HK PROJECT
MF2059 - MECHATRONICS ADVANCED COURSE
Stockholm, Sweden 2024

Autonomous Field Mapping of DeLaval In-Place Reader

Mechatronics "HK" project Spring Report

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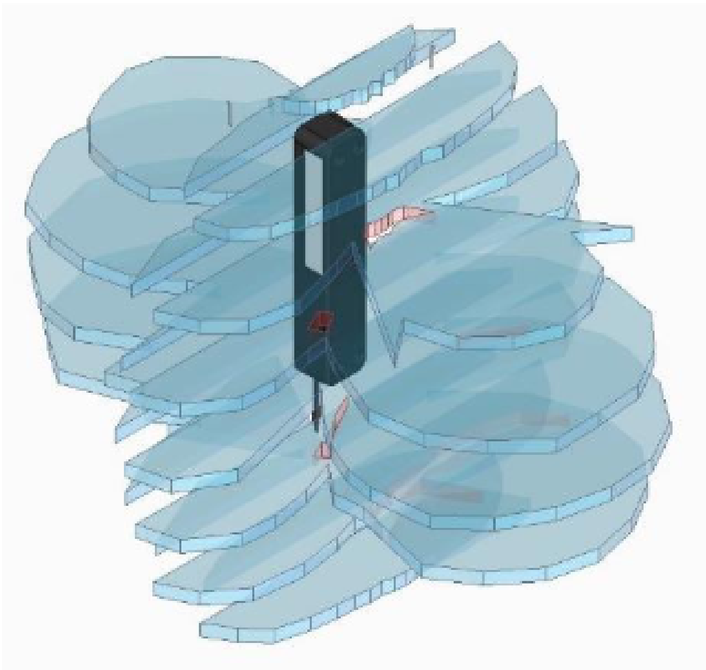

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Nomenclature

Abbreviations

AC	Alternating Current
DC	Direct Current
DOF	Degree Of Freedom
IPR	In-Place Reader
LIN	Local Interconnect Network
RFID	Radio Frequency Identification
RF	Radio Frequency

Technical terms

Accuracy	Error margin from desired point
Motor resolution	Smallest possible step by the motor
Resolution	Smallest measurable step possible by the rig
Step size	Distance between two neighboring measurement points

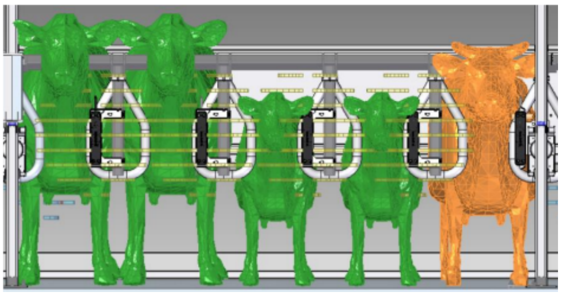
1 Introduction

This section will present the purpose of this project, the background to the project, the stakeholder, the scope, the organisation and finally the requirements of the project.

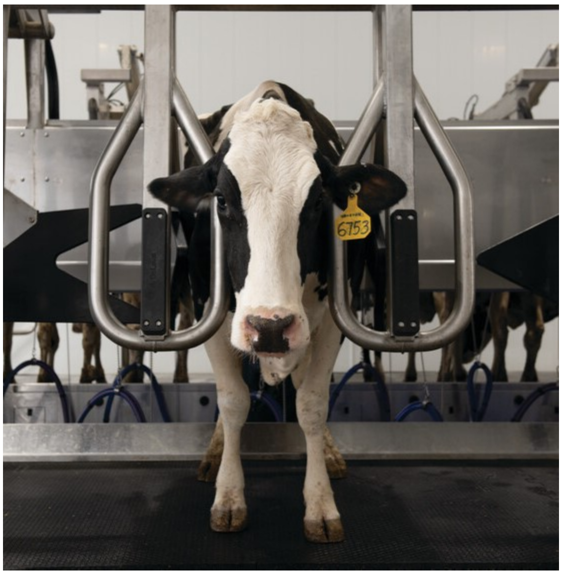
1.1 Background

This project is part of the Mechatronics capstone project course at KTH. It is a collaboration between KTH and the company DeLaval. DeLaval has long since been a market leader and a trusted partner for thousands of farmers around the world. DeLavals vision is to meet the ever growing need for sustainable food production, by supporting their customers in reducing the environmental footprint, improving food production, profitability and maybe most importantly the well-being of the animals and people involved [1]. As they are constantly trying to improve their technology they have come in contact with KTH and asked for help in optimizing the RFID system that they use for cow identification.

The background to this project has to do with the identification of cows, to make sure that the system knows what cow is being milked, or what cow is currently at the food station. All of this is to be able to track the cows habits to gain a better understanding about its health and to make sure that the automatic milking system uses the correct settings when a milking starts. Today the cows are identified by the use of an In-Place Reader also known as an IPR and a personalized RFID tag either around the cows neck or in her ear. The IPR is mounted on a steel structure known as the ”milk can”, this can be observed in Figure 1.1b.



(a) Cows in a stall.



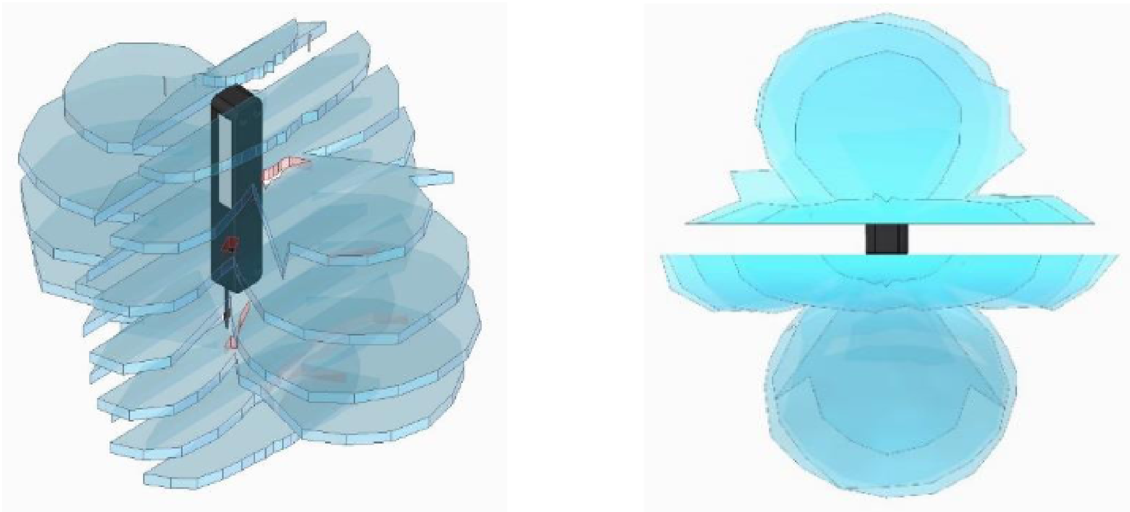
(b) The IPR mounted on the ”milk can”.

Figure 1.1: IPR mounting condititions.

When the cow is placed in a stall like in Figure 1.1a, there is a possibility that it moves its head outside the measurable area of the IPR and thus the signal between the IPR and the cows RFID tag is lost. This is not an ideal scenario for tracking if the cow is in the stall or not. Because of this, optimizing the placement and settings of IPR is of interest.

1.2 Purpose

In order for DeLaval to optimize the placement of the IPR antennas and improve the animal detection, the antenna activation field has to be mapped which is the space around the antenna where the IPR and the RFID tag can communicate. This has previously been done manually, resulting in the fields seen in Figure 1.2, taking two people around six hours. This is typically not an ideal use of time, therefore this project is focused on developing a mechanical test rig for automatically mapping the IPR antenna field.



(a) Isometric view. (b) Top view.

Figure 1.2: Manually measured IPR antenna field.

Then, one may ask if building a mechanical test rig is the most optimal method for finding an antenna field. In other aspects of engineering, such as solid mechanics, finite element analysis is a widely used and viable method for analysing structures. As such, there also exists software for simulating antenna fields, such as COMSOL Multiphysics or ANSYS HFSS [2], [3]. However, such software is generally very expensive and using them is therefore not always a feasible solution. In addition to this, the mapping of the IPR antenna field is very implementation specific seeing as only the interaction between the antenna and RFID tag is of interest, rather than a general gain field. Therefore, this problem does not lend itself well to simulation. Lastly, of course, this project is in the context of a mechatronics education and as such mechatronics-oriented solutions are of priority.

1.3 Project organisation

To ensure the success of this project and also make sure that everyone involved learns as much as possible, a strategy has been set in place. The project will have a project leader that will make sure that everyone in the team knows what has to be done as well as keep track of the project progress and deadlines. For the fall semester the team will then be divided into smaller sub-teams with focus on one aspect of the project, the members of these teams will rotate throughout the semester to ensure that everyone in the team learns as much as possible and understands everything in the project.

To make sure that everyone in the team knows what is going on in all the smaller sub-teams, a weekly meeting will be held each Monday morning where the smaller teams can present what they have been working on and what they will be working on the coming week. This in conjugation with a preliminary Gantt chart will help the project leader keep the project on course. The preliminary Gantt chart, see Appendix D, will be updated with more details as the fall semester approaches.

Throughout the project, documents and code will be shared and available to all parties through services such as Google Drive and GitHub. Communication between team members will mainly occur through Discord. Microsoft Teams will be the communication platform for communication with the stakeholder and communication with the coach is mainly through E-mail.

1.4 Requirements

Below are some of the most important requirements given to us by the stakeholder and how they translate into technical requirements. For the full list of requirements with more descriptions, see Appendix A.

1.4.1 Stakeholder requirements

- The test rig shall be able to dynamically evaluate the signal range between the IPR and the RFID-tag at different points within the testing volume.
- A complete measurement run of an IPR-field shall be done automatically.
- The test rig measurements shall be satisfyingly accurate.
- The measurement time should be less than six hours.
- The test rig shall not interfere with testing.
- The measurement area shall be big enough.

1.4.2 Technical requirements

- The test rig shall have a measurement accuracy for the IPR field boundaries of ±5 mm.
- No RF-disturbing material shall be used inside the testing volume.
- The maximum RFID tag distance from the IPR shall be at least 700 mm.
- The testing volume shall be within $\pm 135^{\circ}$ around the z axis.
- The testing volume shall be within $\pm 90^{\circ}$ around the y axis.

2 State of the art

In this chapter, the state of the art of relevant and adjacent technologies and methods will be presented.

2.1 RFID technology

RFID or Radio Frequency Identification is a technology that allows objects to be identified with the help of radio frequency waves. The first record of RFID in literature can be traced back to the article "Communication by Means of Reflected Power" by Harry Stockman published in 1948. This technology was also first used in World War 2 to identify airplanes as allies or enemies [4][5].

An RFID system consists of two major parts, a tag and a reader. Together they work to enable tracking and information collection. This technology is used in a wide range of applications, all the way from the military, to retails, to animal identification [5]. One of the reasons for its popularity is the fact that it does not require a direct line of sight between the antenna and the reader and can communicate at very far distances [6].

At the most basic level, RFID devices can be divided into two categories, active and passive devices. Active tags are tags that require their own power source, for example a battery. While passive tags do not require their own power source which essentially means they can run indefinitely [6].

When implementing RFID systems, it is important to be able to test and benchmark the technology's performance. However, though testing methods for RFID devices do exist, literature on the matter seems to be very scarce or vague. As of writing this paper, two good papers exist but they specifically look at ultra high frequency RFID systems [7] [8]. There also exists a patented solution, known as the α-gate portal, developed at The Hong Kong University Of Science And Technology for the purpose of RFID benchmarking and testing. Data on this solution is very limited however, due to the fact that it is patented, the instrument also won an academy award in 2008 [9].

2.2 Antennas and Antenna patterns

The central technology used in RFID is a set of antennas. An antenna is an electrically conductive wire or plate which is shaped so that when a switching electric current is applied, a strong electromagnetic field is produced. Inversely, an antenna produces an electric current when subjected to an incoming electromagnetic field. Antennas can be used for a wide range of wireless communication devices and come in a wide variety of shapes depending on their function.

An antenna's radiation pattern describes the distribution of the radiated energy in 3D space. The pattern is highly dependent on the form of the antenna and can be customized for the signal's intended purpose and range. The pattern is typically designed to be either directional, where the energy is primarily focused in one or a few specific directions, or omnidirectional, where the radiated energy is distributed evenly around one axis [10]. In addition the electromagnetic field can be polarized to better handle interference from reflected fields.

Knowing how the radiation pattern looks for a particular antenna is highly important, particularly at further communication distances, to position the transmitting or receiving antennas such that the wireless connection is not lost or diminished. The technology used in the IPR utilizes a pair of loop antennas for transmitting and receiving, which typically create an omnidirectional radiation pattern. Though this is not enough to predict the full RFID system field due to the interactions with the RFID tag field, it may provide an idea of what it may look like.

2.3 Antenna Field Measurement

Due to the lack of data available on field testing of RFID technology, time has instead been allocated to the study of general field testing of antennas.

An antenna can be tested in two different ways, either Far-field or Near-field . When testing antennas, generally it is the far-field performance that is sought after, therefore Far-field testing tends to be ideal. But far field testing is expensive to do indoors and requires a great amount of space, therefore it is most common to do the testing near-field and then use the data to approximate the performance in far-field. That said, for the purpose of this project, this transformation is unnecessary, as the IPR and the RFID tags will always be used in the near-field [11].

It is also important to be aware of the inherent properties of near-field testing. Near-field testing can be done in a few different configurations. Most common is to make the test volume either planar, cylindrical or spherical [11]. Each has their own unique advantages and disadvantages, but spherical gives the most accurate approximation of the far-field results. This makes the spherical method the most common way to measure antenna fields.

Two existing methods for measuring spherical antenna fields are the *Conical Section Method* and the *Great Circle Method*. Results from either of these methods can be identical, the only difference is the implementation. However, it is possible to make a test rig where either of these testing methods can be used [12]. This is the idea behind the most common test rig. A 2 DOF rotational rig (see figure 2.1). The result of the test is usually a so-called gain plot, describing the amplification of the antenna signals in different directions.

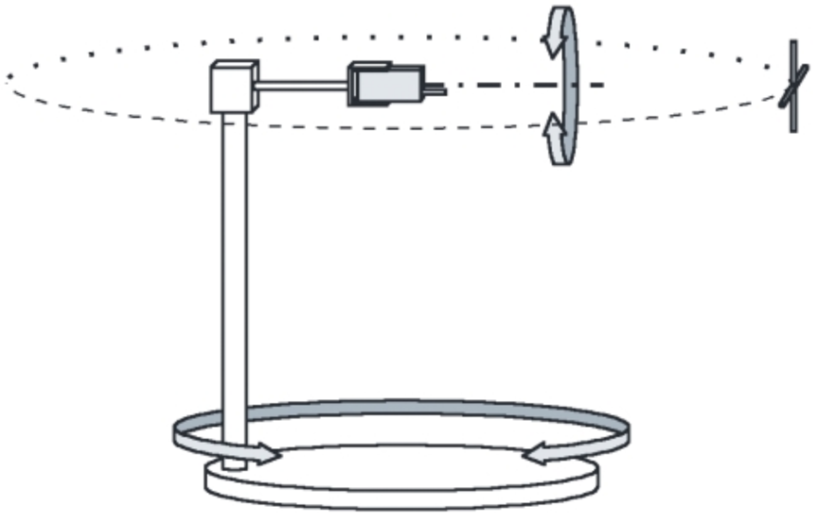


Figure 2.1: Picture depicting the most common solution for near-field measurement of antennas, a two-axis positioner. Picture has been taken from [12]

2.4 Magnetic Communication

This section will talk about different types of magnetic communication, more specifically Half-Duplex and Full-Duplex and how they differ.

2.4.1 Half Duplex (HDX)

HDX is a protocol format commonly used in transponders for applications regarding animal identification. A low frequency reader (in this case, the IPR) utilizes magnetic fields to power a passive tag wirelessly. By generating short magnetic pulses to wirelessly charge the HDX tag. The IPR then turns off to enable the tag to send back the tag identification number without interference from the IPR magnetic field. See figure 2.2.

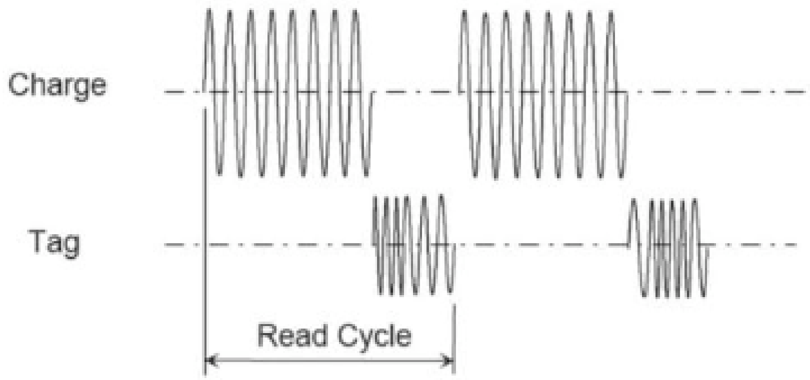


Figure 2.2: Demonstration of HDX antenna and reader

Thus enabling the possibility to detect cows for this project. HDX is currently used by the IPR and the tags on the cows today at DeLaval. Since it utilizes the attributes of the magnetic fields it is not advised to use metallic materials in conjunction with the IPR and RFID tag. The HDX protocol based transponders are designed to operate in the 134,2 kHz band. To transmit a logic 1 from the HDX tag, the transponder in the tag will provide 16 cycles at 124 kHz. To transmit a logic 0 it will provide 16 cycles at 134 kHz [13].

2.4.2 Full-Duplex (FDX)

Another type of protocol commonly used is FDX (Full duplex). While the HDX sends out short pulses to charge the the tag and then waiting for a response, effectively achieving a one-way communication, the FDX transponder instead sends out a continuous magnetic field. This enables a two-way communication where the FDX can send and listen for the tag simultaneously which can be seen in figure 2.3 below:

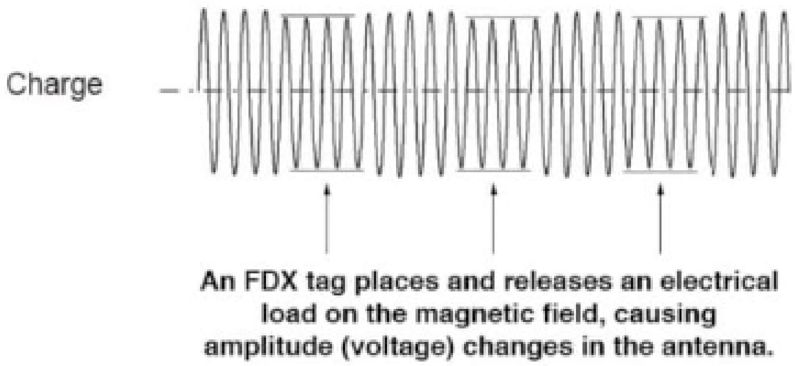


Figure 2.3: Demonstration of FDX antenna and reader

They can be used interoperably but are not compatible, for example a FDX tag and an HDX antenna do not work together however you can synchronize a HDX and FDX antenna to listen to a HDX and FDX tag at the ”same” time [14].

2.4.3 Comparison

The HDX protocol has better noise immunity and allows for larger and simpler antennas because it uses FM (Frequency Shift Keying). As it operates in short pulses it also require less power. With a 20 ms-50 ms charge/listen cycle it can achieve a scan rate from 14 scans per second all the way up to 28 scans per second. However at higher scan rates the tag might fail to receive full charge. FDX can achieve a scan rate of 30 scans per second without compromising performance. Due to its relatively simple construction, consisting of a coil, a ferrite rod and a chip, it can be made very small and thin. Unlike HDX, FDX uses AM (Amplitude Shift Keying) which makes it susceptible to atmospheric noise [14].

2.5 RF Disturbances

In order to make a reliable test rig, the communication between tag and IPR has to happen without disturbances. There is essentially two types of disturbances that can occur. For starters if multiple transponders (tags) are close to each other, then one transponder can block the signal from another, preventing the reader from getting the correct data. Furthermore, a signal from one transponder can be picked up by the reader and be incorrectly interpreted as correct data. The most common causes of RF disturbance come from interfering frequencies and from RF disturbing materials [15].

2.5.1 Frequency disturbance

As stated in subsection 2.4 the HDX protocol operate in the 134.2 kHz band. To avoid disturbing the RFID communication, signals that occupy the same frequencies shall be avoided. This is to reduce the amount of external disturbances affecting the measurement data [15].

2.5.2 RF disturbing material

The electromagnetic waves from the HDX tag will interact with the different materials in the surrounding areas. Depending on the material the signals might be reflected, absorbed or transmitted through the material [16]. This interaction depends on the properties of the material and the frequency of the signal. For RFID tags the most problematic materials are ferromagnetic materials, this is because they are electromagnetically reflective.

2.6 LIN communication protocol

The In-Place Reader (IPR) antenna uses a Local Interconnect Network (LIN) bus for communication, and so it will be described here. The LIN bus was first developed in 1997 and the last version released, version 2.2A, was published in December 2010 [17], [18]. It is a specification for a low-cost communication network in automotive applications, acting as a complement to more complex architectures such as the Controller Area Network (CAN) [19]. The LIN bus is a polled bus with a single master device and one or more slave devices, which over a single wire can transmit data at speeds up to 40 kbit/s [19], [20]. Transmission of data is controlled solely by the master device which means that slave devices cannot initiate communication on their own [19]. As such, the LIN bus is not suited for safety-critical applications, where critical data has to be transferred between multiple master and slave nodes. The protocol works by the following principle:

> The LIN bus connects a single master device (node) and one or more slave devices (nodes) together in a LIN cluster. The behavior of each node is described by its own node capability file. The node capability files are inputs to a system-defining tool, which generates a LIN description file (LDF) that describes the behavior of the entire cluster. The LDF is parsed by a system generator to automatically generate the specified behavior in the desired nodes. [19]

At this point, the master node can start transmitting data and communication is initiated. Messages published on the bus have a header and a response section, see Figure 2.4. The master device then has two communication tasks running, a so-called master and slave task. Each slave node has only one slave task running. The master task polls each slave task in a loop with a message header whereby the corresponding slave either responds with one to eight bytes of data or reads data from the bus, depending on configuration. The master acts as virtual slave node through its slave task, which publishes to and reads from the bus as it if were a slave node. [19]

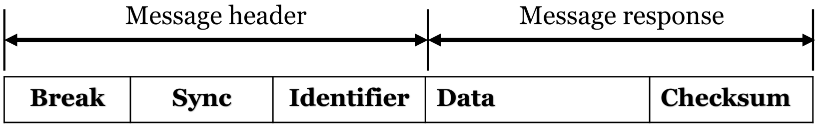


Figure 2.4: LIN message frame. [19]

The break section of the message header simply serves as a start-of-frame notice to all nodes on the bus. The break sync field transmits the character `0x55` which allows devices to automatically detect baud rate to synchronize with the bus. The ID field is used to provide identification for each message published on the bus. All slaves continually listen for ID fields and verify their parities to determine if they are publishers or subscribers for this particular ID. The LIN bus provides a total of 64 IDs, 0 through 59 are used for data frames, 60 and 61 for diagnostic data, 62 is reserved for user-defined extensions and 63 is reserved for future protocol enhancements. [19]

2.7 3D Visualization and Data Acquistion

The acquired data describing the edge of the antenna range volume will be saved in matrix form representing positions in all degrees of freedom. This data should then be turned into a 3D-object to facilitate the visualization of the antenna range volume. There are several tools available in Matlab that do this. Using functions like `triangulation` and `stlwrite` a matrix of coordinates can be converted to a triangulated surface - as is standard for simple 3D-objects - and then exported in the stl-format. Once an stl-file has been generated, any standard 3D-visualization tool can be used. The volume can also be represented directly in Matlab plots using functions such as `mesh` and `patch` [21].

2.8 Varieties of Motors

2.8.1 Servomotors

Servomotors are motors that achieve motion by converting AC, or more commonly DC, into a pulsed, variable power output often referred to as PWM-signals (Pulse Width Modulation). This allows a servomotor to achieve a specific position with high precision based on the duty cycle of the PWM signal. It has a built-in potentiometer to verify its position [22]. There are two types of servo motors: $180°$ servos limited to rotating 180 degrees and continuous servo which can rotate freely 360 degrees.

2.8.2 Linear motors

An alternative choice, when linear motion is desired, is the use of an electric linear motor. These motors are usually described as the "unrolled" version of their predecessors, the electric rotational motors. Instead of producing torque, linear motors produce linear force. A natural consequence of this, is that a linear motor can not extend or retract indefinitely, but has an operating range which needs to be considered [23].

Linear motors are capable of generating reasonable thrust forces, high positional accuracy and eliminates the need for mechanical power transmission components which are included in linear actuators. The benefit of this is that they avoid the effects of backlash, windup and compliance. However, the drawbacks are that they in many cases are difficult to protect from contamination, generate more heat than electric rotational motors and are very expensive [24].

2.8.3 Stepper motors

A stepper motor is an electrical motor that rotates in incremental steps, that is by a fixed amount of degrees, instead of continuously. The internal structure of a stepper motor is setup such that the exact angular position of the shaft is known by simply counting how many steps have been completed.

The three main types of stepper motors are:

- Permanent magnet
- Variable reluctance
- Hybrid synchronous

Permanent magnet type stepper motors yields good torque and also a detent torque which prevents the shaft from moving even when power is not supplied to the motor. However, the drawbacks of this type, is lower speed and resolution in comparison with the other types [25].

A variable reluctance rotor is usually made of soft iron or some alternative ferromagnetic material. The core has a specific shape with a number of poles and the stator has a larger number of slots. The inner mechanism of the motor results in the number of rotor poles and stator slots determining the resolution of the stepper motor. Variable reluctance type stepper motors have less torque drop-off at higher rotational velocities. Therefore, they are considered a superior option for mid to high velocity applications [26]. The drawback is that it often lacks in torque and has no detent torque. Even so it does have holding torque as long as the motor receives energy [25].

The third type, hybrid synchronous, is a combination of the permanent magnet and variable reluctance types. Typically hybrid synchronous type stepper motors have higher resolution, speed and torque and are also correspondingly more expensive due to their more difficult construction [26].

Microstepping is a method used on stepper motors to execute steps of higher resolution. Additionally, it can be used to achieve smoother rotation during low speeds. Microstepping involves dividing a full step into smaller fractions [27].

It is important when using microstepping to take into consideration that the incremental torque decreases as the number of microsteps increase. If there is an arbitrary load torque affecting the stepper motor, it might result in magnetic backlash which displaces the rotor from the desired position. Therefore, it is important to control the sufficiency of the incremental torque produced with each microstep.

Although microstepping increases resolution, unfortunately it generally decreases accuracy as the steps get smaller [28].

2.8.4 Linear actuators

Linear actuators are an alternative to linear motors. In reality, they are not a different kind of motor but an amalgamation of a rotating motor and a mechanism that translates the rotation into translational motion.

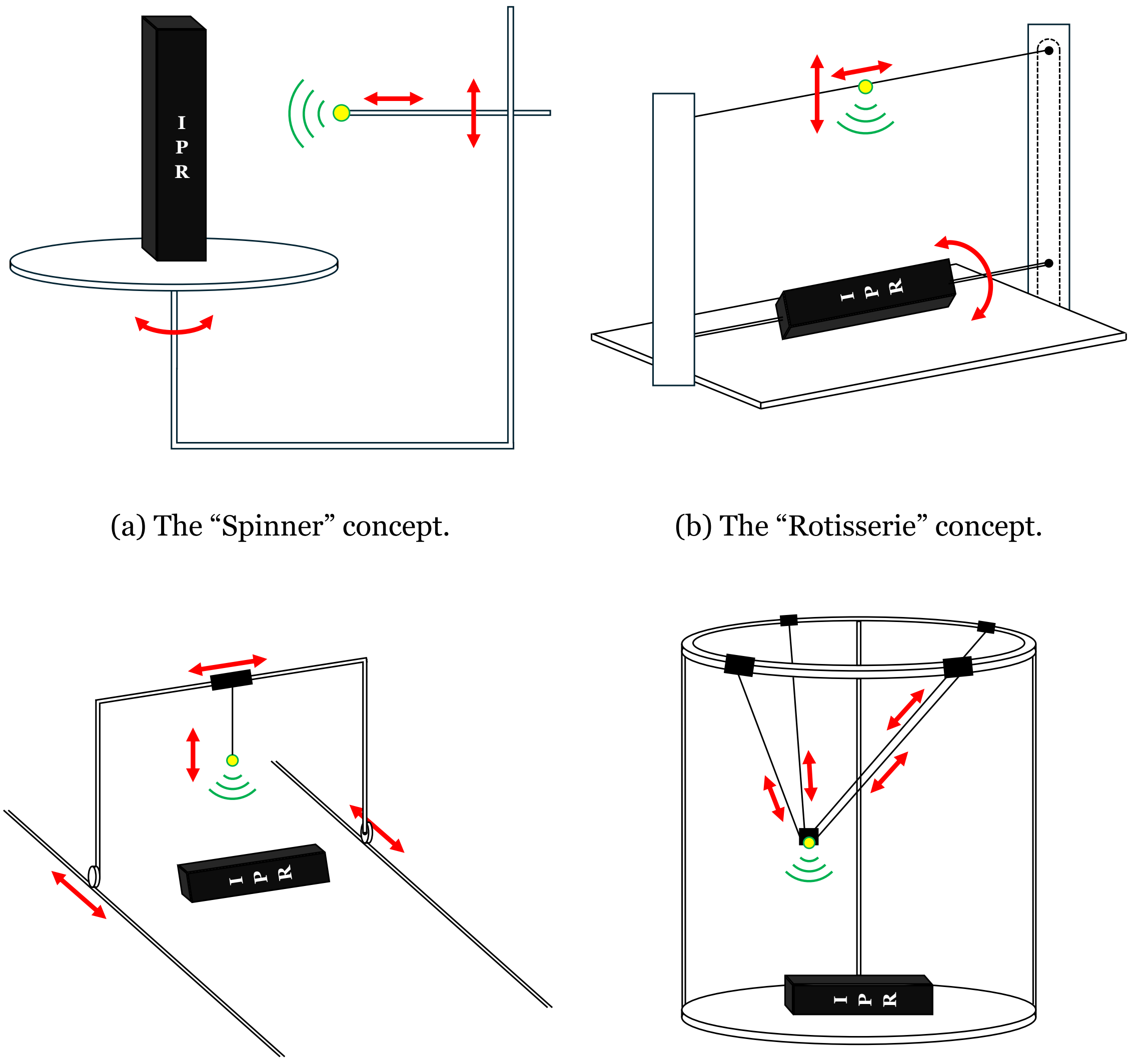
Typically, linear actuators are less costly than linear motors but often require more space to integrate. Moreover, they are more sensitive to wear compared to linear motors.

The resolution of a linear actuator is influenced by factors such as the pitch of the leadscrew or belt and any gearing mechanisms involved in the conversion process. Of course, it is also influenced by the resolution of the rotational motor itself.

3 Design Concepts

This chapter will describe how design concepts were conceived, refined and evaluated to choose a final design.

After the requirements were written down and finalized, see Appendix A, the concept design started. Each team member was tasked with developing 3-4 concepts each, which could later be sorted into four distinct categories: Spinner, Rotisserie, Rail and Spiderman, see Figure 3.1.



(a) The "Spinner" concept.

(b) The "Rotisserie" concept.

(c) The "Rail" concept.

(d) The "Spiderman" concept.

Figure 3.1: Design concepts developed.

These concepts will now be described further with individual pros and cons.

3.1 Spinner

The “Spinner” concept, see Figure 3.1a, works by rotating the IPR antenna on a table and using an arm to move the tag up and down and in and out. This is the concept that is the most similar to the antenna testing equipment found during the state of the art research.

Pros:

- The concept is closely related to existing designs, and so there may exist previous work which could be referred to.
- Placing objects in the testing volume is easy as there are no large motions.
- The concept is easy to visualize and understand.
- The spinner has relatively few moving parts, and no need for synchronization between the degrees of freedom.
- The footprint of the final testing rig is relatively small.

Cons:

- Motors might need to be close to the movement, which can cause interference.
- As it stands, the “arms” moving the tag need to be long to achieve full reach and could therefore be subject to deflection and vibration, impacting accuracy.
- The effect on the antenna performance when rotating the IPR is not entirely certain.

3.2 Rotisserie

The “Rotisserie” concept, see Figure 3.1b, works by rotating the IPR antenna on a table, similar to the “Spinner” concept. However, the tag is mounted on a horizontal axis that goes up and down and back and forth.

Pros:

- Test rig construction is compact.
- Structure can be made stiff, reducing vibrations and deflections which allows for faster tag movement.

Cons:

- The heavy “milk can” and IPR will need to be held up in disadvantageous positions and rotated, requiring a stiff structure and powerful motors, effecting the final cost and/or accuracy of the rig.
- Problematic reaching all measurement points in the required testing volume
- Tag orientation relative to the IPR will change during motion, i.e it is geostationary to the IPR.
- The effect on the antenna performance when rotating the IPR is not entirely certain.

3.3 Rail

The “Rail” concept, see Figure 3.1c, moves the rig along rails on the ground, that run the entire length of the testing volume. The tag moves along the upper horizontal beam and is lowered and and raised from there, which could be done either on a wire or a stiff vertical beam. The rig uses a Cartesian movement set where the tag orientation remains co-planar with the IPR at all points in the testing volume.

Pros:

- This is the most similar to the testing movement done during manual tests performed by DeLaval prior.
- The tag will not need to be dynamically oriented during testing to keep it coplanar with the IPR.
- The testing volume will be free from RF-disturbing material, since the rig can be constructed around it.
- The IPR and ”milk can” would be static which would most accurately reflect the real scenario in the barn.

Cons:

- The rig may become very large, to cover the entire testing volume.
- The entire rig may become quite heavy to be sufficiently robust and accurate. Moving this weight may require large motors and significant power.

3.4 Spiderman

The “Spiderman” concept, see figure 3.1d, works by reeling in and out wires from a few fixed (or moving) points, which are attached to the tag. By adjusting length of the wires, the tag can be moved around the IPR. The Spiderman concept can be realized using various number of wires. The number of wires necessary depends on factors such as the stability of the tag and its ability to reach points around the IPR, where objects such as the IPR itself and/or the ”milk can” is in the way of the wires. Keep in mind that contrary to the figure, the IPR would be placed on some kind of pedestal which would allow the tag to move obliquely below it.

Pros:

- Minimizes the effect of RF-disturbing material in the vicinity of the IPR.
- The construction can be made lightweight.
- The IPR and ”milk can” would be static which would most accurately reflect the real scenario in the barn.

Cons:

- Calibration may be quite difficult.
- The concept’s reliance on relatively long wires requires higher precision in the overall instrument.
- The nature of wires carry the risk of sensitivity to outside disturbances.
- Complex movement and positioning, increasing with the number of wires used.
- Difficulty in reaching certain positions behind or below the IPR (depending on its orientation), due to risk of collision between wires and physical objects in the test rig.
- Likely to be the largest concept.

3.5 Concept Evaluation

After the concepts were developed, discussed and grouped into the four categories or types described above, the evaluation process began. In order to proceed with the project, a final concept had to be selected to be built and realized. The criteria for this had already been laid out in the stakeholder requirements as provided in Appendix A, serving as a perfect foundation for concept evaluation.

An evaluation matrix was used, and each requirement was weighted based on its type and priority according to the table below.

Table 3.1: Requirement weighting

Type	**Priority**	**Weight**
Required	High	5
Required	Low	3
Desired	High	1
Desired	Low	1

Each concept was then scored based on how well it fulfilled each requirement on a scale of 0/1/3/5. This scoring was largely based on the pros and cons listed for each concept above and was evaluated as objectively as possible. The score was then multiplied by the weight of each criteria and added to the total score of each concept. The concept with the highest total score would then be the qualifying concept.

This resulted in two concepts coming out on top. First Spiderman with 196 points, followed by Spinner with 194 points. After discussion, the team concluded that both concepts would qualify and needed to be evaluated further, in collaboration with the stakeholder. The full concept evaluation matrix can be seen in Appendix B.

4 Risk Analysis

During the planning of the project a risk analysis was conducted in order to better be able to handle any future setbacks or problems that the team might encounter. A standard risk analysis chart was used, as shown below.

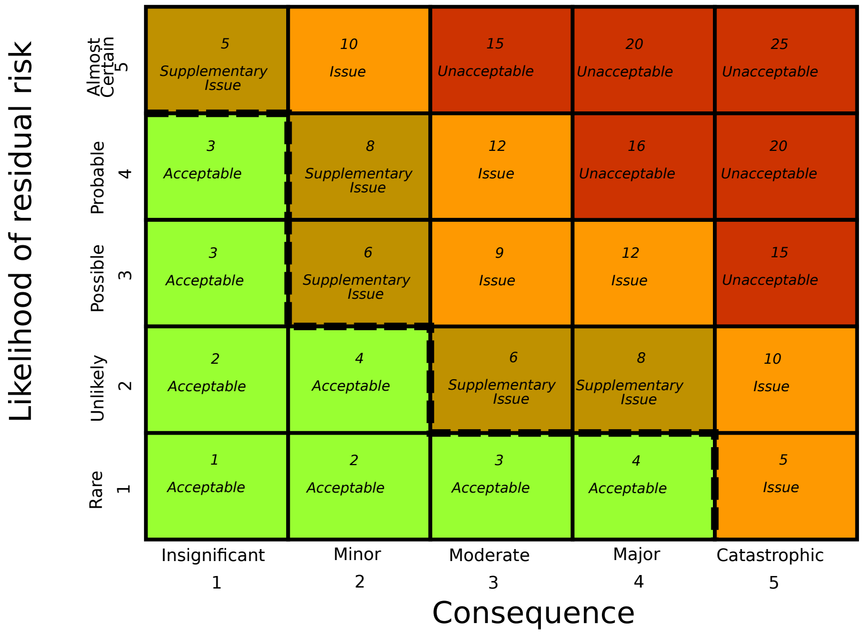


Figure 4.1: Standard risk analysis chart used.

The analysis included events such as parts not arriving on time, parts not working, integration hell, missing deadlines and some conflict handling among others. Using this the team could alter the planning as can be seen in Appendix D, to better accommodate time for likely events that could cause delays if not taken into consideration. The full analysis can be found in Appendix C.

5 Discussion and Future Work

This chapter will be presenting a discussion about the project so far and planned future work

5.1 Discussion

The start of the project during the spring semester was mostly focused on the team and the team-building as well as the SOTA research. The start of the project was heavily dominated by the stakeholder requirements and making sure that the team understood what the problem was. The SOTA research started with the whole team discussing what areas the team wanted to explore and later divide up the work so that each member did research on a specific topic. All the members then presented their findings and the team as a whole decided on what was of interest to the project and summarized it. Going from individual responsibility to a group responsibility was great for productivity since each member could feel that their work contributed to the groups work in a very clear way. This way of thinking was something the team continued with during the concept generation phase of the project, where each member brainstormed a bunch of concepts and potential solutions which they then presented to the group and argued for. This then gave room for a discussion where every team member argued why certain solutions were better then others and the final concepts became better. Again each team member felt that their own work was valuable in the end product. Giving everybody a sense of belonging in the team. This also grew a culture in the team where everybody felt that they could express their own opinion and be respected and listened to. Contributing to a much healthier team environment.

5.2 Future Work

Firstly the final concept will be chosen and after that the necessary parts will be ordered. Then in the fall semester the team will be continuing the same kind of work style as implemented in the spring semester, but in a much smaller scale given that the team will be divided into smaller task oriented sub-teams. The team will be split into three sub-teams. One team will be focusing on the mechanics of the test rig, another team will be focusing on the dynamics and control of the motors and the final team will be focusing on the software. The teams will later on in the semester work more closely with each other as all the different parts will be connected at the end. The current working plan for the fall can be observed in Appendix D.

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Appendices

Content

A Requirement Specification

This appendix contains the requirement specification used to define the project, both from the stakeholders and technical requirements. The requirement *type* is R and D for Requirement and Desired, and the *priority* is H or L for High and Low. Consequently, a requirement of type R and priority L is prioritized over a type D and priority H, even though the priority is higher.

A.1 Stakeholder Requirements

These requirements were provided from the stakeholder and define what the resulting test rig shall be capable of.

Table A.1: Stakeholder requirements

Req. no	Description	Type	Priority	Comment
1	The test rig shall be able to dynamically evaluate the signal range between the IPR and the RFID-tag at different points within the testing volume	R	H	Main objective
2	A complete measurement run of an IPR-field shall be done automatically.	R	H	
3	Measurement step size should be configurable for each axis between the measurement runs.	D	H	The distance between each measured point along each axis should be adjustable between runs.
4	Measured points shall be visualized graphically on a computer in a 3D-plot.	R	H	
5	The test rig should be able to simulate different mounting orientations for the IPR.	R	L	Allow changes in angle and offset along different axes.
6	The test rig shall be able to modularly simulate different use cases/environments within the testing volume.	R	H	For example, IPR mounted on the “mjölkkanna” (a piece of RF-disturbing equipment commonly used to mount an IPR).
7	Should be possible to place additional activation IPRs modularly within the testing volume.	D	L	Allows for additional IPRs to be used just for activation energy and not for listening in order to better activate tags.

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Table A.1 – continued from previous page

Req. no	Description	Type	Priority	Comment
8	Should be possible to use additional/different measurement antennas modularly for data acquisition.	D	H	Allow for different tags to be used as well as separate antennas solely for listening/sending.
9	The orientation of an RFID tag relative to the IPR shall be adjustable for different measurement runs.	R	H	
10	The test rig measurements shall be satisfyingly accurate.	R	H	Measurements should convey a realistic picture of the IPR performance.
11	The measurement time should be less than six hours.	D	H	
12	The measurement area shall be big enough.	R	H	At least half a sphere.
13	The test rig shall not interfere with testing.	R	H	

A.2 Technical Requirements

These measurable requirements will serve as verification for the stakeholder requirements.

Table A.2: Technical requirements

Req. no	Description	Type	Priority	Comment
1	A complete automatic measurement of the IPR field should take less than six hours.	D	L	
2	The step size between two neighboring measurement points shall be configurable between 10-100 mm between measurement runs.	R	H	
3	The test rig shall have a measurement accuracy for the IPR field boundaries of ± 5 mm.	R	H	Accuracy = error margin from desired point.
4	The relative angle between the IPR and RFID tag shall be configurable between $\pm 90°$ around the z and y axes.	R	L	

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Table A.2 – continued from previous page

Req. no	Description	Type	Priority	Comment
5	The maximum RFID tag distance from the IPR shall be at least 700 mm.	R	H	
6	The testing volume shall be within $\pm 135°$ around the z axis.	R	H	
7	The testing volume shall be within $\pm 90°$ around the y axis.	R	H	
8	No RF-disturbing material shall be used inside the testing volume.	R	H	
9	The test rig shall not contain any EM-sources that cause disturbance at the RFID tag's working frequency.	R	H	
10	It should be possible to place additional activation IPRs modularly outside the testing volume.	D	L	Allows for additional IPRs to be used for only activation energy to be able to examine the tags ”talking” range versus its ”listening” range.
11	It should be possible to use additional or different measurement antennas modularly for data acquisition.	D	H	Allow for different tags to be used as well as separate antennas solely for listening or sending.

B Concept Evaluation

This appendix contains the full concept evaluation matrix used to determine the qualifying concepts.

Table B.1: Evaluation matrix

Nr.	Description	Weight	Spinner	Rail	Rotisserie	Spiderman
1	A complete automatic measurement of the IPR field should take less than six hours.	1	3	5	5	3
2	The step size between two neighboring measurement points shall be configurable between 10-100 mm between measurement runs.	5	3	5	3	5
3	The test rig shall have a measurement accuracy for the IPR field boundaries of ± 5 mm.	5	5	5	5	5
4	The relative angle between the IPR and RFID tag shall be configurable between $\pm 90°$ around the z and y axes.	3	1	5	1	5
5	The maximum RFID tag distance from the IPR shall be at least 700 mm.	5	3	3	3	5
6	The testing volume shall be within $\pm 135°$ around the z axis.	5	5	3	5	1
7	The testing volume shall be within $\pm 90°$ around the y axis.	5	5	5	0	5
8	No RF-disturbing material shall be used inside the testing volume.	5	3	1	3	5
9	The test rig shall not contain any EM-sources that cause disturbance at the RFID tag's working frequency.	5	5	3	3	5
10	It should be possible to place additional activation IPRs modularly outside the testing volume.	1	5	1	3	1
11	It should be possible to use additional or different measurement antennas modularly for data acquisition.	1	3	3	3	3
12	Most fun to build.	5	3	3	1	3
13	Easiest to build.	3	5	3	3	1
14	Transportable.	1	5	1	3	1
	Total		**194**	**174**	**141**	**196**

C Risk Analysis

This appendix contains the full risk analysis.

Table C.1: Risk analysis

Risk source	Description	Likelihood	Impact	Risk	Consqeuence	Preventative actions	Reactive actions
Team	Ordered parts do not work as intended.	2	4	8	Project delays.	Order in time.	Order new parts.
	Concept much harder to realize than expected.	4	4	16	Increased workload, project delays, low team morale.	Do thorough reserach.	Simplify, put conservative deadlines.
	Long-term absence in team.	1	5	5	Increased workload, low team morale.	Good work environment, good communication.	Rearrange responsibilities.
	Ordered parts do not arrive on time.	3	3	9	Project delays.	Order in time.	Prioritize other objectives, order from different vendor.
	Long manu-facturing lead time.	3	4	12	Project delays.	Start manufacturing as soon as possible.	Reallocate resources.
	Missing team deadline	4	3	12	Project delays.	Set reasonable deadlines, be transparent with progress.	Reallocate resources, change time plan.
	Missing stakeholder deadline.	2	5	10	Break trust with stakeholder.	Be transparent with progress (restructure if project is behind schedule).	Keep honest and transpar-ent communica-tion with stake-holder/negotiate deadline.

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Table C.1 – continued from previous page

Risk source	Description	Likelihood	Impact	Risk	Consqeuence	Preventative actions	Reactive actions
	Missing KTH deadlines.	2	2	4	Delayed marks in Ladok, Björn disappointed.	Be transparent with progress (restructure if project is behind schedule).	Mail Björn, change priorities if possible.
	Integration hell.	5	4	20	Delays in project.	Effective and continuous communication, structured systems design.	Reprioritize, reallocate, restructure, redesign if possible/needed.
	Conflicts in team.	5	2	10	Delays in project, bad morale.	Follow team core values, clear communication, respect.	Vote, take executive decisions if necessary, sit down and talk it through.
	Major conflicts in team.	3	4	12	Project delays, bad morale, complete standstill.	Follow team core values, clear communication, respect.	Vote, take executive decisions if necessary, sit down and talk it through.
	Disclosure of sensitive information.	1	5	5	Legal liability.	Be clear and transparent, ask DeLaval.	Talk with DeLaval.
Stakeholder	DeLaval supervisor unavailable.	1	3	3	Project delays.	None.	Discuss solution with DeLaval and Björn.
	Trouble booking meetings.	2	3	6	Project delays.	Maintain frequent contact so that everyone knows whats up.	Book meetings as soon as possible. Send reminders, renegotiate.

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Table C.1 – continued from previous page

Risk source	**Description**	**Likelihood**	**Impact**	**Risk**	**Consqeuence**	**Preventative actions**	**Reactive actions**
	DeLaval long order lead time.	3	3	9	Project delays.	Order in time.	Prioritize other objectives, order from different vendor.
KTH	Student supervisor absent.	1	3	3	Project delays.	None	Discuss solution with Björn.

D Gantt chart for Fall

This appendix contains the Gantt chart for the fall semester.

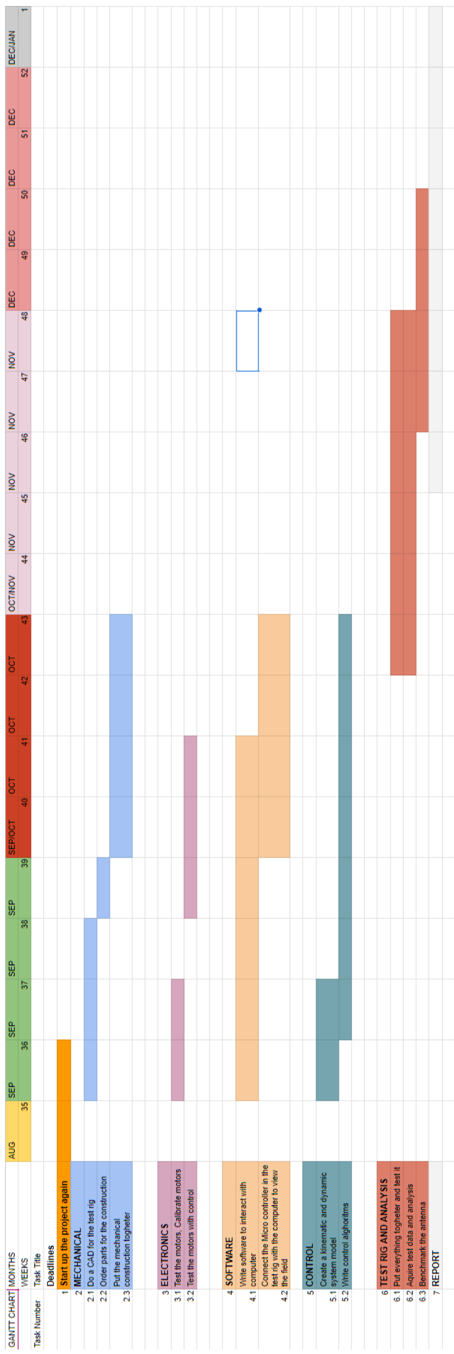

Figure D.1: Gantt chart for fall.