning

The first part of this subsection will describe different kinds of on-track solutions for train positioning. The second part describes the different systems that are used.

2.1.1 Approaches for On-Track Train Positioning

Track circuits are one of the oldest and most commonly used train detecting devices. Track circuits use an along-the-track-technique that are uses the fact that the two running rails are normally insulated from each other except when the axle of the train creates a conducting path between them [11]. To simplify the technique, the track circuit consists of a feed that applies a voltage to an end of a section of line and a relay at the other end. To delimit the extent of line over which the track circuit detects the train and to allow adjacent sections of line to be fitted with independent track circuits, insulated rail joints are also important components of the track circuit. When the section is unoccupied, a current energises the relay, which picks it up. When there is a train present in the section, a short circuit is created and the rely drops. An important safety feature is that if any wire or rail were to break within a section, the track circuit would appear to be occupied. The same thing would happen if the power supply went down. A drawback of the system is that if the train briefly fails to make good electrical contact with the rails and the section will appear to be unoccupied. The main reason for this failure is contaminants such as sand, leaf and rust on the railhead. A solution for this problem has been to use a delay, requiring the train to be absent for a few seconds before the section change to unoccupied state [11]. Another drawback of the system is that the modest voltages required to energise a relay, can easily be generated by the massive electrical currents that exist in its surroundings. Furthermore, the insulated rail joints weaken the mechanical strength of the rail and have poor compatibility with high-speed railways applications [10].

Another old but still used technique for train detection is the treadle. A modern treadle often consists of a pair of needles, side by side, to detect the wheel flange [11]. It is possible for the treadle to determine which direction the train is travelling in by detecting the order in which the needles are deflected. This technique only detects the train and its direction in a certain point and are because of that more limited than the track circuits that have the ability to determine whether a section of line is clear. Another disadvantage is that the moving parts in the mechanical interface will lower the life span compared with techniques without.

The advent of modern electronics and microprocessors has brought a challenger to the dominant track circuit: the axle counter [11]. The detector, known as the axle counter head, comprises a pair of sensors, which detect disturbances in magnetic flux when the wheel passes between them and the rail they are bolted to. The electrical signal are conditioned by a lineside electronic unit in close proximity and passed to the evaluator. The evaluator can determine whether each wheel detected is passing into or out of the section because each head has a pair of sensors. It can because of that keep count of the total number of axles within the section and when that count is zero, it can indicate that the section is clear. A drawback of this technique is the lack of failure mode. If a head stops counting axles, it will clearly fail to detect a train entering a section of line. The same will happen if the evaluator is broken. Another problem would be if the axle counter loses its memory of the axle number and a manual reset is necessary to restart the system. This introduces human factors as a source of unreliability.

2.1.2 Train Positioning Systems

For train positioning application, train control systems today usually use a mix of both on-board sensors providing relative measurements and infrastructure equipment along on-track sensors for absolute positioning. The main reason, among others, for needing train positioning is to be able to use automation, to consume less energy and/or to be able to monitor.

The European Train Control System (ETCS) has its positioning based on absolute position information using balises along the track and on-board odometry. Modern balises are devices that represent points of information that transmit to an on-board receiving apparatus over a radiofrequency channel [8]. The message the balises sends is called a telegram. It is important to keep the telegram as short as possible, and, correspondingly, the time interval needed for the transmission, in order to accommodate the high speed of the train. A passive balise is energized by the approaching train.

Siemens Trainguard MT is a communication based train control (CBTC) system that operates with wireless communication between track and train. It is based on continuous train positioning and train integrity monitoring. The system is used in metros and suburban railway systems all over the world. Two of them are Istanbul Line 1 and Beijing Line 10 and during the time the article [7] was written (2013), Trainguard MT was being installed in the Copenhagen S-Bane system, one of the biggest mass transit networks in Europe. The system, which is radio-based, allows a choice between fixed or moving block operation and achieves headways of 90 seconds [6]. Position is calculated with the help of fixed point balises and on-board odometry like radar and wheel-counter. In order to improve the positioning accuracy, a high number of balises are laid closer to target point along the track.

The high-speed maglev (magnetic levitation) train moves without any contact with the tracks. This is caused by electromagnetic force levitation, and it is driven by a linear synchronous motor [9]. The maglev trains are used in countries like the USA, Japan, China and South Korea. Train detection is crucial to the safe operation of high-speed train. As a result of the noncontact technology, the localization methods that are employed in the traditional wheel-on-rail system, such as track circuits, axle counters and tachometers are not suitable for the maglev system. For the maglev system at the Yamanashi test line in Japan, the train position is detected by using the inductive radio system which includes cross-inductive wire laid all along the test line. In the Transrapid maglev system used in Germany, mounted transponders on the track are used for detecting the vehicle location. In [10], Zhang S. et al propose a new technique of train detection in this application through magnetic field sensing by giant magnetoresistive sensors.

As a similar solution, CRV & AVV, that are an automatic train operation system (ATO) in commercial use in Czech Republic [5], uses automatic driving according to the principles of energy-optimal train control. The lines are equipped with balises and on-board wheel-counters are used for relative positioning on the train. The accuracy for the automatic stopping path is given typically within 2 m.

In [3], a beaconing train using standard 802.15.4 communication is used to awaken the nod closest to the arrival train on the track when getting close to a bridge. This is in the context of monitoring railway bridges. The nodes are placed along the bridge containing information of the status of the bridge. When the first node gets awakened by the train, it wakes the rest of the following nodes. All the nodes will then be able to detect and communicate with the train. In this manner, the nodes along the bridge will have very low energy consumption and at the same time be able to detect the train.

A railway grade crossing is a point at which a railway and a road intersect on the same level. In [2] an intelligent railroad crossing system is described that can be used to detect the train and the road vehicles at a multiple-tracks railroad crossing to avoid collision. The automatic railway-crossing gate uses a radio link for identification and information on approaching and outgoing trains. The train has two transmitters at the beginning and end, which transmit an identical packet that can be identified by the sensor along the track. This packet is transmitted through a radio link and received by a sensor. The sensor sends the information from the packet to a CPU (Central Processing Unit) where the controlling procedure is processed. The CPU consists of packet identification signalling and a gate controller device, among other things. After receiving the packet, the CPU changes the signal and gate-status from the packet type and algorithm stored in the CPU. For safety purposes, two different kinds of signalling posts are used, one for the train and the other for street traffic.

LZB (Linienzugbeinflussung) is probably the oldest loop-based system and dates back to the 60s [8]. It is used for example in High Speed Lines in Germany and Spain and in Munich's S-Bahn system. The system was originally installed for improved safety and traffic flow [1]. The positioning principle is different from most of the other systems. By using two conductor cables that run between the tracks and are crossed every 100 m, both safe data communication and positioning can be handled. The on-board system detects crossings of the cable and determines the position between these crossings using odometers. To overcome the disadvantages of fixed installations along the track, a modular on-board positioning system based on GNSS (Global Navigation Satellite System) is being developed in the German national research project PiLoNav. PiLoNav provides absolute positioning whenever satellite signals are available. The accuracy can be augmented using relative positioning with respect to a reference signals, e.g. RTK (Real-Time Kinematic) algorithms. The goal is to reach a higher level of automation on-board of the train for the railway undertaking without investments in the infrastructure. According to PiLoNav project, the major drawback in other project aiming for developing GNSS-based absolute positioning system is the lack of an integrity indication that is necessary for safety critical applications. Some systems do provide continuous and accurate positioning information, but the interface is restricted to one application only, which makes it difficult to use the positioning information for other purposes. The aim of project PiLoNav is to overcome these constraints by focus on the development of a senor fusion based positioning system for highly precise determination of the position, movement and time of a rail vehicle. For more details about PiLoNav, read [1].

2.2 The Train Models

Nowadays, the only models in commercial use in Stockholm's subway are the C14, C15 and C20. This subsection will describe the dimensions and parameters regarding those models. All information has been provided by MTR, Stockholm.

2.2.1 C14 and C15

The only difference between C14 and C15 is that the equipment was reused from the old models when constructing C14 where as the equipment for C15 was newly manufactured. This only affected their weight; the C15 four tons lighter. Furthermore, both models are referred to as Cx-model, as the parameters are almost the same.

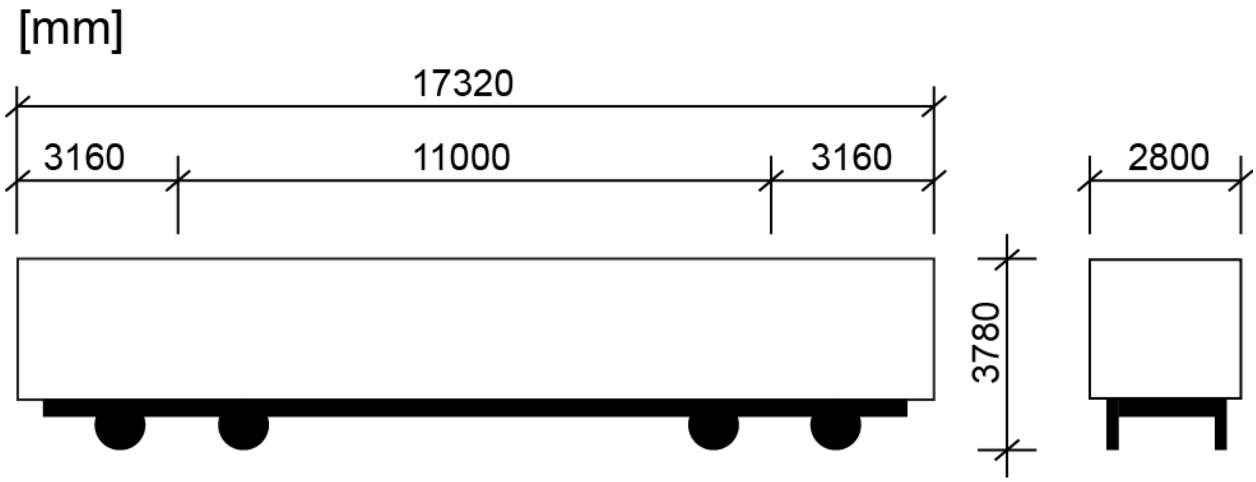


Figure 2. Dimensions for Cx-model

The length of one train car is 17,32 meters (see Figure 2 and Table 1) and it is 2,8 meters wide. The height is 3,78 meters. When the car is empty it weighs 25/29 tons but it can take a load up to 11,7 tons which gives it a total weights of 36,7/40,7 tons. It holds 48 sitting and 108 standing passengers. The cars of the Cx-model are permanently paired. A full-length train contains 8 cars i.e. 4 pair of cars with a total length of 136 meters.

Parameters	***C14***	***C15***
Production [Units]	126	14
Length [mm]	17320	17320
Width [mm]	2800	2800
Height [mm]	3780	3780
Min Weight [kg]	29000	25000
Max Weight [kg]	36700	40700
Max Speed [Km/h]	80	80

Table 1. Parameters for Cx-model

2.2.2 C20

In 1996, a new train model where introduced, called the C20. The length of a car from the C20-model is 46,5 meters (see Figure 3 and Table 2) and the width is 2,9 meters i.e. 10 cm wider than the Cx-model. When the car is empty it weighs 67 tons and fully loaded it weighs 101,2 tons.

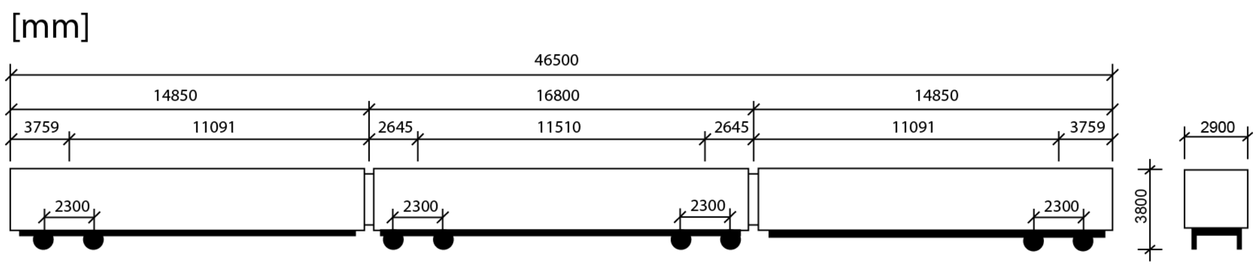


Figure 3. Dimensions for C20-model

This model can hold 126 sitting and 288 standing passengers. A full-length train contains 3 cars with a total length of 139.5 meters. After 9 pm and during weekends, one car is removed and the total length is then 93 meters.

Parameters	***C20***
Production [Units]	270
Length [mm]	46500
Width [mm]	2900
Height [mm]	3800
Min Weight [kg]	67000
Max Weight [kg]	101200
Max Speed [Km/h]	90

Table 2. Parameters for C20-model

2.3 Environmental concerns

The sensors must be suitable to work in both indoor and outdoor stations. A lot of factors must therefore be taken into account. In subway environments, rain, fog and snow during the winter and dirt in all seasons can affect the sensors, and electric magnetic fields can create disturbances that can have huge impact on their output and the functions. To know where to position the sensors, a guideline is needed to avoid placing it too near the train. According to SL's document SL-2008- 1633, version 5, the train is constructed to be on the inside of the profile D (see Figure 4), except for on the top, where profile B is valid. To get a more exact position that fulfils the requirement for the sensors, a visit to a train depot in Rissne and to the Hjulsta station was made for better measurements.

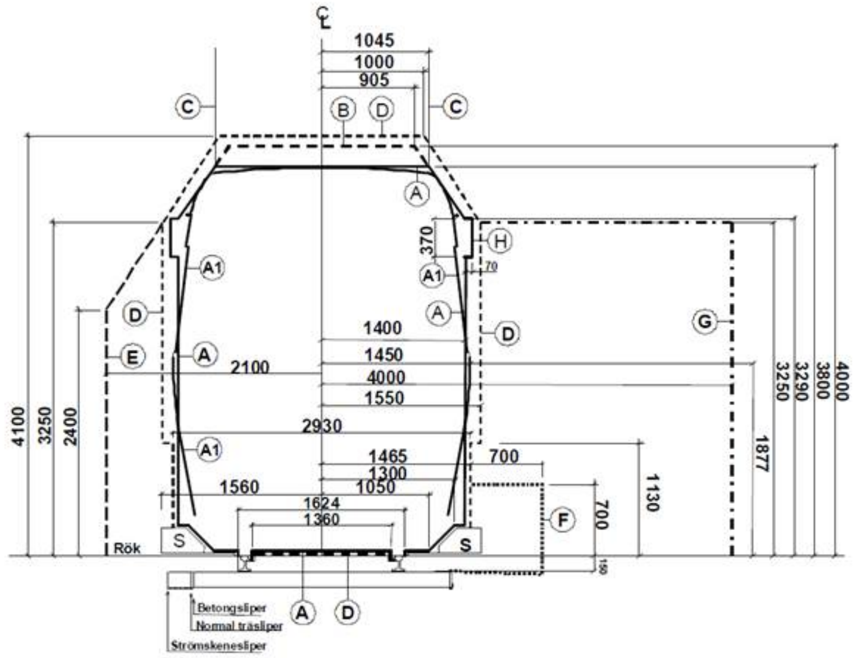


Figure 4. Profile D

2.3.1 Hjulsta station

The station that will be used in the test case is Hjulsta station. It is an indoor station where the train models C13, C14 and C20 are used. According to MTR, this station is one of the most unfortunate when it comes to stopping with one car in the tunnel. Opening the doors in the tunnel could have a fatal outcome if anyone falls out of the train. Fortunately, no one has been injured in this way yet. Still, MTR does not know why this is happening. The drivers for the train have different ages and work experiences. One theory MTR has is that operators might be relaxed when approaching Hjulsta, as it is the last station of its line, and therefore less vigilant. However, this phenomenon is happing at stations that are not end stations. Much data indicates that the reasons are situation dependent.

Even if the temperature at Hjulsta station can vary, the range will not be an issue for the sensors because it is an indoor environment. The same goes for the weather condition regarding rain, fog and snow.

Type of day	*Commercial stops*	*Transportation stops*	*Total*
Mon-Thus	129	7	136
Friday	140	7	147
Saturday	111	5	116
Sunday	100	5	105
Total Week	480	24	504

Table 3. Number of types of stops depending on the day

From Monday to Thursday there are 129 commercial stops and almost as many during the weekend (see Table 3) at Hjulsta station. The sensor needs to handle in total at least 26 208 stops every year. This information can estimate and give an indication of the lifespans of the chosen sensors.

The permitted speed for the train at platforms is 50 km/h.

2.4 Optical detection

This subsection is describes optical detection and the specifications about the used laser sensor used.

2.4.1 Optic detection technology (Laser)

Optical sensors are widely used in all different kind of application, following many different types of principals for measurements [12]. The basic principle of active noncontact range-finding devices is to project a radio, optical, or ultrasonic signal onto an object and to process the reflected or scattered signal to determine the distance [13]. The method the sensor is using to measure distance depends on the accuracy and distance capability required of the device and application. Optical distance measurement methods can be put into three categories: interferometry, time-of-flight and triangulation methods. The sensor used in this project is a laser sensor using time-of-flight measurement and this subsection will focus on that type of principle.

The laser pulse time-of-flight (TOF) distance measuring technique refers to the time it takes for a pulse of energy to travel from its transmitter to an observed object and then back to the receiver. If the energy source is light, then speed of light c is a relevant parameter involved in range counting. The system measures the round-trip time between a light pulse emission and the return of the pulse echo, resulting from its reflectance off an object (target). The distance x is given by elementary physics where the time t multiplied with velocity c gives the distance x.

$$x = c \cdot t \quad (1)$$

The measured time is representative of the light traveling both to the target and back. Therefore the distance must be reduced by half. The actual distance between the sensor and the object is given by

$$x_{half} = \frac{c \cdot t}{2} \quad (2)$$

The elements in a TOF device are a laser transmitter emitting pulses with a duration of 5 to 50 ns, receiver channel, an automatic gain control (AGC) and timing discriminators (see Figure 5). The transmitter optics serve the purpose of both expanding the laser-beam diameter in order to reduce the area density of the laser pulse energy and of reducing the divergence of the laser beam [14]. The receiver optics, on other hand, collects the backscattered light and focuses it onto the detector.

The laser sensor technology was chosen to be a part of the thesis because it is a relative new technology and because manufacturers recommended it as a reliable and straightforward technology when it comes to detection.

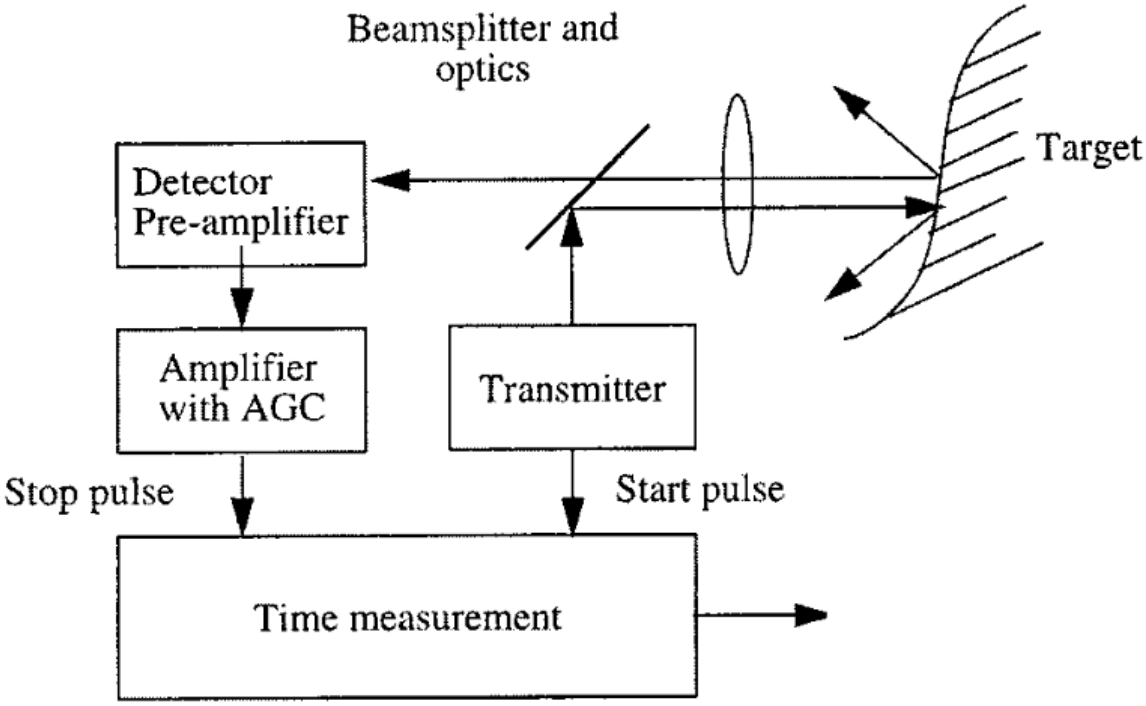


Figure 5. Block diagram of a TOF laser device [13]

2.4.2 The optic sensor (Laser)

The laser senor chosen for this project is the model LR-TB5000C from Keyence Corporation. They have confirmed that this product complies with the essential requirements of the applicable EC Directive [15] and have the CE mark.

The light source is a red laser with a wavelength of 660nm. The pulse width is 4.3ns. The detectable distance is between 60 to 5000mm, which fits the application for this project. The spot diameter is selectable from 40mm or less on a dial on the back of the sensor. The required power voltage for the sensor is between 20 to 30VDC with a maximum current of 150mA. The sensor has a M12 connector (see Figure 6).

The control output can either be a NPN or PNP open collector with 30VDC or less and with an optional analogue output between 0 to 10V or 4-20mA.

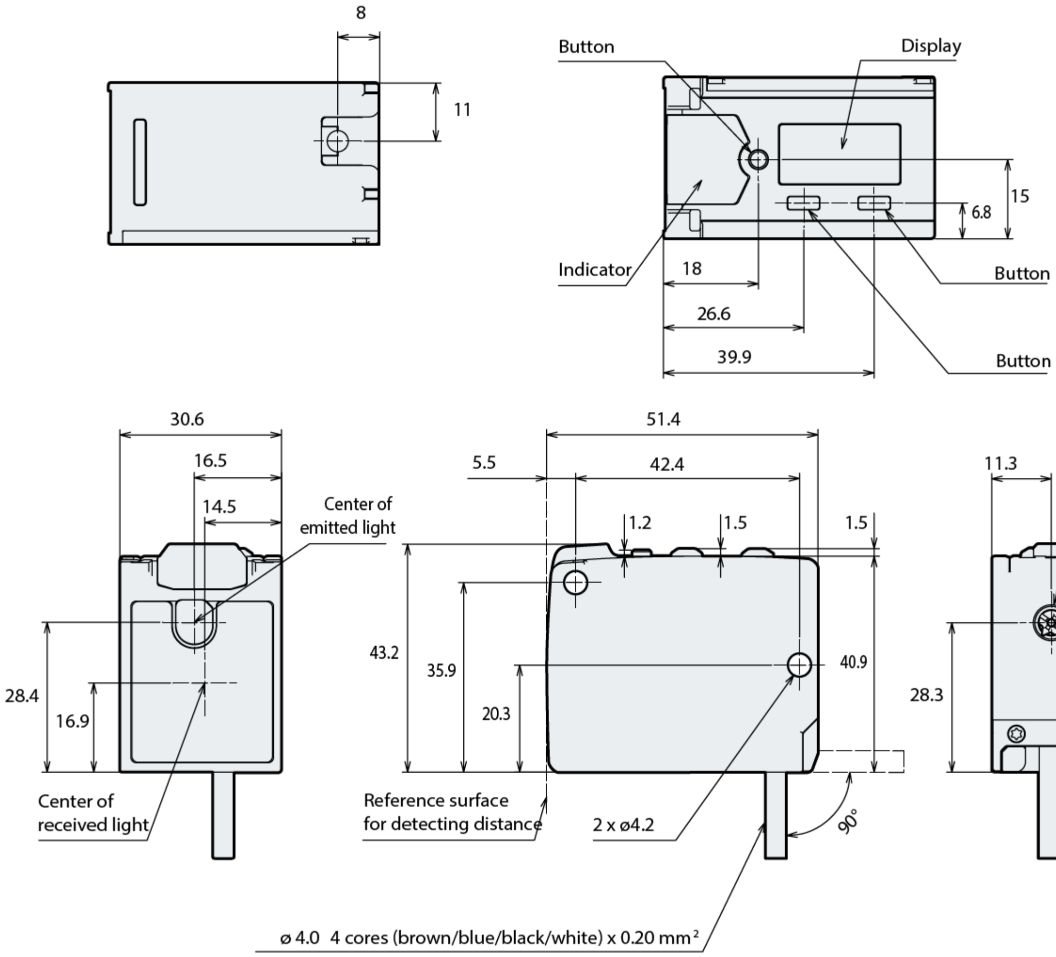


Figure 6. The dimensions of the optical sensor [15]

The sensor can handle an ambient temperature between -20°C to 55°C without freezing and has the enclosure rating IP65. The EMC for the sensor is standard EN 60947-5-2.

The price for the optical sensor including the cable and the mounting bracket is 9.290 sek + tax at Metric Industrials.

2.5 Inductive detection

This subsection is describes inductive detection and the specifications of the used inductive sensor.

2.5.1 Inductive detection technology

Inductive sensors are electronic devices capable of measuring certain distance or performing switching when detecting a metal object that approaches the sensor face [17]. Primarily they are used to measure electric and magnetic fields, or other physical quantities such as displacement and procure that can be transformed into electric or magnetic response. The noncontact inductive sensors can only detect metals. Unlike capacitive sensors, non-metallic media materials between the probe and the target do not affect them. They are therefor well adapted to harsh environments where oil, dirt, dust, or other substances are present. However, they do react differently to different metallic materials such as copper, steel, and aluminium, which mean that they can also be used to identify metals. There is no clear definition to distinguish inductive, magnetic, and electromagnetic sensor. However, the sensors that are primarily made of a simple inductive coil, eddy-current sensors, and variable reluctance sensors are considered to be inductive sensors.

Inductive sensors are designed based on the operating principle and characteristics of an inductor that is an electromagnetic component that relates the interaction between electrical and magnetic fields. The inductor is a passive electrical or electronic component that resists changes in current. The relationship between the voltage and current is given by

$$V = L\frac{dl}{dt} \quad (3)$$

where V is the voltage across the inductor and L is the inductance, I is the current flowing through the inductor, and t is the time.

The inductor is also an energy storage device, storing energy as a magnetic field in or around the inductor. The energy U stored in an inductor is given by equation

$$U = \frac{1}{2}LI^2 \quad (4)$$

There are primary four different classifications for inductors, wire-wound (air) inductors, radial inductors, ship inductors, and power inductors (see Figure 7).

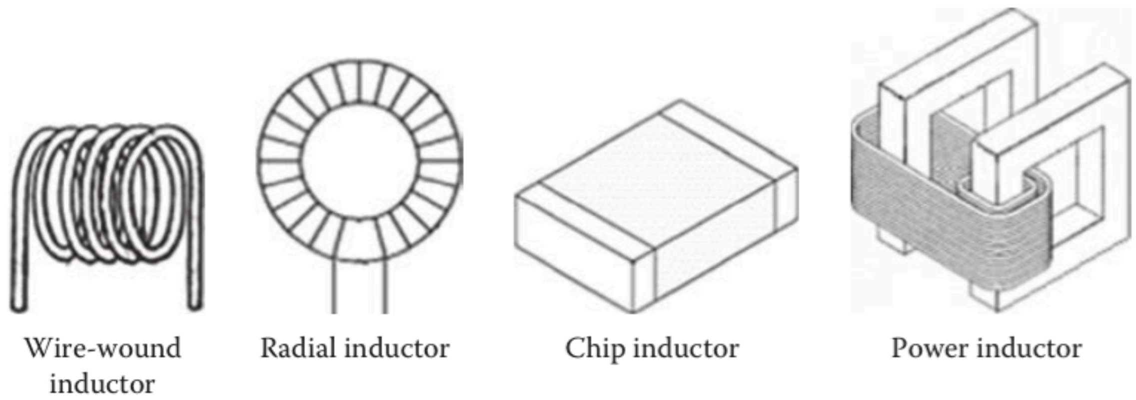


Figure 7. Classifications of inductors [17]

For an inductive sensor to work, five elements are necessary. It needs an inductor, an oscillator to create and emit a high-frequency alternating current, a metal object (target), a sensing or measurement circuit and an output circuit that can convert the detected signal to a proper output (see Figure 8).

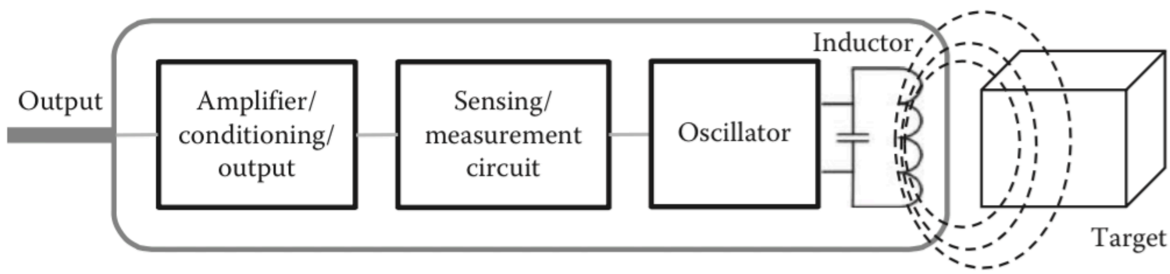


Figure 8. Necessary elements for an inductive sensor [17]

The oscillator is an inductive capacitive tuned circuit (also called RLC-circuit) that creates a radio frequency, typically 500 kHz to 1 MHZ (see Figure 9). The electromagnetic field is emitted from the coil away from the face of the sensor. When a metal target enters the field, currents are induced and circulate within the target. This causes a load on the sensor, decreasing the amplitude of the electromagnetic field. The trigger circuit can now measure the amplitude change to determine the distance to the target or compare the amplitude change with a predetermined value to switch the sensors output state (on/off).

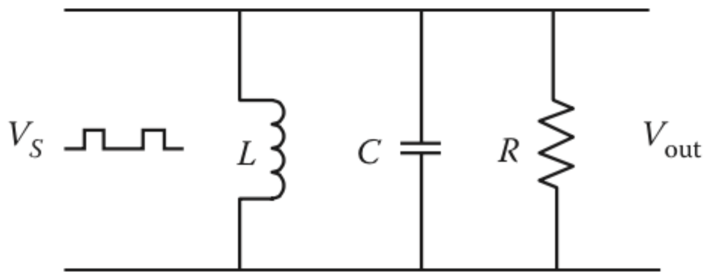


Figure 9. LCR-circuit [17]

This technology was chosen to be a part of the thesis because of its low cost. If it works well with its environment regarding EMI, the sensor is very reliable due to the fact that the train is the only object that can switch the sensor: rain, dirt or people walking in the tunnel will not affect it. This non-contact technology suffer less from corrosion, resulting in less maintenance and a longer life span. Manufacturers recommended this kind of sensor as a reliable and straightforward technology when it comes to detection.

2.5.2 The Inductive Sensor

The inductive sensor is of model ID5055 from IFM Electronics. It is carrying both CE and C-UL Listing Mark [18].

The electrical design of the sensor is a DC PNP-type with a sensing range of 50 mm. The necessary power voltage for the sensor is between 10 to 36VDC with a maximum current of 250mA. The sensor has a M12 connector. The analogue output will be close to 0V or the applied power voltage with a maximum voltage drop of 2,5V, depending if it is switched (detecting) or not. On the side of the sensor there are two indicators (see Figure 10), one showing green when it is on, and on showing yellow when switching (detecting). The IDE5055 has a 70 Hz switching frequency.

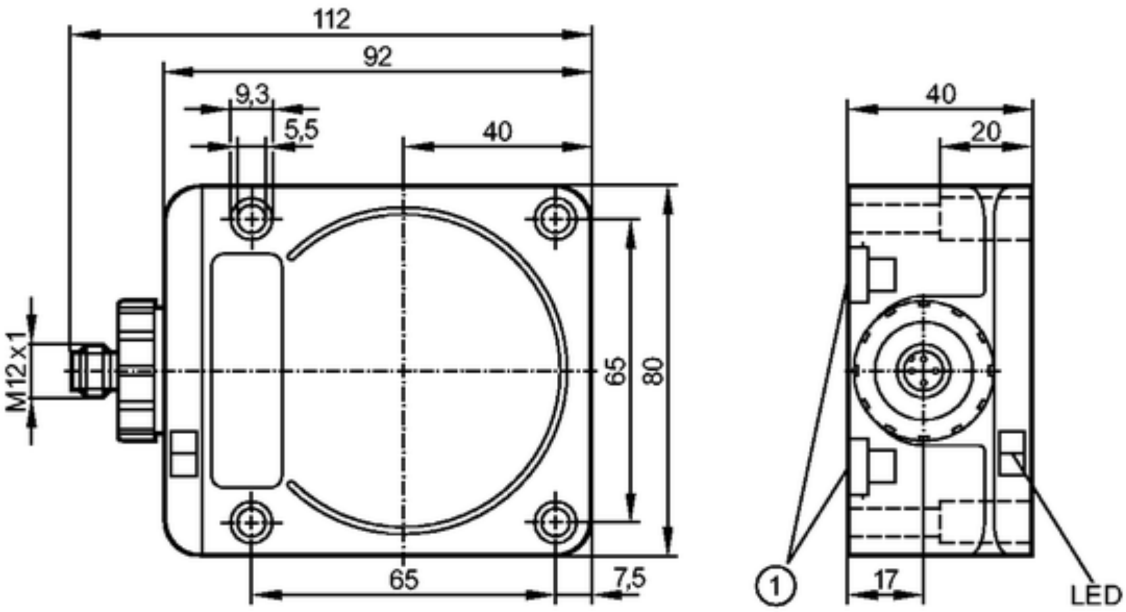


Figure 10. The dimensions of the inductive sensor [X]

The sensor can handle an ambient temperature between -25°C to 70°C and has the enclosure rating IP67. The EMC for the sensor is standard EN 60947-5-2.

The price for the inductive sensor including the cable is 1.166 sek + tax at ifm electronic AB [19].

2.6 Logic

The logic for the system is placed in a microcontroller board called Arduino Uno R3 (see Figure 11). The Arduino Uno is based on the ATmega328 [20]. It has 14 digital input/output pins of which 6 can be used as PWM outputs, 6 analogue inputs, a 16 MHz ceramic resonator, an USB connection, a power jack, an ICSP header, and a reset button. The operating voltage for the controller is 5V.

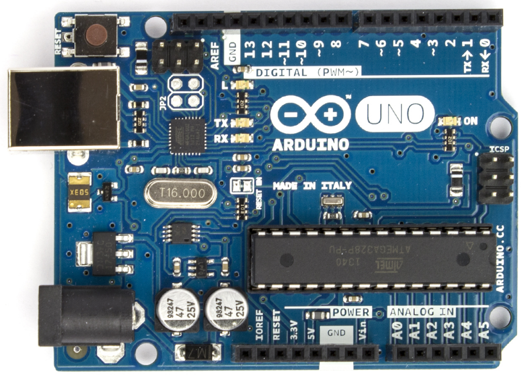


Figure 11. Arduino Uno R3 [20]

It can handle an input voltage between 6-20 V but the recommended input should be around 7-12V. Atmega328 has 32 KB Flash memory, 2 KB SRAM and 1 KB EEPROM. The clockspeed is 16 MHz.

The price for the Arduino Uno R3 is 184 sek + tax [21].

Once the system has been tested and evaluated, the Atmega328 can easily be moved to a more suitable PCB that is designed to work for this application. That will lower the cost and remove unneeded components.

2.7 Software

For observation and study of the real-time constrains of the system, the Arduino is connected through the USB interface to a computer and the output from the sensor is processed in LabVIEW from National Instruments.

2.7.1 LabVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming platform for designing, developing and testing systems [23].

NI-VISA is also required. The Virtual Instrument Software Architecture (VISA) is a standard for configuring, programming, and troubleshooting instrumentation systems comprising GPIB, VXI, PXI, Serial, Ethernet, and/or USB interfaces. VISA provides the programming interface between the hardware and LabVIEW. NI-VISA is the National Instruments implementation of the VISA I/O standard. NI-VISA includes software libraries, interactive utilities such as NI I/O Trace and the VISA Interactive Control, and configuration programs through Measurement & Automation Explorer.

By using JKI VI Package Manager (VIPM), a package manager for LabVIEW that provides an easy way to install and update LabVIEW libraries, the LabVIEW Interface for Arduino (LIFA) can be accessed. LIFA uses open source Arduino firmware (that is included within the LIFA installer) to communicate with LabVIEW.

LabVIEW must be configured correctly, depending on which kind of analysis of the output is necessary and how the output needs to be monitored.

2.7.2 Arduino IDE

For programming the microcontroller on the Arduino Uno, the Arduino IDE (Integrated Development Environment) is required [22]. Arduino IDE is an opensource environment that makes it easy to write code and upload it to the I/O board. It runs on Windows, Mac OS X, and Linux and the environment is written in Java and based on Processing, AVR-GCC, and other open source software. Note that only version 1.0.5 or earlier is compatible with LIFA.

Once the LIFA Firmware is deployed in the Arduino Uno, LabVIEW will be able to process the output of the microcontroller that is received from the sensors.

2.8 Communication

Because of the high EMI that exists in the environment, the communication to the indication, which is located at the time of the testing 100 meters away from the microcontroller board, will be using a 26LS31 driver on the microcontroller board side and a 26LS32 receiver on the indication side. Both need to have a 5V supply voltage.

The driver and the receiver are using RS-422 (also known as TIA/EIA-422), a technical standard originated from Electronics Industries Alliance [24]. RS-422 is a balanced serial interface for the transmission of digital data and can handle the data rate of 10 Kbit/s on a 1200 m distance (see Figure 12). The advantage of a balanced signal and the main reason for using this standard in this project is the greater immunity to noise from the environment.

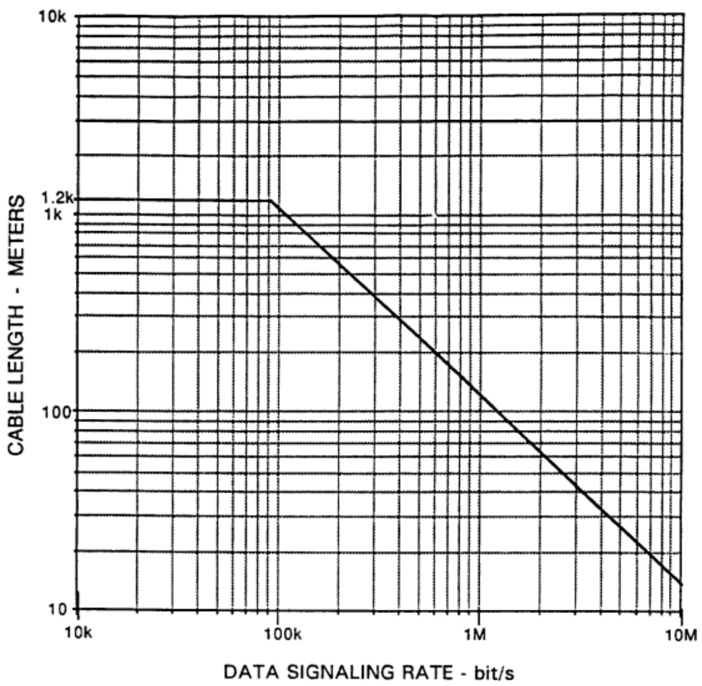


Figure 12. Data signalling rate with respect to cable length [24]

The transmitted data is coded as a differential voltage between the wires. The wires are named A (negative) and B (positive) and when B > A then the output is a mark (1 or off) and when A > B then it is counted as a space (0 or on). A mark is 1V for the A line and 4V for the B line (see Figure 13). Furthermore, a space is 1V for the B line and 4V for the A line. The voltage difference at the transmitter end should not exceed 5V and not be less than 1.5V. The voltage difference at the receiver end should not be less than 0.2 V.

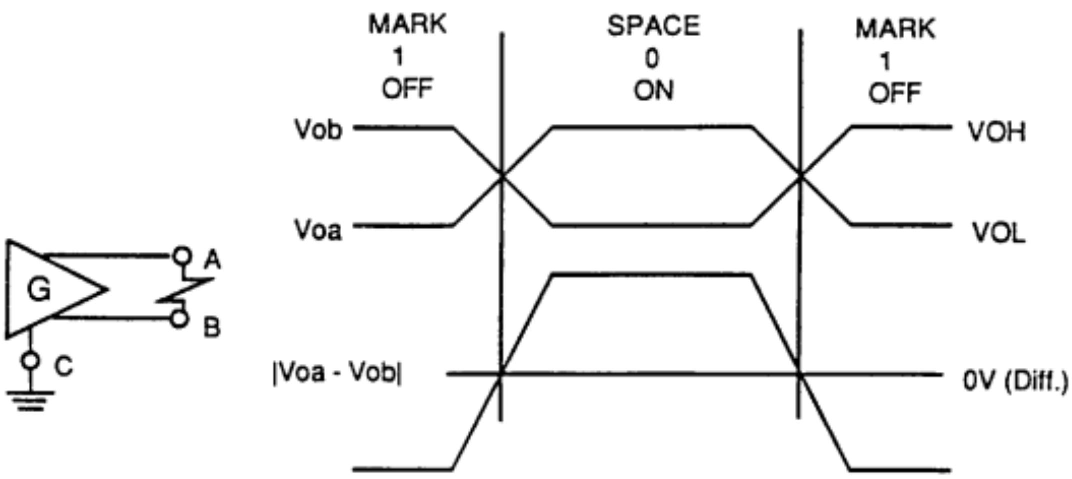


Figure 13. Signalling sensing [24]

Basically, in this application, when the microcontroller sets the input to the driver as high (5V), the output of the receiver will also be high. The voltage of the output is not strong enough to power the relay so the output is connected to a transistor circuit that will amplify the signal.

2.9 Indicator

According to MTR, there are a lot of rules to be followed when it comes to setting up induction signals near the rail area. Because it is outside the scope of this thesis to do deeper study regarding this, a 12V strobe will be used just to make sure that the system works properly. The strobe will be controlled by a SRD relay, SRD-5VDC-SL-C (see Figure 14). When the output from the receiver is high (5V) the relay will switch on the strobe.

Figure 14. SRD relay [25]

3 THE PROCESS

In this chapter the working process is described. First, the approach for testing and evaluating the sensors will be presented, then the method for analysing the data.

3.1 Main Approach

Because the sensors have two different technologies, optical and inductive, not all tests will be performed in the same manner for both of the sensors. There will be no need to test the sensor though, if they already have been tested according to their specifications.

3.1.1 Monitoring and observation

While performing the tests, the sensors will be connected to the microcontroller on the microcontroller board, Arduino Uno. The microcontroller will be connected to a computer and will be programmed with the LIFA Firmware so LabVIEW will be able to process the output the microcontroller receives from the sensors. LabVIEW must be configured so it will be possible to plot and save the data.

3.1.2 Hardware

The sensors will be connected to the Arduino Uno through an optional analogue pin (A0-A5). Depending on the output from the sensor, it needs a voltage divider to scale down the signal, to fit the 5V logic that is on the microcontroller.

$$V_{in} = i \cdot (R_1 + R_2) \quad (5)$$

$$V_{out} = i \cdot R_2 \quad (6)$$

$$V_{out} = \frac{R_2}{R_1 + R_2} \cdot V_{in} \quad (7)$$

This is made with two resistances. To know which resistance to choose; the following equation (7) is used (see Figure 15), derived from Kirchhoff's second law (5) and Ohm's law (6).

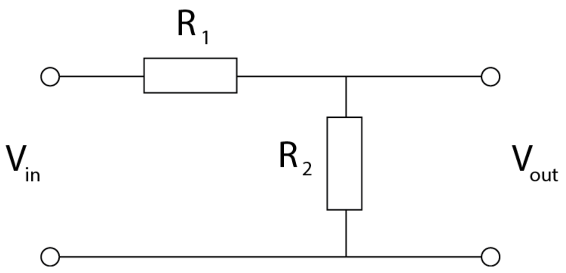


Figure 15. Voltage divider circuit

3.1.3 Position of the sensors at the platform

The most crucial requirement for this system is to be able to detect all used train models; therefore the position for the sensors first must be investigated. In order to do that, a mounting bracket must be constructed and designed for the inductive sensor. The sensor needs to be within a distance of 5 cm from the train. There will be two different approaches for the position of the inductive sensor, one at the edge of the platform and one next to the rail. Two mounting brackets will be designed so it is possible to tune the distant within millimetres, both vertically and horizontally, one that can be attached horizontally near the rail and one vertically in the platform.

The optical sensor will be placed on the wall and has a long working distance so the mounting bracket that comes with the sensor will work for that application and need no further investigation. To make sure that the train is not stopping with the sensor in between two cars and falsely indicate that the whole train is at the platform, the senor needs to have an angel of 45° or more. The sensor will then only indicate freely way if the whole train has passed. One possible positioning is to place the sensor underneath the platform, about 3 meters away from the tunnel. Neither the sensor nor the laser marker on the wall will then be seen from the platform.

While performing the test, the optical sensor will be placed on the platform near the tunnel. It will save a lot of time and effort not to mount it on the wall and will remove the requirement of needing licensed personnel attending during the tests. The test will still produce same result.

3.1.4 Electromagnetic capability

In the environment of the subway underground, there are different electromagnetic interferences (EMI). As a consequence of this, it is important to investigate if the sensors have the right electromagnetic capability (EMC) to ensure the correct operation in that environment. Both the sensors are CE marked and follow a specific standard. This standard must be compared to the level of EMI in the underground environment.

3.1.5 Noise in the supply voltage

The ability to handle noises applied to the supply voltage will be investigated.

3.1.6 Weather disturbances

There are different kinds of disturbances from the weather that can easy disturb and change the output from a sensor. The sensor will be used and operate in a Swedish climate. They both need to fulfil the requirements regarding the temperature and the water/dust resistant. Furthermore, the laser sensor needs to be evaluated on its ability to work with rain and dust interfering with its sights.

3.1.7 Light disturbances

Depending on the position, station or time, the sensor will be exposed to light from for example in- or outdoor lights, headlights from train or reflection from the sun. These are nothing that could affect the inductive sensor but it could easily block the laser sensor from reading the reflexion of the laser beam. Therefor the optical sensor will be investigated in regards to its sensitivity to light.

3.1.8 Continuous use

To make sure that the sensors are able to operate in a continuous manner, the sensors will be tested for three days in continuous operation. Meanwhile the output will be logged for observation of changes in behaviours and performance.

3.2 Data Analysis Method

All the test data will be logged and plotted in LabVIEW. The output data from the different kinds of tests will be compared and analysed.

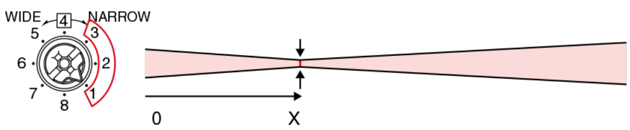
4 CONFIGURATION AND TESTS

This chapter describes in details how the experiments and tests were performed and the configuration of the parameters of the prototype system.

4.1 Configuration of the laser sensor

The laser sensor can handle a supply voltage of between 20-30VDC. The chosen voltage for this system is around 24V. This voltage is selected because it is a commonly used standard. Thus, selecting a higher voltage will not affect the output. To ensure no damage to the sensor, a 140mA fuse was attached between the sensor and the 24V outlet.

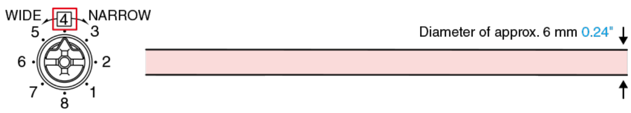
Narrow Spot Setting



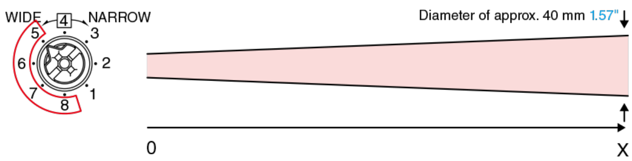
Unit: mm inch

NARROW	1	2	3
X (Approx.)	500 19.69"	1000 39.37"	2000 78.74"

Parallel Light Setting



Wide Spot Setting



Unit: mm inch

WIDE	5	6	7	8
X (Approx.)	5000 196.85"	3000 118.11"	1500 59.06"	750 29.53"

Figure 16. The configuration for the spot diameter

To be able to use the laser sensor, some initial settings first need to be set up. This must be done when the sensor is turned on for the first time and it is done from the small display on top of the sensor. The first step is to choose the unit for measuring. It is possible to choose between mm, inch and feet. The selected unit is mm, but this will not affect the result.

The second choice is to select the I/O. The options are Out1+Out2, Input +Out1, Out1+Analogue or Input+Analogue (NPN or PNP). The selected I/O is input+Analogue.

The third choice is about the output. The options are between 4-20mA and 0-10V. The selected output is 0-10V.

The following two choices are about scaling and are not necessary for this application.

The last choice is between NPN or PNP output. PNP is selected.

It is possible to adjust the spot diameter with a dial on the back of the sensor. According to the manual [15] the spot diameter should be 40 mm or less at the desired detecting distance for the best result. The adjustments are illustrated in Figure 16. Because of that, the spot diameter must be configured when the sensor is placed in its intended position.

The pins are connected according to Figure 17.

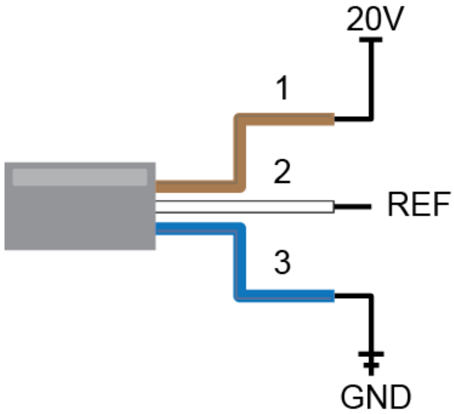


Figure 17. The connection for the laser sensor

The sensor is placed underneath the platform, about 3 meters away from the tunnel (see Figure 18). During the test, the sensor was placed on top of the platform.

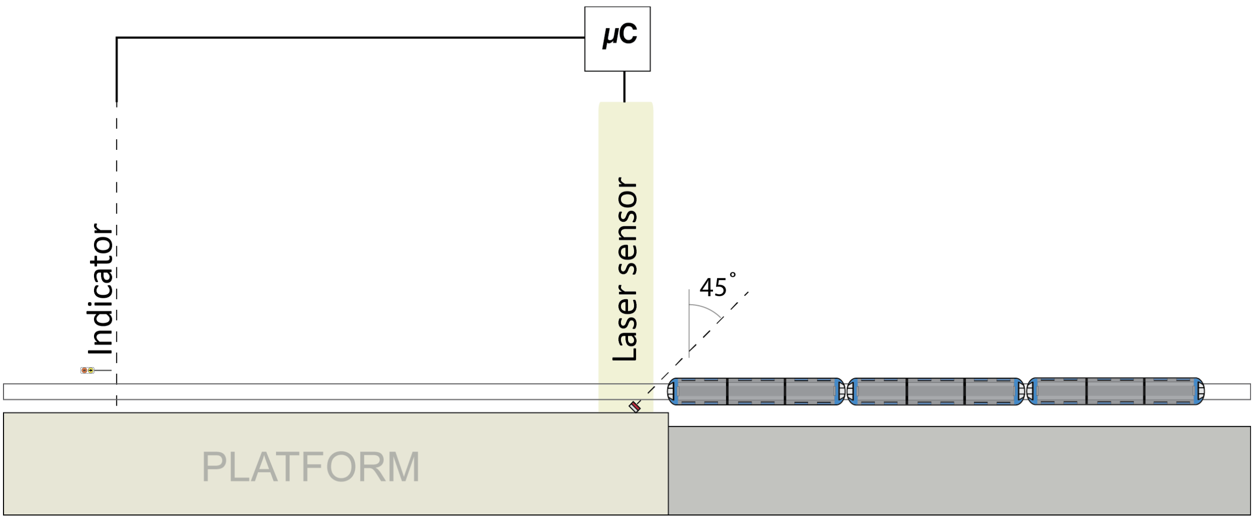


Figure 18. The configuration of the laser system

4.2 Configuration of the inductive sensor

The inductive sensor can handle a supply voltage of between 10-36VDC. The chosen voltage for this system is 12V. This voltage is selected because the output, when the sensor is switching, will be around 10V, and that will be closer to the 5V that the microcontroller is using. To make sure not to damage the sensor, a 250mA fuse is attached between the sensor and the 12V outlet.

The pins are connected according to Figure 19.

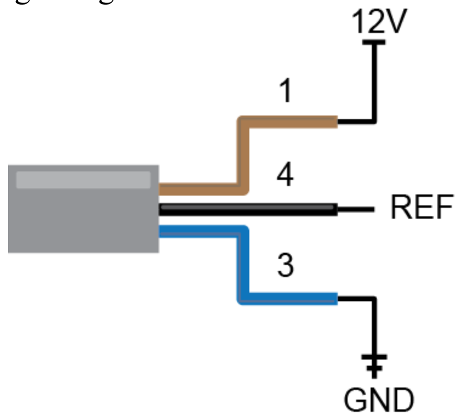


Figure 19. The connection for the inductive sensor

To be able to know where to place the inductive sensor so it can detect both kinds of train models used, two temporary adjustable mounting brackets were designed in CAD (Computer Aided Design) and cut out in 1mm steel with a water jet. Testing the sensor at Hjulsta station showed that by putting the sensor 3 cm horizontally out from the edge of the platform and 1cm down, the sensor could detect both train models. But because of the waist shaped side of the C20 model, the detection was too unstable. Another problem was that if the train stopped with the sensor position between two cars, the sensor might indicate that the whole train had passed. This approach was rejected because of these problems. Another approach is to place two sensors near the wheel, one in the tunnel and one at the beginning of the platform and count the number of axles. This would mean that when the same number of axles had passed through both sensors, the system would know that the whole train had passed by and was positioned at the platform for a safe stop (see Figure 20).

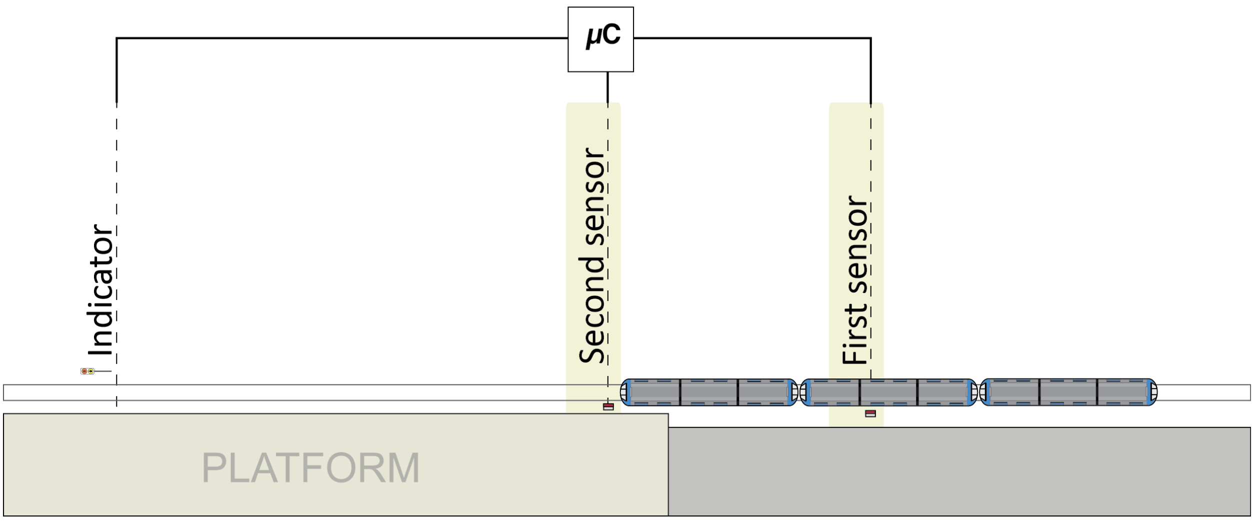


Figure 20. The configuration of the inductive system

The distance between the two sensors should be 11,5 meters or more so that the number of counted axles would only be the same amount when the whole train had passed (for both the Cx and C20 models).

4.3 Monitoring and observation

To enable LabVIEW to read, log and plot the sensor output through the Arduino, LabVIEW needs to be configured. There are two different windows in LabVIEW that are part of the interface: the Block diagram (see Figure 21) and the Front panel (see Figure 22). The Arduino-functions are constructed in the Block diagram and the sensor output will be showed in the Front panel while the program is running.

The Arduino Init-function will initialize a connection between the Arduino and LabVIEW by running the LabVIEW Interface for Arduino sketch (LIFA). The first input decides from which port on the computer LabVIEW will connect to the Arduino. The second input is based on which baud rate this will be in. This must match the baud rate defined by the Arduino firmware; by default this is 115200 bit/second. The third input is the Arduino board type, which is where the type Uno is selected. The Init-function is connected to the while-loop where the Analogue read pin-function reads the analogue voltage on the selected Arduino input pin. Instead of having a fixed pin, the desirable pin can be selected from the Front panel with help of the Analogue pin-switch. Both a waveform chart and a numerical voltage display are connected and will display the sensor output on the Front panel. The File path-function makes it possible, from the Front panel, to decide where the data will be stored on the computer. It will be logged together with the iteration number; e.g., the sampling number.

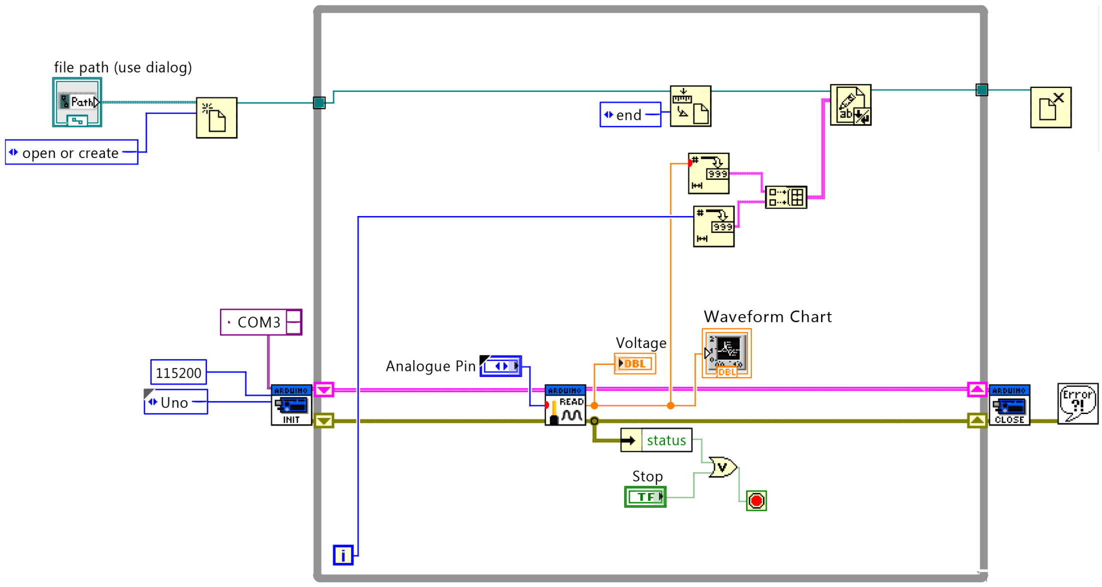


Figure 21. The Block diagram in LabVIEW

The stop button is for killing the execution, so the program will stop the while-loop. The Arduino close-function will then close the active connection to the Arduino. If an error occurred, the error handler will return a description of the error.

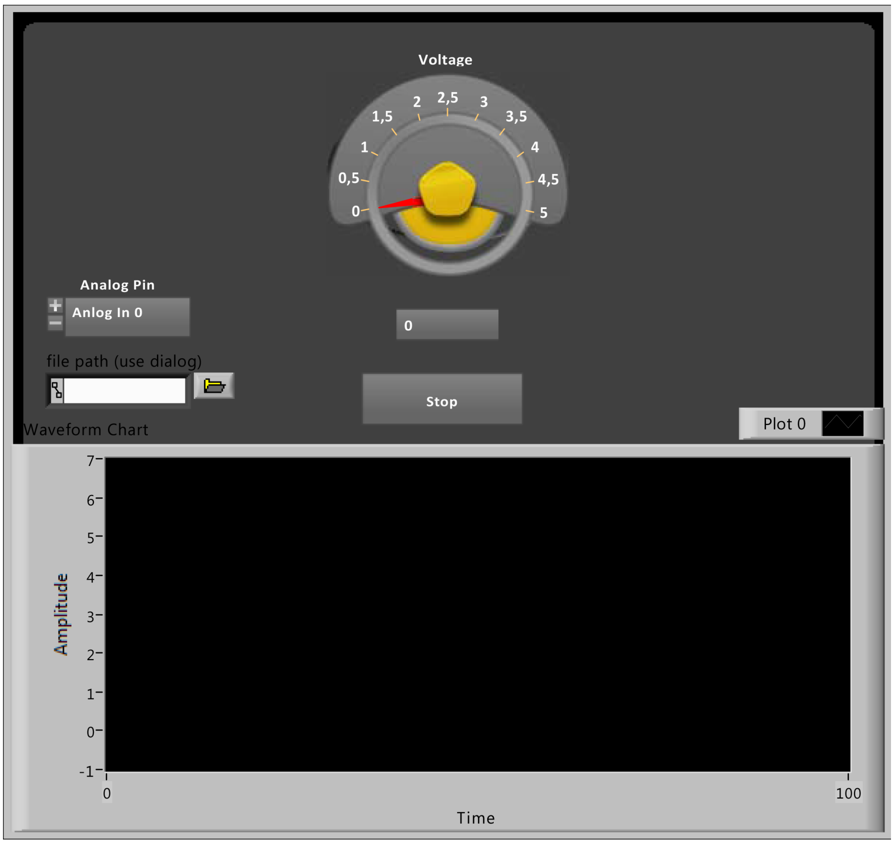


Figure 22. The front panel in LabVIEW

4.4 Hardware and logic (software)

There are two different modes to set up the microcontroller and the logic. The first part of this subsection describes the configuration for monitoring the output from sensor with LabVIEW through the microcontroller. The second part will be about closing the system and adding the logic for the final application.

4.4.1 Configuration for observation

To make the Arduino Uno send the output from the sensor like an output to the computer, the LabVIEW Interface for Arduino (LIFA) must be installed on the microcontroller. To achieve this the Arduino needs to be connected to the computer through an USB-port. The program is deployed to the microcontroller with help of the Arduino IDE (Integrated Development Environment). Once the LIFA Firmware is deployed, LabVIEW will be able to process the output the microcontroller is receiving from the sensors.

The first analogue pin, A0, on the Arduino is chosen to read the output from the senor. When it is necessary to connect more than one sensor at the same time, the other sensor needs to be connected in another optional analogue pin (A1-A5). The analogue pin that needs to be observed is chosen in the LabVIEW Front panel. The output from both the sensors will be around 0-10V. This is scaled down to 0-5V with help of a voltage divider. The divider is constructed according to equation (7), e.g. two 1KΩ resistors (see Figure 15). The ground pin from the voltage divider is connected to an optional ground pin on the Arduino board.

The laser sensor is connected to the voltage divider with its reference pin 2 (white) and the ground pin 3 (blue), which is connected to the ground on the power supply. Pin 4 (black) is not used.

The inductive sensor is connected in the same manner except that pin 4 (black) is used as the reference pin. Pin 2 (white) is not used.

When everything is set up, the run-button in LabVIEW is pressed and the output from the sensor will be displayed as a plot and a numerical value off the output voltage in LabVIEW. The data will also be saved in the file path decided in the Front panel.

4.4.2 Configuration for logic

To set up the logic in the microcontroller, the program needs to be changed. With help of the Arduino IDE, a new code was made for when using the laser sensor, called TrainDetection.ino (see **APPENDIX 1**). The microcontroller will continuously read the analogue input from the sensor and will put the pin 9 as high (5V) if it receives an input value that is within the selected range in the if-statement. The analogue input range is between 0-1023. For the laser sensor, which will be placed on the wall, the values (trainrangemin and trainrangemax) in the if-statement is used for making sure that the sensor only will alert the detection of train if the laser beam is blocked in a specific range. This prevents it from wrongly signalling detection of a train if something else is blocking the sensor outside that range. Those values will be absolute when the position of the laser sensor is decided. As long as something is blocking the sensor within that range (value) the indicator will indicate that the train is still in the tunnel. The counter flag N is counting the times the sensor is blocked. This can be used if it necessary to validate the number of detections.

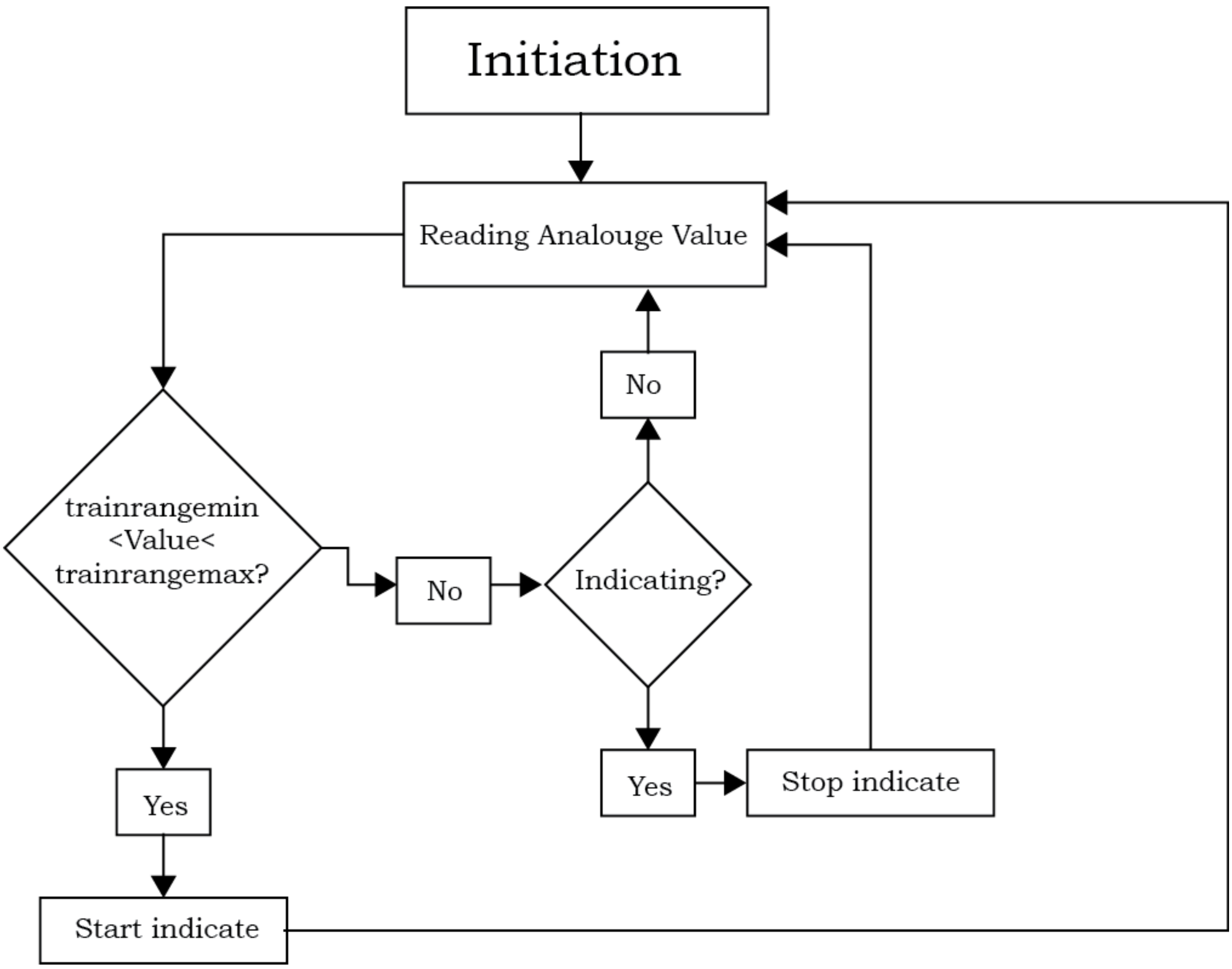


Figure 23. Flowchart for TrainDetection.ino

For the inductive sensor, the code WheelCounter.ino was made (see **APPENDIX 2**). The program is interrupt-based and will count the number of axles at both sensors. If the first sensors output is falling (going from 5V to 0V) and first sensors counter is zero, the system will start indicating putting pin 13 as high. If the opposite happens: the second sensor's input is falling and the first sensor's counter is zero, the system knows that the train is leaving the platform going in the opposite direction and will not indicate. To prevent erroneous counting if one of the sensors misses an axle, the system will reset the counting after 2 minutes without any change of the input from any of the sensors. The system will then stop to indicating.

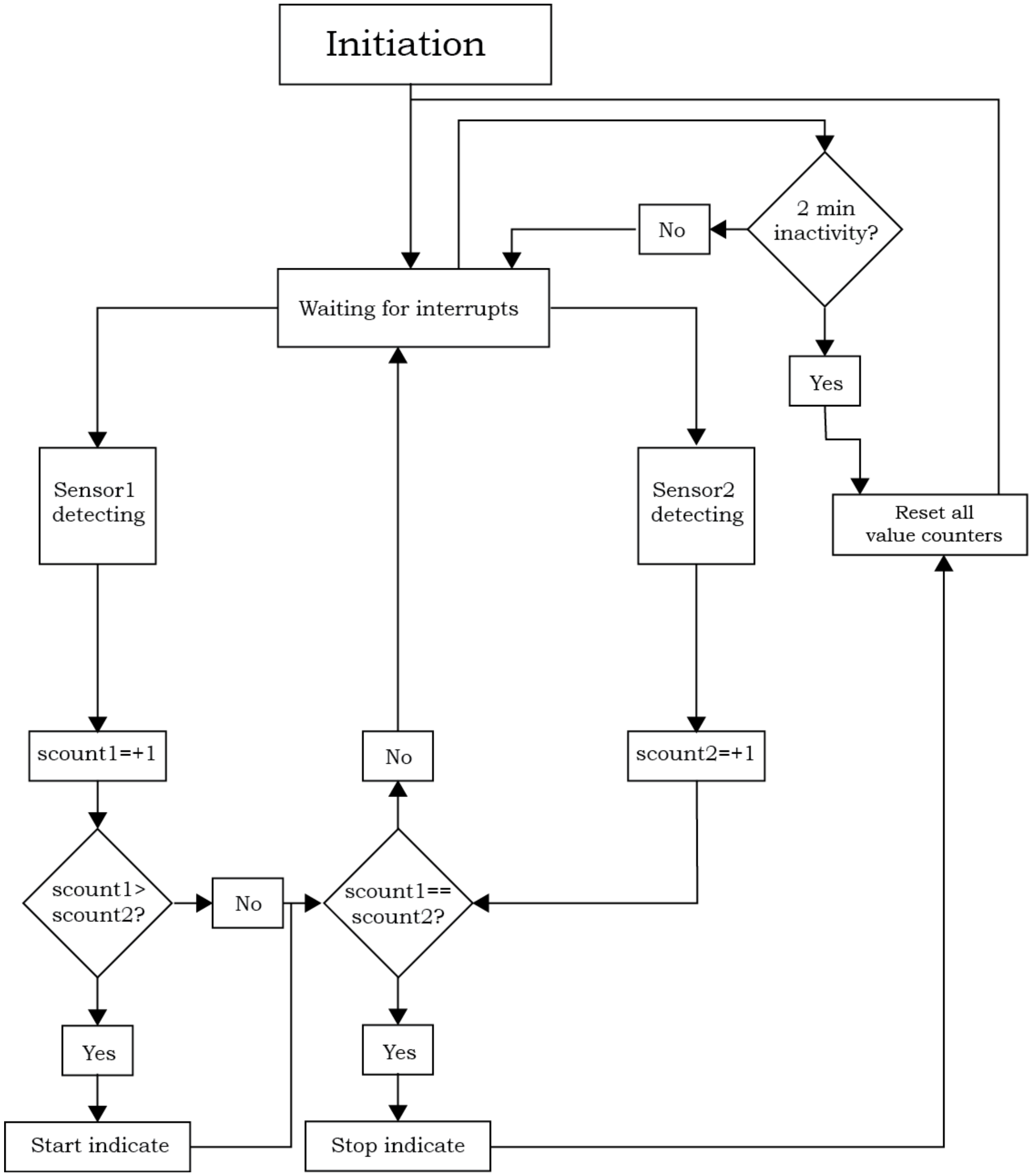


Figure 24. Flowchart for WheelCounter.ino

4.5 From Arduino to Printed Circuit Board (PCB)

To remove all unnecessary parts, lower the cost for the logic and make the system more robust, all of the components could be integrated on the same PCB. Constructing the PCB will not be a part of this thesis. Nevertheless, the final schematics of the PCB are presented in **APPENDIX 3** for the laser system and

APPENDIX 4 for the inductive system but will not be a part of the implementation.

4.6 Platform test

Both types of sensors with their respective systems will be tested at the platform. The laser sensor will be placed at the platform at a 45° angle pointing towards the tunnel. The inductive sensors will be placed at the rail, attached in the concrete railway sleepers. The strobe will be attached at the other side of the platform; about 100 meters away from the microcontroller. The communication between the 26LS31 driver and the 26LS32 receiver will be connected with a telephone cable. For the best performance, a pair of twisted shielded cables should be used to connect the components, but telephone cable is used instead in this instance to lower the costs during the prototype phase.

5 RESULTS

In the results chapter, the results that are obtained with the methods described in the Method chapter are compiled, analysed and compared with the existing knowledge and theory presented in the Frame of reference chapter.

5.1 Analysis of the sensors

This section describes the analysis of the given parameters for the sensors regarding the requirements.

5.1.1 Electromagnetic capability

The EMC for both the sensor is standard EN 60947-5-2. During the test there was no indication of impact from EMI from the environment. Both sensors EMC comply with the requirements.

5.1.2 Noise on the supply voltage

The optical sensor is, according to the manual, able to handle 10% ripple. That means that with a supply voltage of 24V, the output will not be affected with ± 2,4V, which is adequate with the requirements.

The inductive sensor will switch to high when detecting regardless if the supply voltage is higher than 10V. With a supply voltage of 12V and with an ability to handle a drop to 10V, the system can handle 16,7% ripple, which fulfil the requirements.

5.1.3 Disturbances and effect because of weather

They both fulfil the requirements of the temperature and the water/dust resistant.

5.1.4 Disturbances of light

According to the manual the optical sensor can handle a light at 100000 lux, which is direct sunlight. This fulfils the requirements.

There were no noticeable effect or disturbances on the output caused by light from the train or the environment during the tests.

5.1.5 Continuous use

Both sensors were turned on and put under observation with their output logged for three days. There was no interfering with the sensors during that time the test was performed in the laboratory. The inductive sensors output was straight zero the whole time (low) and the laser sensor had a ±0.01V change of input. When testing the sensors functions after the test period, no change of performance could be noticed, which fulfils the requirements.

5.2 Platform test

Both systems, the inductive and the optical, were installed and tested at the platform. This section will describe the result from the tests.

5.2.1 The indication system

The indication worked without any glitches, interference or noticeable delays. The indicator was activated or deactivated according to the logic.

5.2.2 The optical system

The laser sensor was placed on the platform pointing towards the tunnel. When the train came in to the tunnel, the sensor directly reacted and started to indicate. As soon as the train has moved out of the tunnel and was not longer blocking the sensor, it stopped indicating. The test was performed five times with the C20 model and five times with the CX model with desirable result. There were no distinct differences between the outputs from the different models. Figure 25 shows the output from the sensor. The coloured area is the threshold for when the system will indicate that a train is in the tunnel (blocking the sensor).

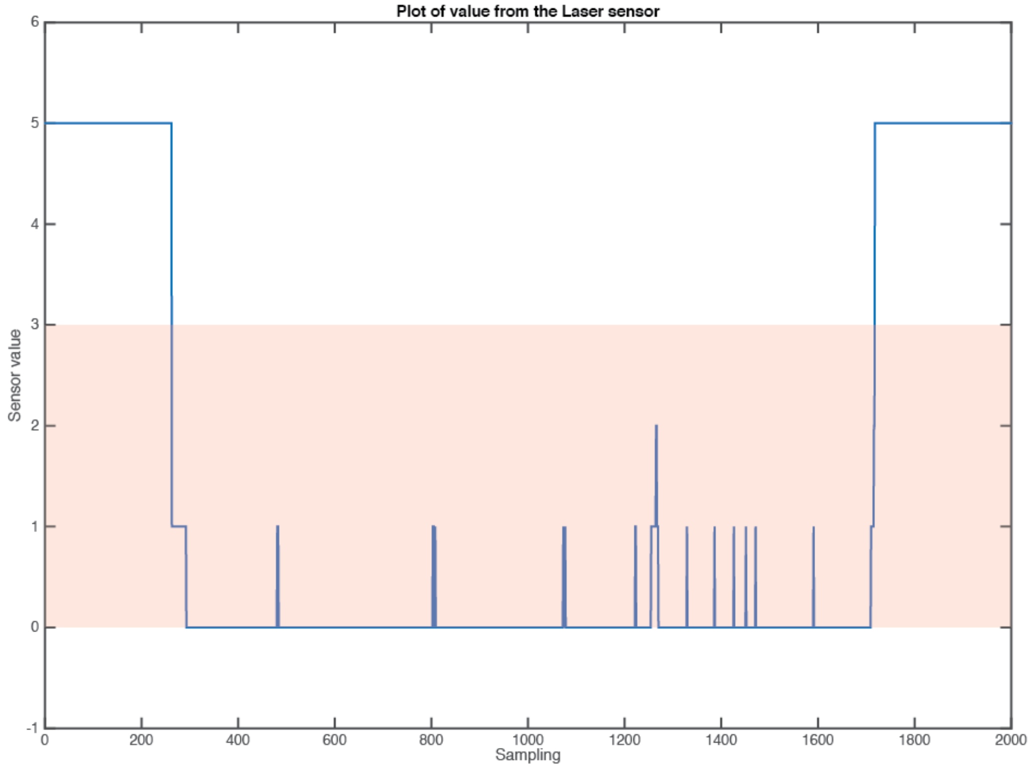


Figure 25. Plot of the output from the laser sensor

5.2.3 The inductive system

The inductive sensors and their mounting brackets made with the water jet were attached in the railway sleeper during the tests. The sensors were on the outside of the rail (see Figure 26). They were placed with a distance of 11,5 meters.

The sensors only detected the wheel when the train had a lower speed. When the train was approaching the platform the system did not start indicating until the train had reduced its speed to approximate 20 km/h. When the train was leaving the platform, the second sensor missed one axle.

Figure 26. The position of the inductive sensor

According to the evaluation of the geometry of the wheel and the train, it was much better to place the sensor inside, between the rails. It is then possible for the sensor to detect a much bigger area of the wheel (see Figure 28 and Figure 28).

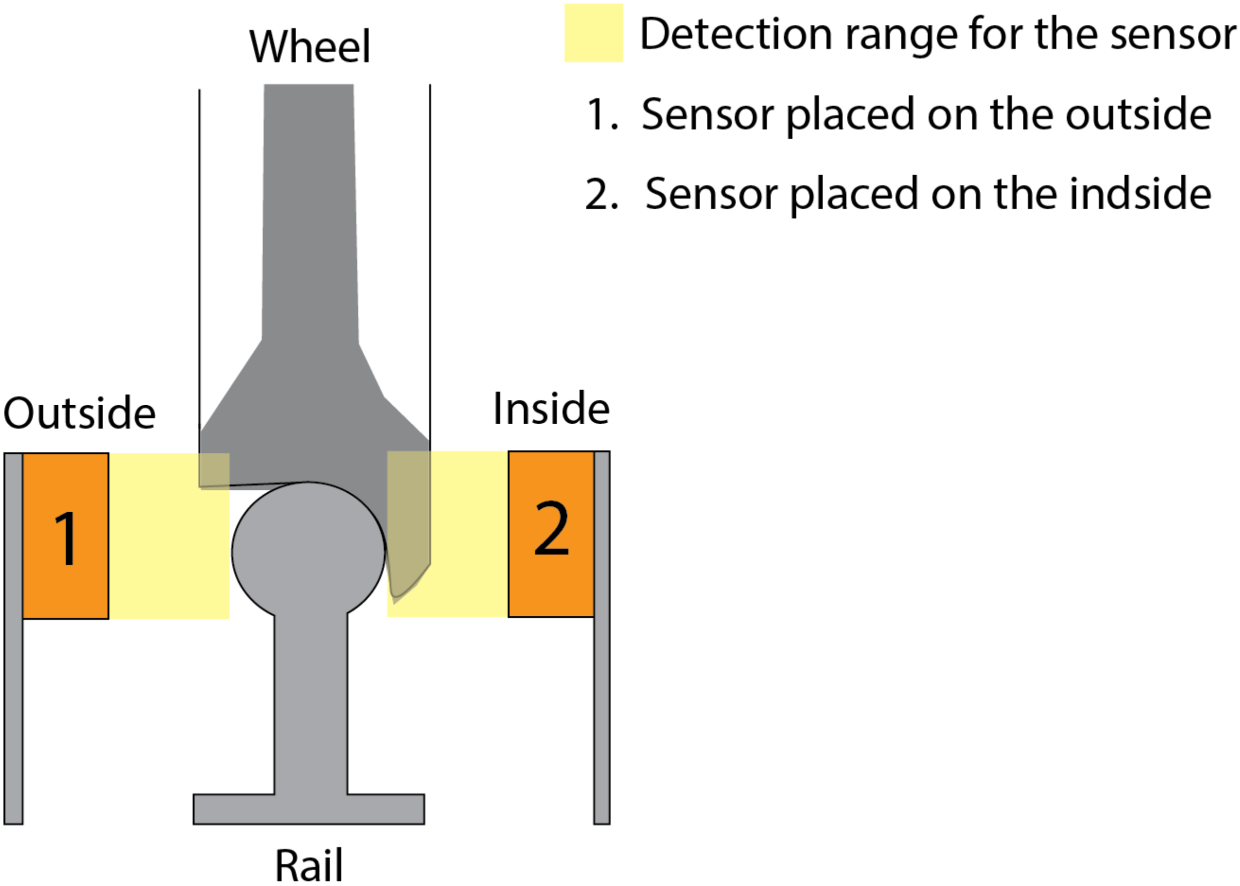


Figure 27. The evaluation of the sensor position

The tests from the first configuration show that the sensors were able to detect the train at low speed even if the detection area was limited. When moving the sensor, the result was desirable even at high velocity.

Figure 28. The geometry of the wheel

Figure 29 shows the plot of the one of the sensors when the sensor is placed inside the rails.

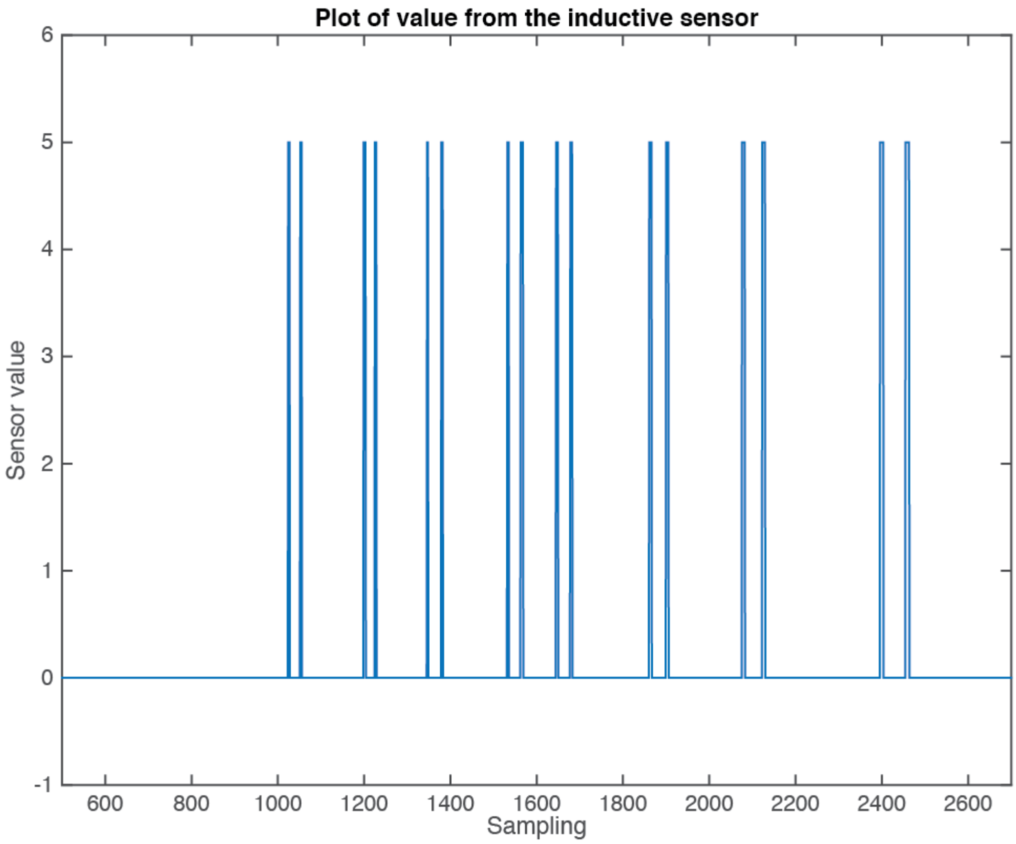


Figure 29. The output value for the inductive sensor

Each pulse represents one axle in the graph. This was a short X20 having 16 axles which can be seen in the plot. The test was performed four times, with desirable results. Figure 30 shows the final position of the sensor.

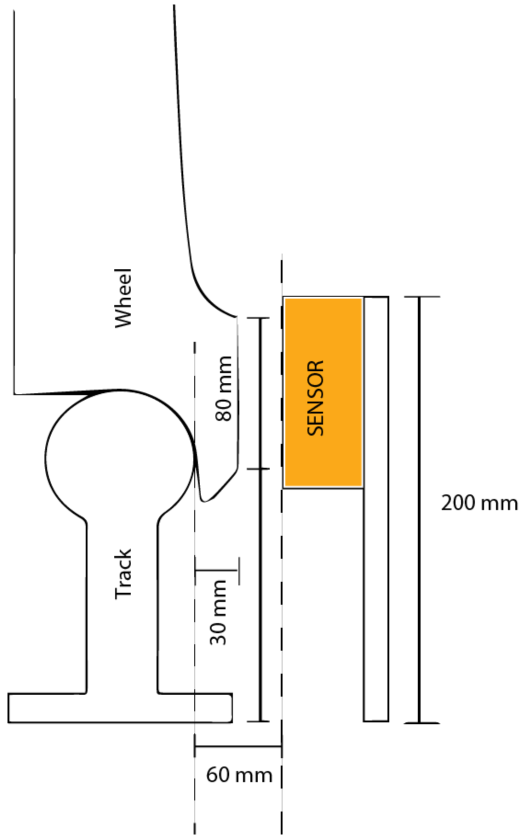


Figure 30. The final position of the sensor

6 DISCUSSION AND CONCLUSIONS

A discussion of the results and the conclusions are presented in this chapter. The conclusions are based on the analysis with the intention to answer the formulation of questions that is presented in the first chapter.

6.1 Discussion

To get a more reliable result, the systems need to be tested for a longer period of time. Because of the strict rules of accessing the rail area and because of the difficulties working during operational hours, the number of tests were limited. Also, more time is needed to get a better evaluation of both the systems.

Placing the optical sensor underneath the platform will protect the sensor from rain and will hide it from people standing on the platform. For the indoor stations, the sensor could also be placed in the celling having, the laser pointing down towards the rail. That would make it even less accessible for passers-by and workers walking along the rail. It will not interfere with the system (as long as they do not walk on the rail).

To find out how dust and dirt will affect the optical sensor, the system needs to be used over time in both indoor and outdoor stations. The question is not *if* but more *how often* the lens need to be cleaned to keep the system reliable and operational. This will most likely vary depending on which location and station.

The biggest obstacle concerning the inductive sensor is that it needs to get within 50 mm of what it is meant to detect. When designing the system and the position of the inductive sensors, the plan was first to avoid placing the sensor between the rails so the cable had to go under the rail. This was just an unnecessary conclusion.

6.2 Conclusions

Upon evaluating the results from the test, both the optical and the inductive senor are operational and fit for the Swedish environment (see Table 4 for the comparison).

The optical system was working as desired according to the tests, but it needs more tests to know how the system will work over time. Because of its nature, the laser sensor will need maintenance i.e. cleaning. Its life span is also much lower compared to the inductive sensor.

The inductive sensors cost less and are a low maintenance system that are less affected by its environment than the optical sensor.

The optical system is 5 times more expensive than the inductive sensor.

The inductive sensor is less sensitive to its environment. Leaves, dust and rain could affect the system at an outdoor station when using the optical system. Also, personnel walking along the track could also interfere with the system.

	Laser system	**Inductive system**
Maintenance	High	Low
Cost	High	Low
Difficulties to implement	Low	High
Accuracy, train detection	High	Middle
Affected by environment	High	Low
Life span	Middle	High

Table 4. Comparison between laser and inductive sensor

7 RECOMMENDATIONS AND FUTURE WORK

In this chapter, recommendations on more detailed solutions and/or future work in this field are presented.

7.1 Recommendations

The recommendation after the test and the analysis is that the inductive system would be the best configuration. It is less sensitive to the environment and needs less maintenance compared to the laser system. The cost is also just 1/5 of the price of the optical system.

7.2 Future work

The result from this project is just a functional prototype. The PCBs need a case that works in the environment and a better and safer mounting bracket needs to be designed. Better cables need to be used. The indicator needs to be developed.

To make the system reliable and safe, whether it is inductive or optical, a safety system that indicates if the detecting system is malfunctioning needs to be developed.

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APPENDIX 1: Code for the laser sensor, TrainDetection.ino

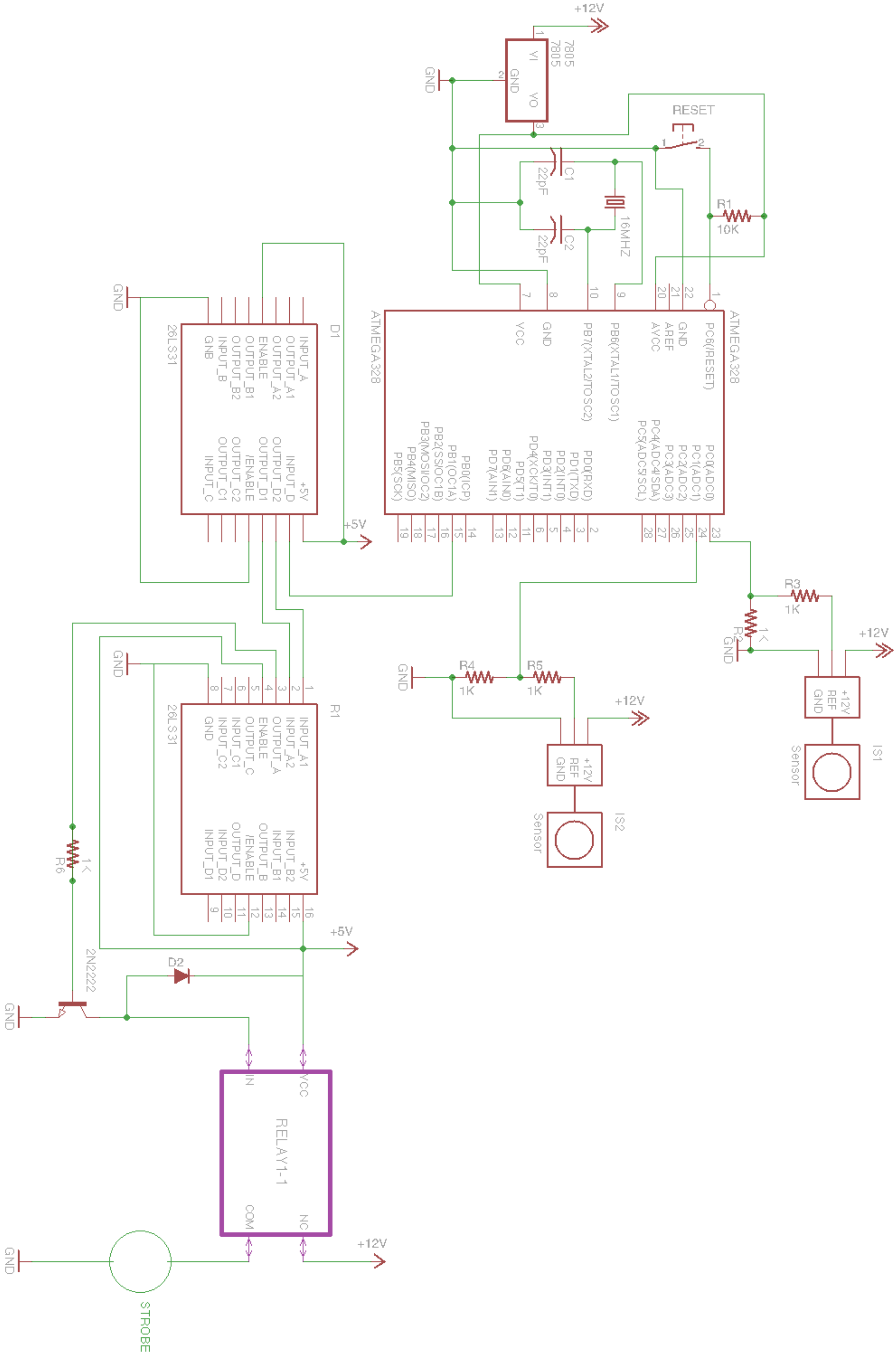
```
const int analogInPin = A0;  // Analog input pin that the sensor is attached
to
const int analogOutPin = 9; // Analog output pin that the LED is attached to

int sensorValue = 0;        // value read from the sensor
int outputValue = 0;        // value output to the PWM (analog out)

int trainrangemin = 200; //Minimum value the system will start indicate
int trainrangemax = 400; //Maximum value the system will start indicate
void setup()
{
  // initialize serial communications at 9600 bpsm for serial monitor:
  Serial.begin(9600);
}
void loop()
{
    int Value = analogRead(analogInPin);
    if(Value>trainrangemin && Value<trainrangemax) {  // the terms for
when to light the indicator
    outputValue = 255;  //on
  }
  else
  {
    outputValue = 0; //off
  }
  // change the analog out value:
  analogWrite(analogOutPin, outputValue);

  // print the results to the serial monitor:
  Serial.print("sensor = " );
  Serial.print(sensorValue);
  Serial.print("\t output = ");
  Serial.println(outputValue);

}
```

APPENDIX 2: Code for the Inductive sensors, WheelCounter.ino

```
#include <avr/interrupt.h>

const int SensorPin1 = 2;
const int SensorPin2 = 3;
const int OutputPin = 13;

volatile int scount1=0;
volatile int scount2=0;

void setup()
{
  Serial.begin(9600);
  pinMode(OutputPin, OUTPUT);              // Pin 13 is output to which the
26LS31 is connected
  pinMode(SensorPin1, INPUT_PULLUP);    // Pin 2 is input to which a
sensor is connected = INT0
  pinMode(SensorPin2, INPUT_PULLUP);    // Pin 3 is input to which a
sensor is connected = INT1
  attachInterrupt(0, count1, FALLING);  //Interrupt when axle passing by
first sensor
  attachInterrupt(1, count2, FALLING);  //Interrupt when axle passing by
second sensor
}

unsigned long lastClear=0;  // Flag for restarting value if interrupts within 2
min.
byte lastprint=0;
int printed1=0;
int printed2=0;

void loop() {
  unsigned long t=millis();
  if ((scount1 == scount2)||                     // If the same number of axles
has passed both sensor
        ( (t - lastClear) > 120000ul) ){         // or if 2 min has past since last
interrupt

      digitalWrite(13, LOW);                     // Make pin 13 low, indicationg
stopped

      // Reset all valuse/counters
      scount1 = 0;
      scount2 = 0;
      lastClear = 0;
      }
```

```
  // Printing when debugging
  if(scount1 != printed1)
     {
      printed1=scount1;
      Serial.println("scount1: ");
      Serial.println(scount1);
     }
  if(scount2 != printed2)
     {
      printed2=scount2;
      Serial.println("scount2: ");
      Serial.println(scount2);
     }
}


void count1(){              // Interrupt service routine
  if (scount2>scount1)
  {
  scount1 = scount1 + 1;    // Counting without indicating (train going other
direction)
  }
  else{
  scount1 = scount1 + 1;    // Counting
  digitalWrite(13, HIGH);   // Start indicating
  }

  lastClear = millis();     // reset lastClear
}

void count2(){              // Interrupt service routine
  scount2 = scount2 + 1;    // Counting
  lastClear = millis();     // reset lastClear

}
```

APPENDIX 3: Schematics for inductive system



APPENDIX 4: Schematics for optical system