# GAUSS SENSOR FOR MAGNET ARRAY FILTER

Design Document


TEAM NUMBER : SDMAY 20-27

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## Development Standards & Practices Used

- Circuits standards
  - Within safe power rating
  - IEEE 1522-2004 - IEEE Standard for Testability and Diagnosability Characteristics and Metrics
- Software Development Standards
  - Accuracy in taking measurements
  - Reliability in procuring data
  - Establishment of specific or custom software for designing,fabrication and installation

## Summary of Requirements

Functional Requirements:

- Sensor able to detect magnetic particles up to 0.05 µm
- Able to detect iron particles
- Resistant to continuous vibration and temperature changes
- Able to withstand heat and vibration

Economic Requirements

- Able to detect when then buildups reach the threshold, indicating the time to change the filter, decreasing the amount of time and money used to gradually check and changing the filter.

- With the ability to know when the filter is full allows consumer to make sure metal is not going through system increasing life of engine.

- Minimal impact design standard

## Applicable Courses from Iowa State University Curriculum

EE 201/230/285/332/330/333

CPR E 185/281/288

## New Skills/Knowledge acquired that was not taught in courses

- HTML Programming
- Usage of Gauss meter

# Table of Contents

# Frontal material

## List of Figures



## List of Tables



## List of Definitions

# 1 Introduction

## 1.1 Acknowledgement

We would like to acknowledge the help from the following people and organizations:

Magnet Array Company, Dennis O'neel, Dr. Mani Mina, Dr. Brian Stewart, Wei Shen Thea, Texas Instruments, Honeywell, Dr. Akilesh Tyagi, Dr. Joseph Zambreno

## 1.2 Problem and Project Statement

**General Problem Statement:**

A problem with closed systems is contaminants that can build within a mechanical system because with moving parts there will always be slight wear with the components that leads to particles traveling through the system. The filter for a vehicle helps to try and trap these particles but is not very effective for small contaminants. Thus the magnetic array filter acts as a second barrier in trapping these contaminants in the filter. Currently there is still no way of knowing when the filter has reached a certain threshold to where particles will not be caught. Our project is to design a sensor that is able to accurately determine when this threshold is reached and alert the user that it is time to change the filter.

**General Solution Approach**

To solve this problem, the team has to build a sensor array that works in conjunction with a microcontroller to alert the user when it is time to replace the filter. This will better protect their machinery and increase its life time.

## 1.3 Operational Environment

The magnetic field sensor created will have to withstand typical vibration found in combustion engines and hydraulic equipment. The sensor would also have to withstand wide temperature fluctuation existing in the combustion engine. The sensor would be used on a car engine, which is expected to be exposed to different weather conditions according to the season of the year. For example, the sensor would be expected to withstand extreme low temperature during winter, to withstand extremely high temperature during summer, to have water resistivity during rainy seasons, to withstand dusty sand from the road etc.

## 1.4 Requirements

For our project, the requirements intended includes functional and economic regarding the sensor that is to be designed.

First of all, in the aspect of functional requirements, the sensor has to be able to detect magnetic particles down to 0.05 microns. Additionally, our sensor also has to be able to detect iron with high accuracy. Also, depending on time availability, a plausible additional functionality would include detecting brass and aluminum particles through the system. Our design also has to be resistant to continuous mechanical vibration and frequent temperature changes ranging from ambient to 200 F. The sensor has to detect the particle buildup and accurately depict when it reaches a certain threshold. It should also inform the user if there is a huge jump in particle buildup to indicate a pending catastrophic failure of the system.

In terms of economic requirements, the sensor should be able to detect iron, brass and aluminum particle buildup and informs the user of the current level. The idea of it is to indicate the predicted time to change the filter, thus decreasing the amount of time and money used to gradually check, change and replace the filter. It is important for consumers to make certain that no metals from the friction at sliding interfaces in combustion engines do not seep through the whole engine that could damage the whole system.

Before, the user would have to frequently do an inspection manually on the filter and it took time on it. Not to mention, it is an inefficient way to make certain of the “exact” time to change the filter. Hence, with help from the sensor, it should have the ability to inform the user of the current buildup; and if the threshold is reached, the filter can be replaced at optimal periods, thus increasing the life expectancy of the machine and improve the efficiency of the overall maintenance process.

## 1.5 Intended Users and Uses

The intended users of our product are the drivers of motor vehicles, users of machineries and users of magnetic arrays. The sensor created would be expected to be able to monitor the change in magnetic field inside the machinery spin-ons filter, which is correlated to the iron particles accumulation in the filter. It is also expected that the sensor created should report the degree of iron particle accumulation to the microprocessors on the vehicle to help the car users to keep them updated about the situation of the car filter.

## 1.6 Assumptions and Limitations

Our board will have to withstand rapid temperature changes from ambient to 200 degrees Fahrenheit
This board will first be tested on the benches provided by Dr.Brian then we will look into implementations in machinary most likely as an LED indicator on the dashboard.
The board will have a voltage rating of 12-24V
Currently we will not be able to test the field with increasing temperatures accurately because we will not have direct access to a vehicle.

## 1.7 Expected End Product and Deliverables

1. **Sensor array for Magnetic Array Filter**

    The sensor array filter is designed specifically for the Magnetic Array Filter (MAF) that serves as a complement in utilizing the MAF to its full capacity on industrial and commercial usage. The sensor array functions in detecting the amount of particle build up in the magnetic filter. The sensor works with the hall effect sensor to monitor the changes in magnetic field on the filter that is mostly caused by the accumulation of metal particles -- mostly iron. With this, the sensor can detect the amount of metal amassing inside the filter.

    The data collected by the sensor will also be directed to the user for their information. With a set amount of threshold, they will have a clear indication on the level of the build up inside the filter, and depict the appropriate time to change them -- increasing the feasibility and efficiency of the MAF.

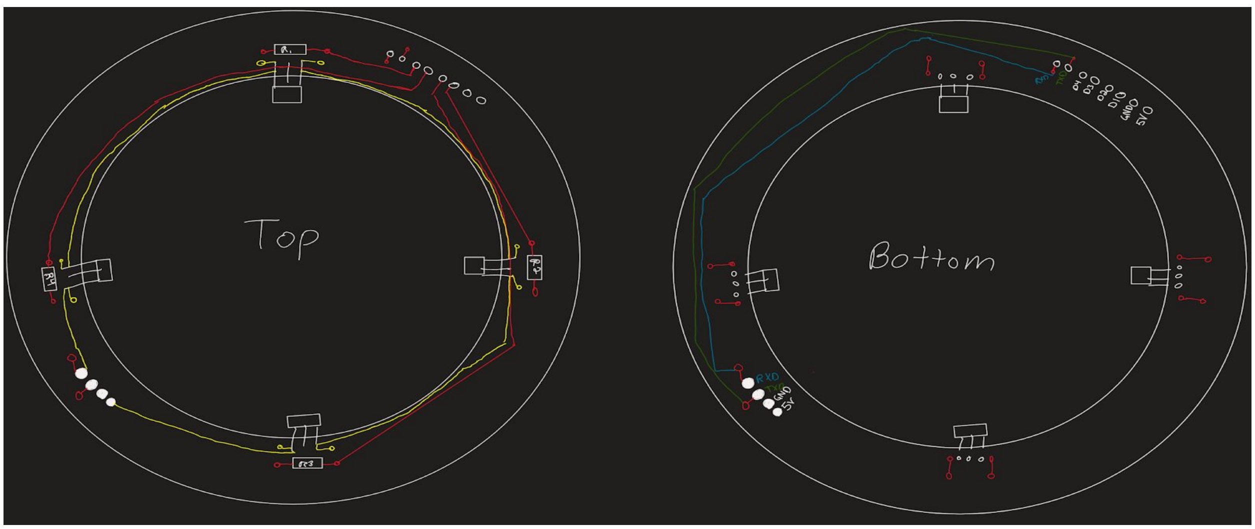
2. **User's Manual**

    The client will be provided with a clear and concise User's Manual of the completed sensor for the Magnetic Array Filter. The user's manual will serve as a guidebook on providing summary and overall information relating the presented product, detailed manual on steps of utilizing the sensor in the filter, and other miscellaneous related to the sensor.

# 2. Specifications and Analysis

## 2.1 Proposed Design

For our initial prototype we plan on designing a ring shaped PCB that will sit on top of the collar when it is connected to an oil filter. This will allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. It will allow us to hopefully get more accurate changes with the magnetic field. We will also be using two different types of hall effect sensors to see which one will be more accurate for our purposes. The board will also have pin outs that can be directly connected to an arduino that will be used to collect the changes in field.




[1]Figure 1: Proposed Design

## 2.2 Design Analysis

Thus far, our team has drafted a design of a prototype and we are looking into possible parts as well as circuit designs that could be incorporated into the design. Currently, we are looking for possible hall effect sensors from Texas Instruments and Honeywell. We acquired some samples which includes DRV5053, DRV5056, DRV5057 from Texas Instruments and SS49 and SS49ET from Honeywell.

Besides that, we have not done any testing yet as we are still in the process of ideating. However, after finishing our prototype, we should test it using a testbench that was constructed by Dr. Brian in his lab. The testbench consists of tubes and a filter where

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[1] Figure 1: Proposed Design

contaminated oil will run through the filter which is fitted with the magnetic array. After testing, we should have an idea on how to improve our design.

One of the advantages of our proposed design is it could be easily installed as it just needs to be placed on top of the magnet array. This makes our sensor easily accessible to the user which eases the user to abstract data/information from the sensor.

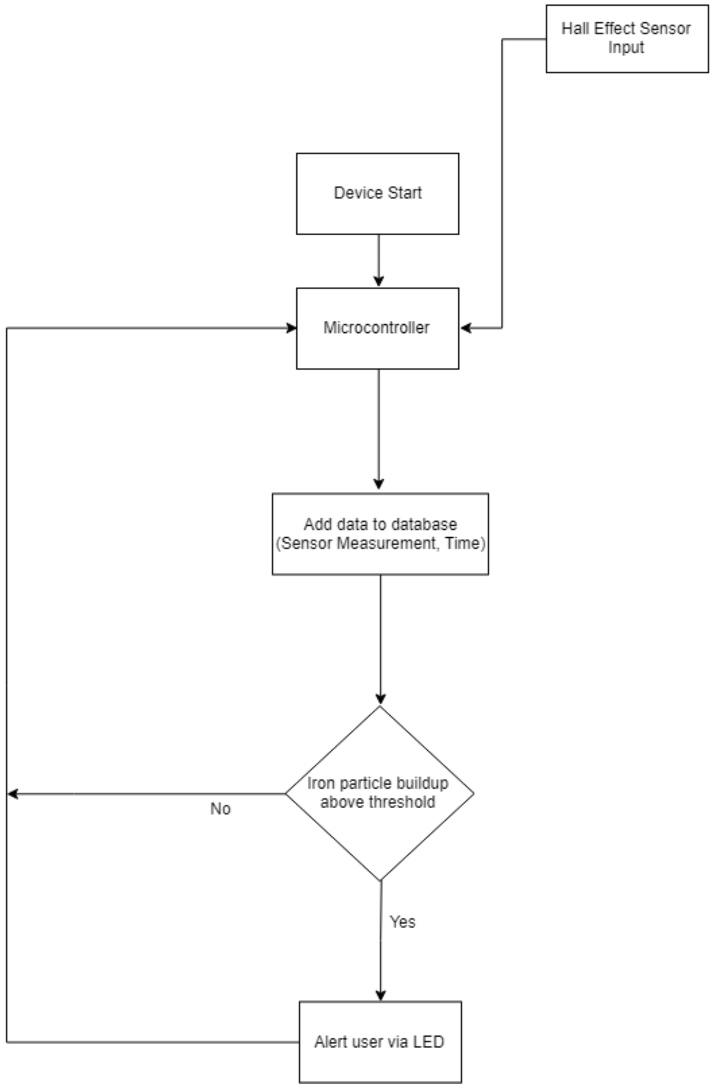
## 2.3 Development Process

The development process used for this project is Agile. Our Agile process is as follows: Initiation of project followed by a team meeting. Then, it is followed by development of the sensor. We will then gather data based on our initial readings. It is then followed by internal evaluation. Then, we will go back to team meeting then development and evaluation. Then, we will have it evaluated by our client. In between all of these processes, reports are made and recorded.

## 2.4 Design Plan

First, we identify the problem to be solved, which is stated in our problem statement. Then, we gather the information from client and end-users regarding the product limitations and requirements. Then, research is done by the team regarding issues that has to be solved and product end design is drafted. Then, possible solutions are thought about by the team members and discussed. The product feasibility is also discussed during this session. Then, a prototype design is selected and built. After that, testing is done and any problems that surface is discussed and the whole cycle restarts.

We will use three sensors in our initial testing that are not affected as much by temperature fluctuations and vibration which are Texas Instruments DRV5055, DRV5056, DRV5057. Then, we will design a circular PCB board that can be attached to the Magnet Array Filter. The PCB board is connected to a microcontroller that collects analog data from the sensor. The microcontroller will then decide whether the amount of particle buildup has reached the threshold. In the software design, we will take the input from the sensor and save it to a local database. The database data is tracked and if a sudden fluctuation is recorded, the alert will be sent to the user as well. Thus, there are 2 instances where the user will be alerted, which are when the threshold is reached, and if there is a sudden fluctuation in particle build up indicating a terminal failure. The microcontroller and sensor will use 12-24V inputs from the vehicle battery or the machinery that it is attached to. The microcontroller will be attached to a location away from the sensor via wires to avoid temperature changes and vibration to it. The following diagram is used in the microcontroller:




[2] Figure 2: Design Plan

[2] Figure 2: Design Plan

# 3. Statement of Work

## 3.1 Previous Work And Literature.

Background of project:

Fundamentally, as mechanical system ages, the probability of failures increases. This is due to the primary drawback with closed system as lubrication such as oil in a system engine breaks along with the moving parts of the engine. This allows components in the machine to wear, producing ferromagnetic debris particles in the circulating oil system. Hence, gradual monitoring of the system and preventative maintenance are to be conducted to prevent the machine from experiencing catastrophic failures that could break down the machine entirely.


Figure 3.1: Magnetic Array Filter (MAF)

Although, nowadays consumers typically uses oil filters to trap the wear debris particles, one of the limitations of the oil filter is that it is not highly as effective towards small particles. Standard oil filter is mostly effective for only particles approximately 20um and larger. This is concerning since many of the destructive ferrous wear particles are under the 20um limit. Hence, one solution for this dispute is the application of the Magnetic Array Filter (MAF)[3.1], designed and patented by our client, Dennis O'Neel from the Magnet Array Company. This magnet array filter acts as a secondary filter for the oil filtering system of the machine which helps in trapping these metal debris particles that are not removed by the conventional oil filter. The magnet array is designed as a collar and attached to an oil filter[3.2] of the machine.

Currently there is still no way of knowing when the filter has reached a certain threshold to where particles will not be caught. This is because as more of the wear debris metal particles are trapped by the magnetic array filter, the particle build ups causes a deterioration in the ability to attract any more of the wear particles inside the oil system.

Therefore, our project is to design a sensor that is able to accurately determine when this threshold is reached and alert the user that it is time to change the filter, to increase the lifespan of the machine. Our sensor designed for the filter utilizes the hall effect sensors which detects the changes in the magnetic field around the filter which indicates the changes in buildups of the metal particle debris on the filter. The information is then transferred into a software integrated in a microcontroller attached with the sensors, and displayed to inform the user. The software also provides threshold for the user to compare with the current build up, indicating and alerting the user on the time to change the filter. This will then improve the feasibility of the magnet array filter as a preventative maintenance mechanism to help increase the lifespan of the machine or vehicles.

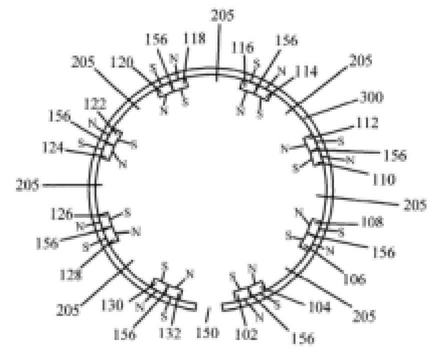


FIG. 3

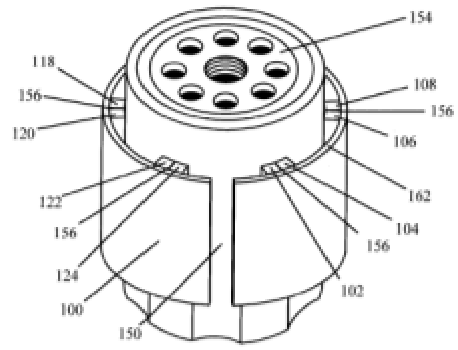


FIG. 4

Figure 3.2: MAF attached on Oil Filter

## 3.2 Technology Considerations

In consideration to our circuit design and implementation, since we are using sensors, one important aspect that is to be considered is the accuracy in measuring data. In addition to that, considering that the design is primarily used for an oil filter of a vehicle or an industrial machinery, we need to take into account the effect of temperature fluctuations and the effect of vibration towards the measurement of the sensor. The first solution that we came up with was to use the Hall effect sensors available from Texas Instrument. Specifically, for our testing we used the DRV5053, DRV5055, and DRV5056 Hall effect sensors from Texas Instruments. Also, other available sensors that we used for testing was the SS49 and SS49ET sensors from Honeywell. The reason these sensors were used are because they are not affected by temperature fluctuations and vibrations.

Also, the sensors will be connected to an Integrated Circuit, which for this part we will use an Arduino to connect the output. The necessity of Arduino is that is has an Analog-to-Digital-Converter (ADC) that helps in converting the analog signal inputs from the sensors to digital output, where it will be used in a user-interface software that we will develop alongside with the PCB. The software will take in the digital data and store the inputs into a local database and plot the changes in magnetic field that is then converted to the current level of the wear particle build ups inside the magnet array filter and the result displayed to the user. The software will also be provided with thresholds, where the software will alert the user if the current level reaches the threshold, pointing out that it is time to change the filter.

Moreover, the database data is tracked and if a sudden fluctuation is recorded, an alert will be sent to the user as well. Thus, there are 2 instances where the user will be alerted, which are when the threshold is reached, and if there is a sudden fluctuation in particle build up indicating a terminal failure.

One advantage in our design is that the sensors can be used while the machine or vehicle is online, meaning that we can get a live data of the reading without having the necessity of shutting down the machine or vehicle first. With this, it allows the user to obtain a real-life data and an immediate notification regarding sudden changes on the machine or vehicle. It also prevent additional cost or the necessity to shut-down the machine and examine the magnet array filter that are attached to the oil filter.

<u>Design alternatives:</u>

For our initial prototype design, we plan on designing a ring-shaped PCB[3.3] that will sit on top of the collar when it is connected to an oil filter. The ring-shaped PCB also has a mounting compartment available for the sensors that allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. This is done to ensure that the sensors are mounted into place, ensuring that the sensors are not affected by the vibration from the engines, allowing us to hopefully get more accurate changes with the magnetic field. The board will also have pin outs that can be directly connected to the arduino which is located differently from the PCB, far from the oil filters

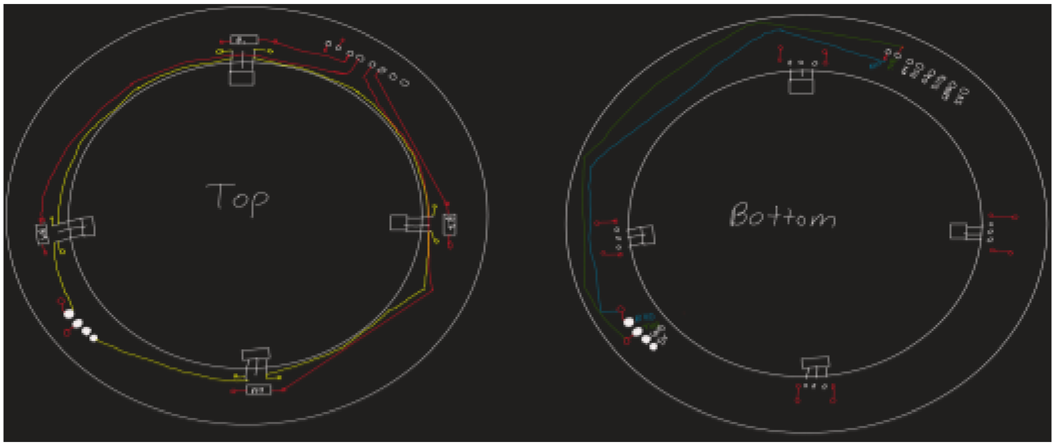



Figure 3.3: Initial Design (Ring-Shaped PCB)

by long connecting wires. This is to prevent the Arduino to be affected by the heat produced from the engine of the machines.

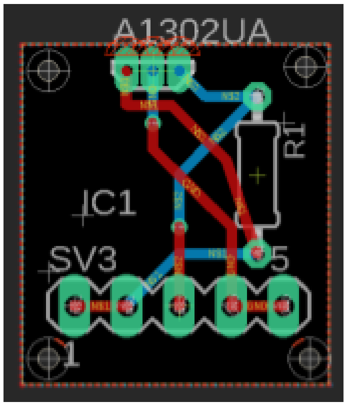


Figure 3.4: Square PCB

After going through some testing and discussion with the team, we decided to change the design of the PCB from the ring-shaped approach to a square PCB[3.4]. This allows a simplification in modelling the PCB and easier in terms of wire connection. The PCB will also be mounted on a circular silicon or plastic ring that will sit on top of the magnet filter instead of having the whole ring as PCB. As before, this will allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. The collar is also designed for both top and bottom of the oil filter, having a total of 8 sensors for both PCBs to ensure that the sensor covers the whole perimeter of the Magnet Array Filter.

[3.5]Figure 3.5 shows the 8 output pins for the sensors that are to be connected and mounted on the plastic ring mount as with the four square PCBs[3.6]. The necessity of using a plastic or silicon ring mount is the characteristic of both materials that are a good heat insulator, preventing the PCB mounted to conduct excessive heat.

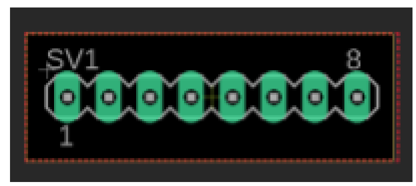


Figure 3.5: Output Pins

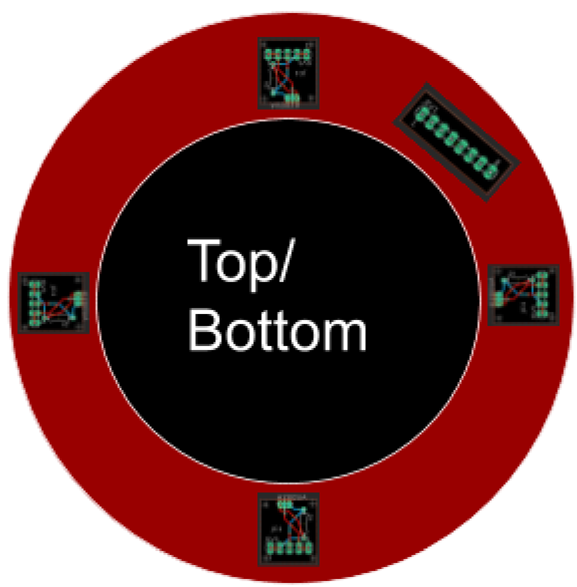


Figure 3.6: Square PCB and Output Pins on Plastic Ring Mount

# 3.3 Task Decomposition

## Project Plan[3.7]

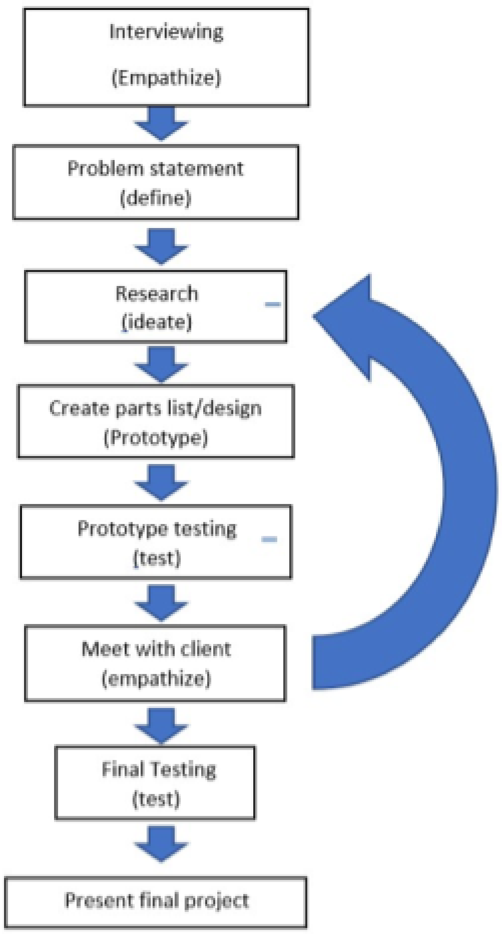



Figure 3.5: Project Plan

1. The first part of the project is to gain information from the client which is apart from the empathizing stage. This step is done in order to really know the problem the client is facing and discussing the expected outcomes.

2. The second step is defining the problem statement. After receiving the information from the client, the team should formulate a thorough problem statement which would represent the problem the client is trying to solve and the expected outcome.

3. The third step is to ideate which is where the team does research and collect data that could help in solving the problem. This step is where the team brainstorm ideas and connecting them all together.

4. The fourth step is where the team collects the required parts in order to build a prototype based on the ideas generated earlier.

5. The fifth step is where the team conducts rigorous testing on the prototype and prove that the solution works.

6. After requiring a possible solution, the team should present it to the client and receive feedback. If the requirements are not met, the team should go back to the ideate stage and formulate a new plan to tackle the problem.

[3.7] Figure 3.7: Project Plan

7. If the client is satisfied with the outcome, the team should conduct a final testing on the final product to endure the quality of the product.

8. After the final testing, the team should present the product to the client and public. At this step, the team should be confident that a quality final product is made.

## 3.4 Possible Risks And Risk Management

Include any concerns or details that may slow or hinder your plan as it is now. These may include anything to do with costs, materials, equipment, knowledge of area, accuracy issues, etc.

## 3.5 Project Proposed Milestones and Evaluation Criteria

What are some key milestones in your proposed project? Consider developing task-wise milestones. What tests will your group perform to confirm it works?

## 3.6 Project Tracking Procedures

What will your group use to track progress throughout the course of this and next semester?

## 3.7 Expected Results and Validation

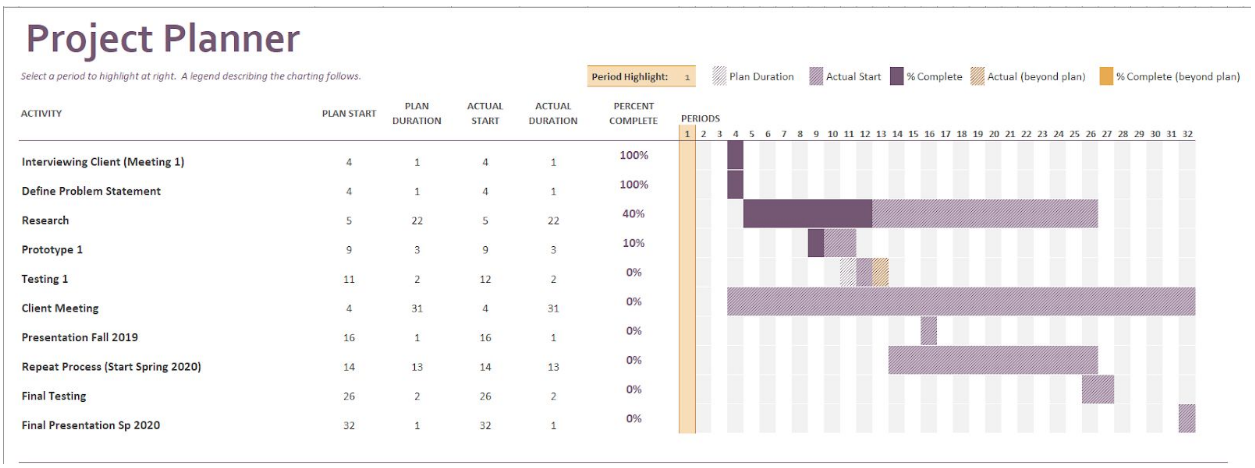
The desired outcome of our project is a sensor array that will accurately depict when a certain change in magnetic field has been achieved by a vehicle or systems oil filters. This would mean the the filter is full of particulates that would otherwise travel through the system. The array will then tell the user when it is necessary to change the filter out

We will confirm or work by running many tests on different types of oils at different stages in their life, use change in temperature of the oil in order to understand how that affects the magnetic field, and run specific amounts of 10 micron particulates to understand how each particulate effects the field. We will be conforming to the IEEE 1413-2010 - IEEE Standard Framework for Reliability Prediction of Hardware and IEEE 1641-2010 - IEEE Standard for Signal and Test Definition. These standards will help to ensure that we are creating an accurate and effective final product.

# 4. Project Timeline, Estimated Resources, and Challenges

## 4.1 Project Timeline

Figure 4 is the Gantt Chart derived from the tasks that was specified in Section 3.3. This Chart specifies the timeline that our group planned in order to complete the project in the given time.




| ACTIVITY | PLAN START | PLAN DURATION | ACTUAL START | ACTUAL DURATION | PERCENT COMPLETE |
|---|---|---|---|---|---|
| Interviewing Client (Meeting 1) | 4 | 1 | 4 | 1 | 100% |
| Define Problem Statement | 4 | 1 | 4 | 1 | 100% |
| Research | 5 | 22 | 5 | 22 | 40% |
| Prototype 1 | 9 | 3 | 9 | 3 | 10% |
| Testing 1 | 11 | 2 | 12 | 2 | 0% |
| Client Meeting | 4 | 31 | 4 | 31 | 0% |
| Presentation Fall 2019 | 16 | 1 | 16 | 1 | 0% |
| Repeat Process (Start Spring 2020) | 14 | 13 | 14 | 13 | 0% |
| Final Testing | 26 | 2 | 26 | 2 | 0% |
| Final Presentation Sp 2020 | 32 | 1 | 32 | 1 | 0% |

[4] Figure 4: Gantt Chart

The first step that the group took was to gain information about the project. After we were assigned to this project, we initiated contact with our client and set up an initial meeting to kick off the project. The first meeting is crucial as we would negotiate about the expectations of the project and what the client wants the group to achieve by the end of the semester. This was done around the 4th week. After that, we would have to define our problem statement which is the problem that we are going to solve and it dictates the direction that the team would be taking for the rest of the semester. This step was completed the same week as that we met with our client. On the other hand, research is a step that is done throughout the semester as the team would be searching for ideas to improve our proposed solution. That is why this step is scheduled until the team conducts the final testing whereby we achieved the satisfied final product.

The next step is a repetitive process that is done according to the improvements that the team applies to the prototype. This step involves building the prototype, testing, client meeting and back to the research step. The first prototype started in week 9

[4] Figure 4: Gantt Chart

whereby the team designs the circuit and builds the PCB. After that, we proposed to start the first testing in week 11 but changes were done to the circuit design which caused the first testing to be scheduled in week 12. After testing, we would have to schedule a meeting with our client to report our progress as well as our findings. The feedback that the team receives will be used to improve our design and the cycle repeats. We scheduled the client meeting as a process that is also done throughout the semester. At the moment, the team meets with the client once every 2 weeks.

The final testing is tentatively scheduled for a month before the final presentation in week 32. This step is not yet to be determined as it depends on the challenges that the team faces over the semester. Finishing a few weeks before the final presentation would give the team time to organize the material gained from the project and successfully complete any remaining requirements.

## 4.2 Feasibility Assessment

A series of collected data for reference and proposals of some suggested methods to detect the change in magnetic field in oil filter due to brass and aluminium will be provided at the end of this project. Realistically, a prototype of a magnetic array sensor might be created but the prototype might be flawed due to time constraint. The calibration of the sensor array requires a large amount of time which might cause the outcome of the project to be very limited.

Foreseen challenges:

1. Time consumption
    - This project relies heavily on the sample data collected as we are using those data to calibrate the gauss meter and the magnetic array filter created by the team. For instance, we need the magnetic field reading of the filter at 1000 miles, 10000 miles, 20000 miles etc. Hence, a large amount of time is actually needed to obtain sample data.

2. Accuracy of data collected
    - The sensitivity of hall effect sensor can greatly impact the accuracy of the data collected as we are dealing with a very small change in magnetic field. The sensitivity of hall effect sensor varies among different brands and models. Hence, it will be a challenge for us to decide which brand and model of hall effect sensor to use.

## 4.3 Personnel Effort Requirements

| **Task** | **Projected Effort** |
|---|---|
| Identifying problem statement | ● Initiate contact with client<br>● Identify the needs of client |
| Identifying the outcomes of the project | ● Research on magnetic array sensors<br>● Propose ideas to team advisor<br>● Determine if the need of client is achievable<br>● Determine the outcome of the project we can provide to the client |
| Searching for alternative options | ● Research on the possibility of using the physics of eddy current to detect the change in magnetic field caused by brass and aluminium<br>● Determine the possibility to use the physics of eddy current towards our goal |
| Obtaining required tools and equipment | ● Creating a list of the tools needed<br>● Request lab and equipment access from ETG(Electronics Technology Group) of Iowa State University |
| Obtaining sample data for setting the threshold | ● Initiate contact with CyRide to request for used oil filters<br>● Research on the effect of sensitivity of sensor on the accuracy of data |
| Creating prototype | ● Creating board designs<br>● Running test on the created prototype to minimize errors<br>● Improvements of prototype |
| Presenting the outcome of project to clients | ● Display and explain the results and effectiveness of the prototype<br><u>In cases where the prototype does not meet the requirements</u><br>- Research on the possible improvements of the prototype<br>- Creating a better prototype |

Table 4.3: Personnel Effort Requirement

## 4.4 Other Resource Requirements

| Part Name | Part Number | Part Price | Quantity | Total Price |
|---|---|---|---|---|
| Linear Hall-effect sensor (honeywell) | SS39ET | $0.85 | 3 | -- |
| Linear Hall-effect sensor (TI) | DRV5055-Q1 | $0.74 | 3 | -- |
| PCB | | | 6 | $26 |
| Arduino Uno | | $14.98 | 1 | $14.98 |
| Total | | | | $40.98 |

## 4.5 Financial Requirements

At the moment, the team does not require any use of capital from the client as the resources used are readily available for students in the ECPE department.