MECH 554 MECHATRONICS

PROJECT REPORT

THE SORTING SYSTEM

Instructor: Shen Chao

Lab Instructor: Patrick Chang

Chinnappa Allapanda (V00864775)

Robin Thomas (V00818887)

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1.0 Objective and Project Description

As part the lab requirements for Mechatronics 554, a final project had to be completed. A sorting system had to be setup to sort cylindrical parts of four different types in an allowed time of 60 seconds. The four different parts are Black Plastic, Steel, Aluminum and White Plastic. The parts has to be sorted on a conveyer belt using sensors and has to be collected in four designated sections of a tray. The parts are supposed to fall in the corresponding sections for the project demo to be successful.

The apparatus consists of the conveying subsystem, inspection system and the sorting subsystem.

- The conveying subsystem

The conveying subsystem is used to transport the cylindrical parts to the tray which passes through the sensors. The system consists of the conveyor belt, DC Motor and the motor driver which is synced with the other system using the code.

- The inspection stations

The inspection station includes the sensors to provide feedback and sort the parts passing through the conveyor.

- The sorting subsystem

The sorting system includes a tray with four sections mounted on a stepper motor which rotates with respect to the appropriate parts.

2.0 Introduction

To initiate the sorting system, the parts has to be manually placed on the conveyer belt by the team members. The conveyor belt is run by a DC motor which has a pre-set speed. The four quadrant tray as showing in green in Figure 1, is mounted on a Stepper motor which has to turn ±90 and 180 clockwise and counter clockwise directions real-time as the sensors sort the parts into categories. The sensors used to detect the parts are namely Ferromagnetic Sensor, Reflective Sensor, Hall Effect Sensor and three Optical Sensors. The sensors are used as follows:

- Ferromagnetic Sensor to detect and determine steel part, if the material has magnetic properties
- Reflectance Sensor to define visual characteristics of the objects
- Optical Sensors to determine entrance and exit of objects, as well as recognize objects in between these stages
- Hall Effect sensor is used to keep track of the position of the tray with reference to the starting position.

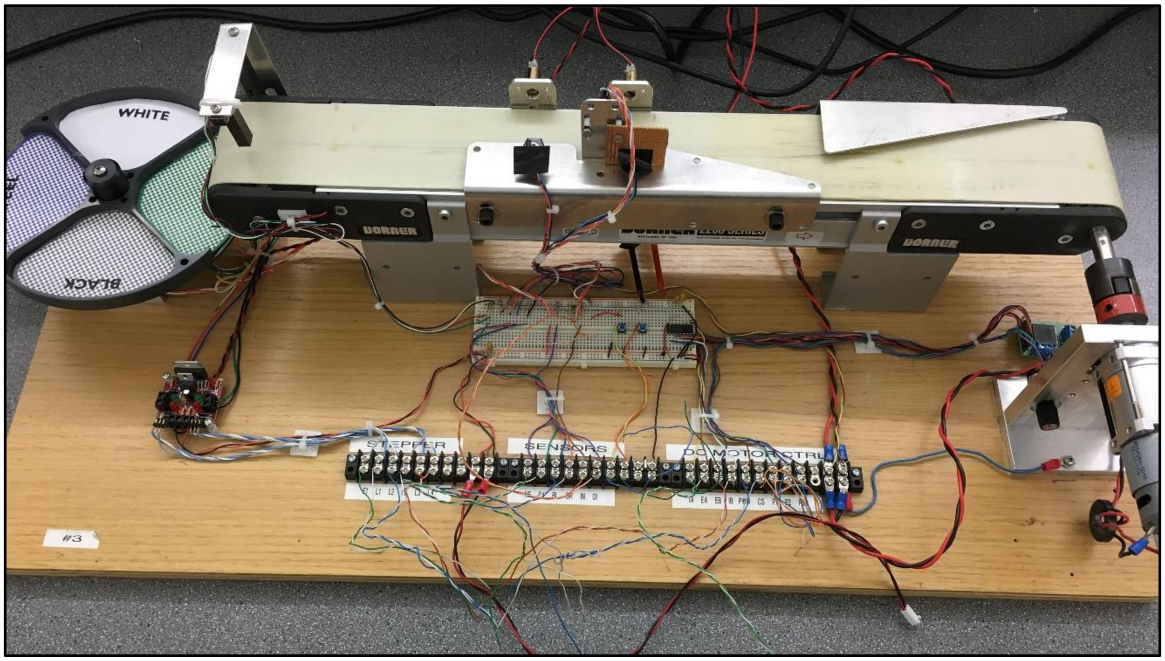


Figure 1: The Sorting System

3.0 TImeline

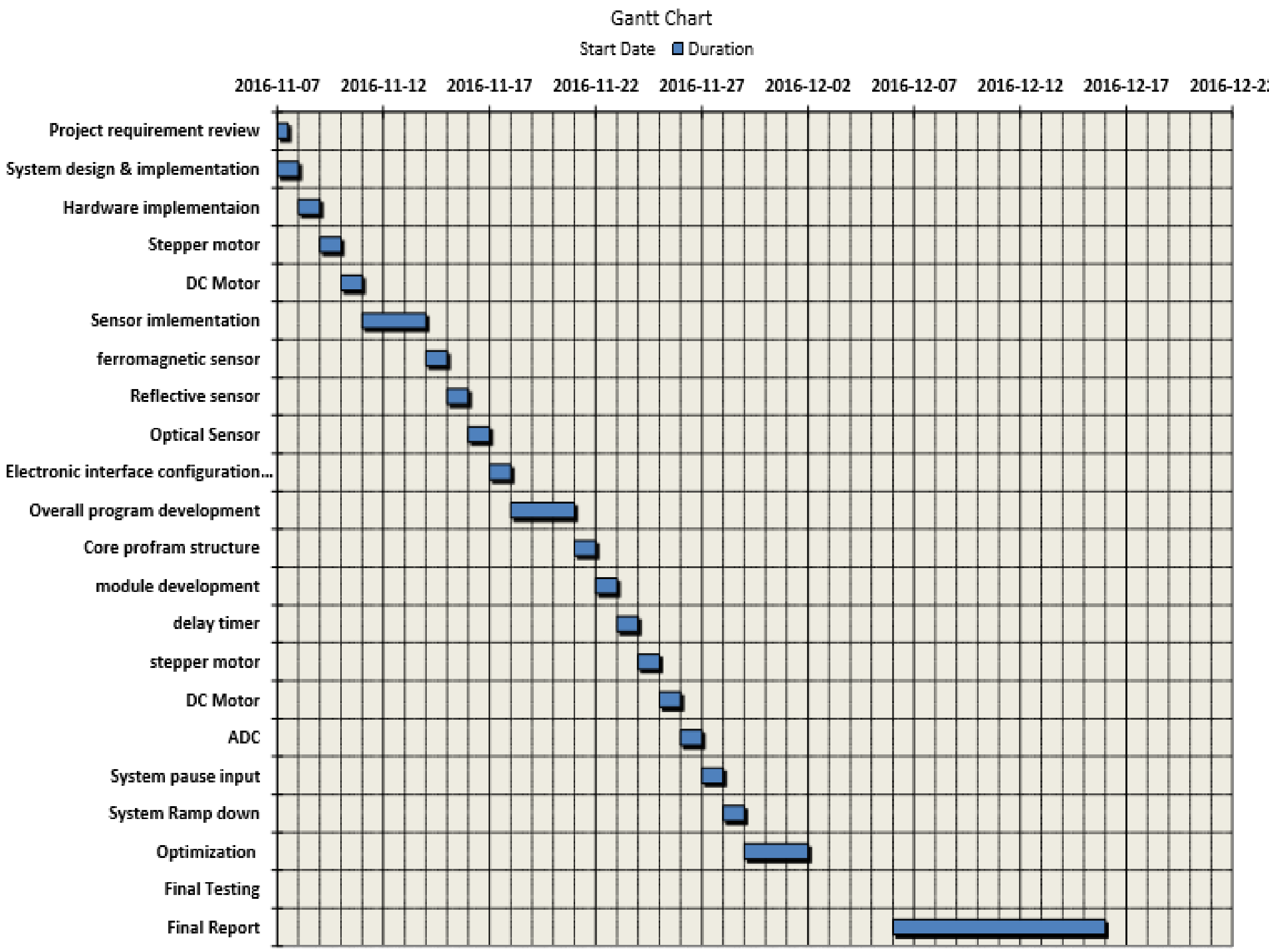


Table 1: Timeline

4.0 System Technical Documentation

4.1 System Algorithm

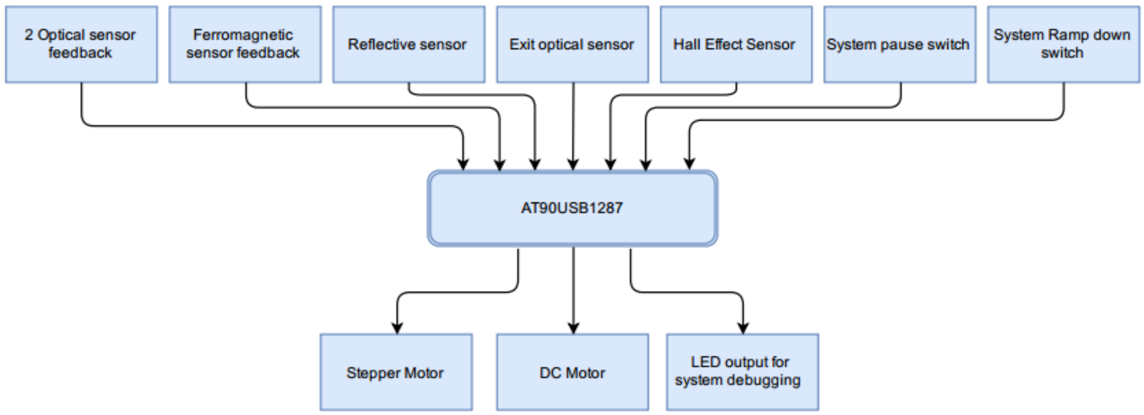


Figure 2: System algorithm

The sorting system is designed to sort the four type of objects which are distinct in color and material. The objects are loaded on the conveyor belt run by a DC motor, programmed to follow a specific predetermined speed which is actuated using PWM signal from the microcontroller. The Objects are passed through sensor fields where the type of objects are determined. The signal obtained are then processed to control the conveyor and the tray which is mounted on a stepper motor to facilitate sorting.

When an object reaches the 1st optical sensor and the inductive sensor, the object gets added to a queue to record the number of parts coming in and the Ferromagnetic sensor records the change in inductance caused due to the magnetic properties if the object is steel. As the object moves through the belt, it passes through the optical reflective stage which consists of optical sensor 2 and reflective sensor. At this point, the reflective sensor collects samples of the parts passing through and sent the corresponding analog signals to an ADC where it gets converted to digital signals which can be read by the microprocessor. If the current result of the collected sample is greater than the previous reading, the ADC continues to update the new maximum value and whenever the reflective sensor is active, ADC is initiated. The information is crosschecked with the predetermined reflective value obtained by calibrating the objects. The output information is then used to categorize the parts. When an object reaches the optical reflective stage, objects from the first queue are added to another queue after determining the type. When the parts reach the exit sensor (Optical Sensor 3) after passing through the sensor stages, parts from the second queue are dequeued to sort the objects. The belt stops if the quadrant of the sorting tray does not match the object to be sorted. If the object matches the quadrant of the sorting tray, the belt will not stop as the object approaches the exit sensor and fall into the right quadrant of the bin.

A pause and ramp down switch is used to control and display the information of the sorted objects. When paused, the DC motor stops and the LED's display the type and quantity of the objects sorted at any point during the process. The first nibble or the least significant bits are used to display the type of objects and the rest of the four LED's are used to display the quantity. Ramp down switch can be used to shut down the system. When switched, the system is programmed to wait for 10 seconds before shutting down to ensure all objects on the conveyor belt is sorted. After the system shuts down the LED's display the type and quantity of the sorted objects.

4.1.1 Delay Timer

mTimer function is the general delay used in the program to time the delay. Timer 1 is the timer register used in the project to time the delays in between the program.

Timer 3 is used for Ramp down delay as a delay for the time defined for Ramp Down to shut down the system after a finite time. A different timer was used for this feature so that the timer could work exclusively for Ramp Down function irrespective of other interrupts or mTimer delay of the system.

4.1.2 Stepper Motor

The stepper motor was controlled based on its characteristics and properties which makes it capable of turning in steps. 1.8 degrees correspond to 1 step in the stepper. It takes 50 steps for the motor to turn 90 degrees and 100 steps to turn 180 degrees. Dynamic strategy of movement where considered for the rotation of the motor as the tray attached to the stepper gets heavier as the process progresses. Worst case scenarios were considered and good amount of time and effort were put towards the optimization of the speed of the motor.

Figure 3: Sorting tray on stepper motor

Port A is used to connect the stepper to the microcontroller. The delay between each steps of the motor is the most important part to adjust the speed of the motor. The speed of the motor has to have a uniform acceleration and deceleration for precise movement of the trays to the right position of the bins to collect all the different parts. The speed profile of a stepper motor is as shown in figure 4 was continuously subject to improvement. The objective was to have a gradual and smooth transition from acceleration to constant speed to deceleration. The safest approach to adjust the delay between the steps were to start form a delay of 20ms and reach a minimum speed of 8 to 5 without skipping steps in between. The robustness of speed profile were checked every once in a while to make sure it does not fail as it might work differently in other apparatus's in the lab.

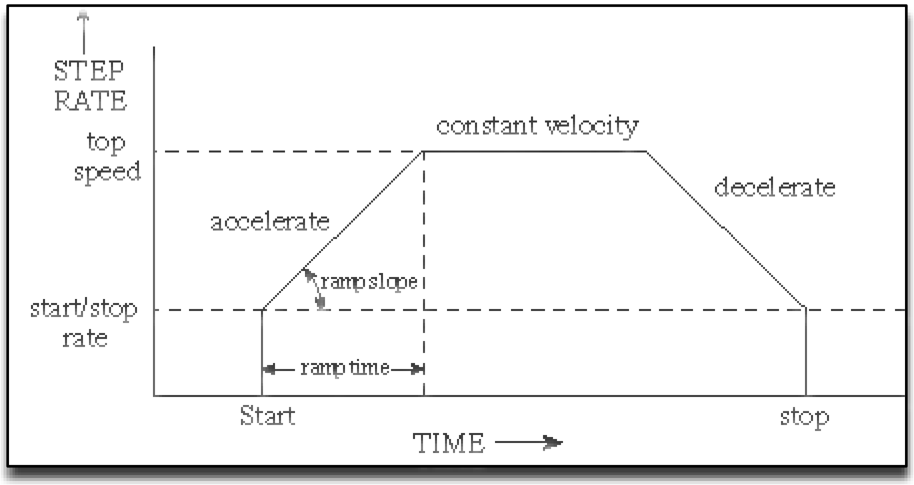


Figure 4: Speed profile

4.1.3 DC Motor

A DC motor is used to run the conveyor belt of the system. The motor is set to run at 40% of full speed through PWM. The motor is used as an actuator to transport the objects to the sorting bin through the sensors. The motor is controlled using the feedback from the exit optical sensor to allow the detected objects to fall into the right bins. It is programmed to stop an object at the exit sensor to allow the stepper motor to reposition and match with the detected object.

4.1.4 Analog to digital conversion

ADC 1 was used to connect the reflective sensor to the microprocessor. An optical reflective sensor set were used for sampling the objects passing through the sensor for calibration and sensing the type of object. Multiple samples of reflectiveness are required to determine the kind of object. The analog signals from the sensors are converted to digital and was read and displayed using LED outputs connected to the microcontroller on the bread board. The parts which has to be sorted is calibrated for the process as different sets of object has different reflectiveness as they are not manufactured out of the same raw materials. ADC 1 was used to connect the sensors to ADC converter on board the microcontroller. If the current result of the collected sample is greater than the previous reading, the ADC continues to update the new maximum value and whenever the reflective sensor is active, ADC is initiated.

As the cylindrical part passes through the sensors experiences a gradual change from its high state to low when the part reaches the middle of the object on the belt and a gradual transition to high. Samples for conversion are collected at this interval of time.

4.1.5 Ferromagnetic Sensor

Ferromagnetic sensor is used in the system to differentiate between steel and aluminum. The difference in the change of inductance of the sensor will produce different voltages for steel and aluminum as the magnetic properties of the materials are different.

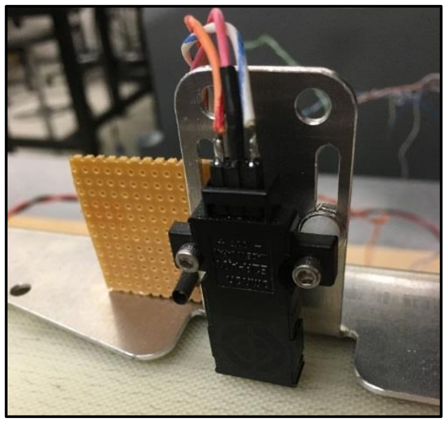


Figure 5: Ferromagnetic Sensor

4.1.6 Reflective Sensor

Reflectiveness of the objects passed on the belt are read using the reflective sensor. The objects passed disturbs the transmitted waves between the emitter and receiver. The amount of disturbance corresponds to the analog signal output from the sensor.

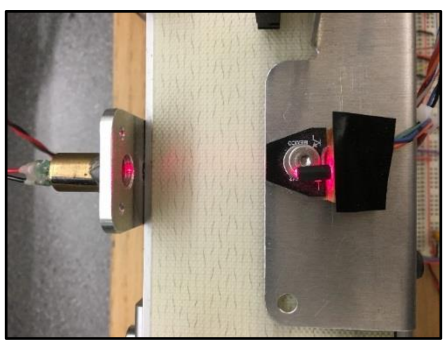


Figure 6: Optical reflective stage

4.1.7 End of Travel

End of travel sensor plays a very important role in the sorting process. Based on the control algorithm, when an object interferes with the range of the exit sensor, the DC motor stops and the stepper positions to the corresponding section of the tray with respect to the type of that object determined by the sensor when it passed the optical reflective sensor stage.

The position of the end of travel sensor is equally important. When the belt comes to a sudden stop at the exit sensor to reposition the stepper, the object might fall off the belt in to the wrong quadrant of the tray resulting in an error. Therefore the sensor was positioned in such a way that none of the parts will fall off irrespective of its weight.

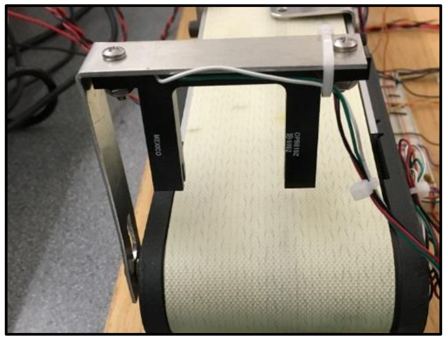


Figure 7: Exit optical sensor

4.1.8 System Pause Input

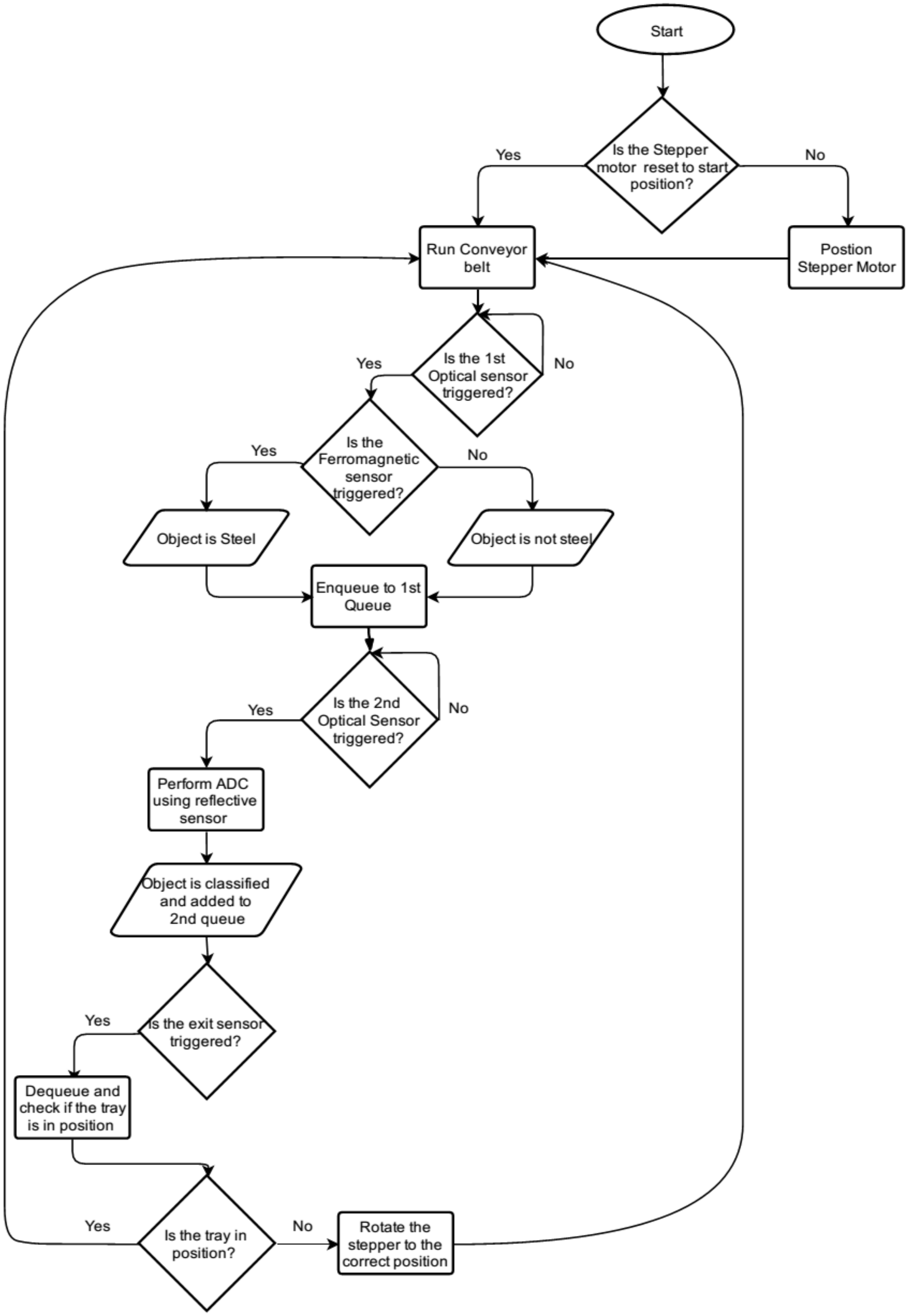
The system pause function facilitates a switch on board the system to pause the whole system when triggered and display the details of the sorted objects at any point of time during the process. The LED's which are set, display the type of object in using the first four LED's from the right and the quantity of the corresponding part using the four LED's through the most significant bits of PORT C.

The pause interrupt is also required as part of a system robustness test during the demo. A system has to be paused just before one of the set of four objects reaches the end of travel sensor. The goal is, when the system is paused, it has to display the type and quantity of the 3 sorted objects and when resumed, the system has to run and sort the object on the belt which has to be displayed when paused again.

4.1.9 System Ramp Down Input

The system ramp down is another feature of the system which can shut down the system and display the details of every object after making sure every object on the belt are sorted and displayed. The system runs for 10 seconds after the Ramp Down is triggered using a switch on board to make sure all the objects on the belt are sorted.

4.2 System flow chart



4.3 Pseudocode

#include <avr/interrupt.h>
#include <avr/io.h>
#include <stdlib.h>
Initialize and declare global variables
Initialize and declare linked list structures
Declare Main () modules
Main ()
{

- Configure and Set-up MCU
- Initialize Timers
- Initialize pre-scalar for mTimer ()
- Disable Interrupts
- Initialize I/O port data directions
- Initialize PWM
- Initialize LEDs
- Initialize Stepper
- Set Stepper to home
- Initialize interrupts
- Enable required external interrupts
- State interrupt edge detection
- Initialize ADC
- Enable ADC and interrupt
- Goto Polling_Stage

Interrupts

- Loop based on stage variable
- Display number of each sample type
- If Magnetic Optical Sensor
  Record Magnetic Sensor value to linked list
- If Conveyor Belt exit sensor
  Change to Tray Positioning Stage
- If Hall Effect sensor
  Set Tray to home position
- If Pause button
- If already in Pause, switch to Sorting Stage
  Switch to Pause Stage
- If Ramp Down button
  Set ramp down requested flag
- If ADC Conversion Complete
- If current result is greater than stored result, update with new max value
- If Reflectance Optical sensor still on, initiate another ADC
- Reset ADC flag

If BAD_ISR

Set BAD_ISR flag to active
return(0)
}

4.4 Circuit Diagrams

The circuit diagram of the system is shown in the following figure 8. A resistor and capacitor was added in circuit for optical sensors, pause switch and Ramp down switch in order to avoid current interference caused due to the DC motor in loop.

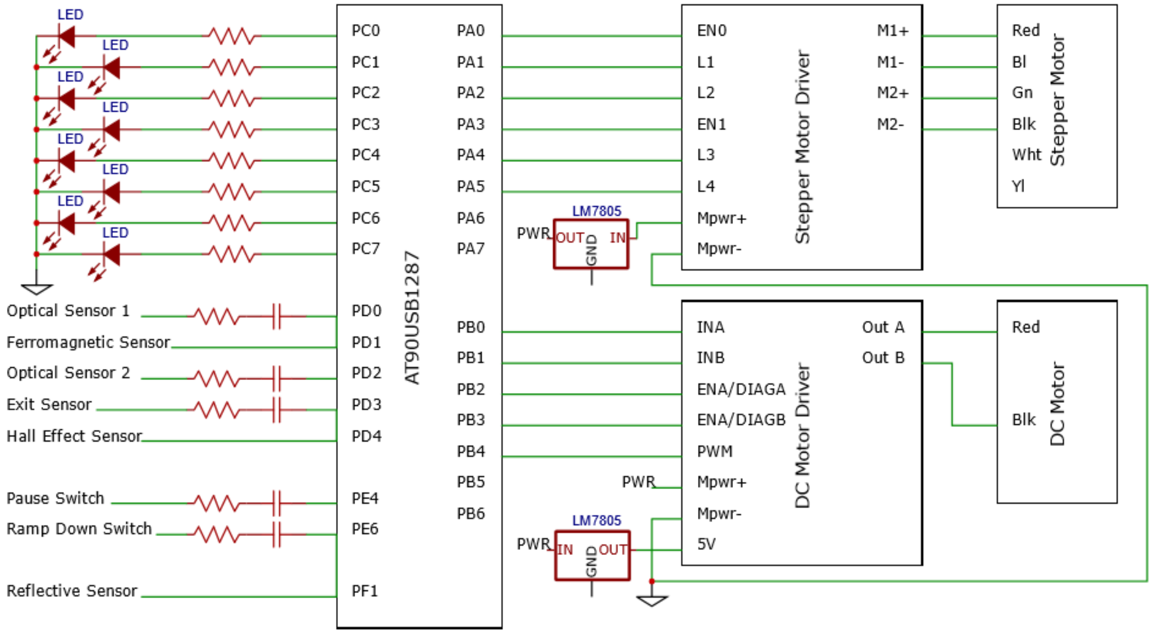


Figure 8: Circuit Diagram

5.0 System Performance Specifications

The algorithm used in this project was very efficient and robust for most part of the system. However, there were some challenges during the trials such as:

1. The sensor misses a count when two objects interfere come across the exit sensor and the reflective stage at the same time.
2. Objects used to fall off the belt into the tray when the motor come to a sudden stop. Therefore the exit sensor was positioned at an optimal angle.
3. Speed optimization of the sensor was another challenge, as the number of parts increases the sensor will skip steps due to inertia of the tray. To solve the issue, a dynamic speed profile was selected.
4. Most of the time, calibration of black and white objects had an overlap in reflectiveness. The problem was improved by calibrating objects with the extreme values to have a safe range.

The overall system performance is calculated based on System Performance Index (SPI).

$$SPI = \frac{N_C - N_I}{T_{MAX}}$$

SPI = System Performance Index
NC = The total number of correctly identified objects by the system
NI = The total number of incorrectly identified objects by the system
TMAX = The maximum time allotted to pass the objects through the conveyor system

During system demonstration on 6th December 2016, the system was tested for robustness and time taken. During the first trial, the process took 43 seconds with no errors. During the second trial, there was a human error while loading the object on the belt resulting in the object rolling on the belt which lost count. In the final run, the system sorted in **42 seconds with no errors** and was considered the best of the 3 trials. Based on the results the system can be considered reliable and repeatable.

6.0 Testing and Calibration Procedure

Various test procedures were considered throughout the progress of the project to check the hardware works.

1. Stepper motor optimization: A separate function was created in the code named as “teststepper” to optimize the speed of the motor. The function can be used to run the stepper in any predetermined speed curve to rotate 90° and 180° in clockwise and anti-clockwise directions for a number of times to test is the motor is skipping steps at any point of rotation. The test also includes loading the motor to test if it can endure and withstand the weight by maintaining the defined speed. A dynamic control strategy was used in the motor. The strategy includes three different speeds at three different point as the count of the sorted object increase. Two batteries were considered as full load to calculate the seed at the last half of the process where the number of sorted objects approach 48 objects. Speed for the first half was defined by using one battery as the load. And the second half using a battery and some steel objects.
2. Calibration for reflectiveness: Various objects available from all the stations in the lab were calibrated at different points of the project to get a voltage range for reflectiveness. Most of the time Black and White objects had an overlap in values which caused misinterpretation of parts. The range was then adjusted separating the largest value of white and the lowest of value of black objects. During calibrating the parts the USB cable is detached to avoid voltage interference.

On the demo day, three black objects were not uniform with the others although it came with the same set of objects. During the trial runs, those parts were sorted correctly most of the time and incorrect once or twice.

3. End of position sensor: The exit sensor had to be calibrated during every sorting process and on the final demo. The idea was to use black and white parts to test if it falls off the belt when it comes to a sudden stop to move the stepper to the right bin.
4. DC Motor speed: Various speeds for the DC motor were used to sort the parts. It was already understood that the number of samples read by the ADC will be reduced at high speeds. The motor was set to 60% of the full speed after testing it if the parts can stay on the belt without falling off the belt during a sudden stop. It was also observed that when the belt comes to a sudden stop which runs at high speeds will cause the following objects to go off track and moves to the edge of the belt.
5. PORT C as output: LED's connected at PORT C were used as output for tests and debugging procedures. PORT C were set to high at certain point of the code to check if the compiler has executed that part of the code as a test. The LED's were also used to test if the sensor readings are correct by assigning each type of object to each bit of PORT C. In the project, four bits from the least significant bits were assigned to output the type of part and the rest four were used to display the quantity.
6. BADISR is a service routine in the microcontroller identify if there is any unexpected firing of interrupt. LED's on PORT C are sent to provide an output pattern when it occurs.

7.0 Limitations and System Tradeoffs

Reflective properties of the same type of parts were distinct from different sets. Due to this reason the system could not be relied upon for proper sorting. The issue was mostly found between black and white parts. Based on the information from the lab, the parts were not purchased in one lot which will make a difference as they are manufactured from different raw materials.

During trials and demo, it was not possible to sort the objects correctly when more than four parts were loaded on the belt at once. It was observed that when an object reaches the exit sensor and another object is in front of the ADC reflective sensor, the part in front of the ADC is not read. This can occur due to priorities of the interrupts used in the system and based on the fact that an interrupt cannot be fired when another one is running.

8.0 Experience and Recommendations

It was a great experience to go through the lab work and meeting the milestones. In fact, the lab instructor was very helpful in the teaching certain aspects of the system such as how to deal with the spikes in the current which are generated out of the DC motor armature. All the knowledge and skills acquired from the lab can be applied in various mechatronics applications. Learning how to code and interface between the sensors and microprocessor was the most important take away from the course.

Based on a general issue faced by most of the project groups, the reflectiveness of white and black parts has a lot of variations. Therefore it is recommended to change the material used to make either white or black parts and keep the color same. The reason to recommend this is students can be confident that there system is reliable and will work and during the demo. It can also be useful to them to use the time to improve other parts of the system to improve the time and to add hardware's such as an LCD to their system to learn more about interfacing.

It is recommended that as part of the labs, it would be a great experience for the students if another mechatronics applications making use of sensors such as gyroscope and proximity sensors.

Appendix II- Summary of Contributions

Completing the project was a great experience for both the team members. It was a lot of fun, learning and teamwork throughout the project. The knowledge and support provided by the lab instructor was the most important contribution. Research on the how to implement each system was performed by both the team members. Effective discussion between the team members was the best approach to solve an issue.

Individual Contributions

Robin Thomas:

- Brainstorming of every problem faced during the progressing stage of the project until the completion.
- Algorithm optimization.
- Troubleshooting.
- Constant improvement of speed profile to attain a dynamic speed strategy for the system based on the loads.
- Hardware integration, debugging and testing.

Chinnappa Allapanda:

- Microprocessor Code Development
- Code Debug and Testing
- Sensor Integration
- Sensor and Stepper Calibration
- Code Optimization