Design and Development of Robotic Manipulator and Conveyor System for Automated Industrial Process

Shamim Ahmed
S. M. Mahabub Ul Alam Shuvo
Muammer Din Arif
Department of Mechanical Engineering (ME)
Military Institute of Science and Technology (MIST)
Dhaka, Bangladesh
shamimahmed.polash@gmail.com
mahabubulalamshuvo@gmail.com

Abstract

In industrial and manufacturing processes conveyor belt plays a prime role in supply chain management and flow of materials or products. In recent years, with the help of robotic actuators and control systems, production processes have become more automated. Consequently, direct human contact in industrial process has reduced, saving time and improving efficiency. Such conveyor and robotic manipulator arrangements also abound in bulk material handling and processing sectors, where continuous material handling is a matter of critical concern. Belt conveyors, hydraulic/ slurry lines and platform managerial process are some of the present material handling systems. Any addition of robotic manipulators to this type of systems will enable extra degrees of freedom. Therefore, the current work details the design and development of a smart material handling, sorting and storage system utilizing a trough belt conveyor system with robotic actuator. The system is tested using objects having varying weights and shapes which are sorted via load cells and IR sensors. Two automated pneumatic cylinders are employed to eject faulty products outside of set tolerance levels for weight and shape. With a pick and place robotic arm, the faulty products are taken for further operation or waste disposal. On the other hand, products within compliance are moved to storage via the conveyor system. The system is developed to optimize power consumption, product handling time and consistency. For optimization, numerical data of the system such as belt length, belt width, motor speed, robotic arm movement speed and angle, load capacity were analyzed using SolidWorks. The amount of load and material movement were simulated using SolidWorks 2019, while relevant electrical circuits were designed and simulated through KiCad. The results obtained will enable fabrication of an optimized material handling and sorting system vital for automated industrial processes.

Keywords
Industry 4.0, Smart material handling system, Robotic manipulator, Fault detection, Sensor

1. Introduction
Conveyor belts have been performing a prime role from the very beginning of production processes. In the current industrial revolution 4.0, with advent of smart manufacturing, which marries physical production with machine learning and operates under smart digital technology, production processing has gone to another dimension. In this scenario, direct human contact in the industrial process is reduced to get maximum efficiency in the shortest possible time.

From a military context, for long-distance transportation of heavy equipment, there are heavy vehicles, but in case of indoor transportation (i.e., room or inside the building) it is a bit difficult process and for heavy products or very sophisticated equipment (i.e., shell, weapon, repairing element) manpower is still used which reduces the efficiency and increases danger. Therefore, a smart conveyor system needs to be designed and developed in such a way that

Bangladesh military can be benefitted through different circumstances like production processing to handling of fighting equipment and military hardware.

1.1 Objectives

The current paper has the following objectives to design a conveyor system for automated relocation of products and capability analysis for sorting of faulty products.

2. Literature Review

There is growing interest in creating an agile conveyer system with autonomous robotic applications for the production process. All the high-tech industries have already taken this concept in versatile developed mode to increase their efficiency and make the production process at ease. In this conference paper, the design and analysis of a smart conveyor system will be presented.

The industry 4.0 concept is referred to as the fourth industrial revolution and is the current trend in automation and a growing issue in the production processing sector. This concept was introduced in 2011 by German research and development. At present, Industry 4.0 has already crossed the German border and is becoming the dominant industry concept, which is expected to grow significantly after this worldwide pandemic.

In this pandemic, the world faced such a delicate situation which shows that still how much helpless we are to nature. Last year almost all the industries and factories were closed due to the absence of workers. The production system of the whole world stood still. Even after recovering from the pandemic the world is still in a financial dilemma. A consequence of this is the present price hike, increased delivery cost, shortage of products in the market. Aaron and Ember (2021) mentioned that Las Vegas and Orlando also had among the top 10% highest employment declines of all metro areas from November 2019 to November 2020 (the most recent data available at the metro level). This is the scenario of the world's higher GDP holding metro cities.

One of the main reasons for this situation is a dependency on human individuals in production processing. If human direct effort could be minimized in production processing, the after effect of the pandemic were dealt in a better way. An automated production system that is monitored by the sensor and feedback action will be taken according to the arduino programming.

Full digitalization of production processes is the most important issue of the industry 4.0 concept to increase the efficiency of SME (Small and Medium-sized Enterprise) manufacturing. To build a bridge between the real production system and its digital twin, an open platform communication (OPC) technology for data synchronization in both directions was implemented using OPC UA Server (OPC DCOM –Distributed Component Object Model). The OPC server must ensure three communications: the first to the digital twin model, the second to the cloud platforms, and the third to the PLC system (Zibek et al., 2020). In this context, a conveyor system is a possible solution where the product can undergo proper surveillance and any feedback action can be taken.

In controlling the automation, Iseramen (2018) took the reference of Programmable Logic Controller (PLC) from Modicum which means Modular Digital Controller which can simply be adjusted to make changes to an industrial process without having to physically re-wire several relays (Hayden, Assante, & Conway, 2014). It reduces the complicacy of changing relay connections for different actions. However, PLC controlling system cost is very high i.e., in our university, there is an industrial control work cell provided from LJ-create company which costs 25500$ USD in MRP. So, in our system, we would like to use Arduino Uno to make it cost-effective as a prototype sample.

Maximum use of sensor feedback and rectifications are the reasons for flawless production processing. In this smart conveyer system, any type of sensor can be operated. Considering the above-mentioned factors Load cell and IR sensor will be used in this conveyer system.
1kg load cell for electronic scale will be used in this system. The load cell module of HX711 has a maximum load of 3 pounds, the maximum operating temperature of 121° Celsius, and accuracy of ±0.7% (WYMA,2020).

Tunji et al (2020) mentioned that the time for ultrasonic sensor to respond to measure the height is less than 160 microseconds during on and off respectively. The ultrasonic sensor operates based on a sound wave with better accuracy than the IR sensor. However due to cost-effectiveness, IR is used. IR sensors use an infrared transmitter and receiver to emit and detect objects. Most IR obstacle avoidance sensors are an affordable option for hobby projects. Figure1 is schematic close-up of an IR sensor module (learnroboticsbd.org).

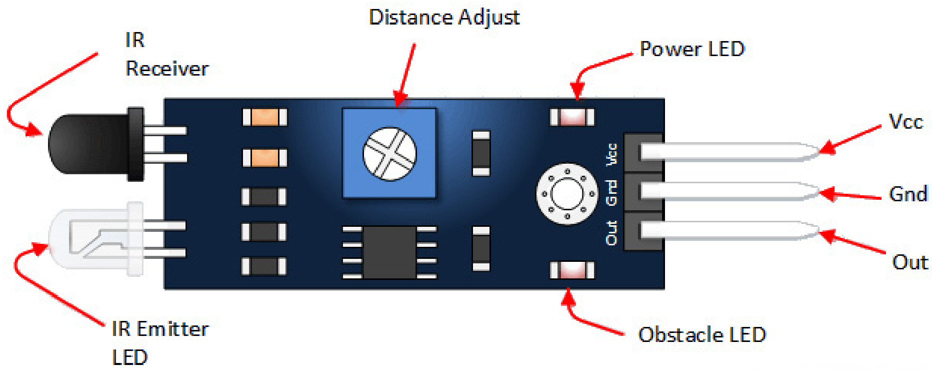

Figure1: Diagram of IR sensor

Therefore, due to cost-effectiveness, only two sensors are used in our conveyor system but there will be flexibility to use any type of sensor in this system for product analysis.

From the sensors Arduino will read the product feature. If it is not within learned value, the product will be taken off from the conveyer belt. A pneumatic cylinder will be used for pushing off the products from the conveyor. From research at Zhejiang University, China is shown that by using the PLC circuit, the experimental results showed that the energy recovery efficiency exceeded 23%. When the critical pressure was set to 0 bar, 0.5 bar, 1 bar, and 1.5 bar, the times for pneumatic actuation to complete the three working cycles were 4.9 s, 5.1 s, 5.2 s, and 5.3 s, respectively (Zhai et al.,2021). In this aspect, linear cylinders and pneumatic cylinders both can be used. Due to the availability of pneumatic cylinders in the local market, we have used them in our system.

Dynamic seals represent pneumatic actuators' most critical components because it withstands high air pressure. Belforte et al (2008) in their research showed that under different contact pressure elastomeric seals can withstand higher pressure with less friction and more reliability of the cylinder. Availability of air compressor and air pump will enable to operate pneumatic cylinder without any interruption.

To construct a conveyor system is not only about just carrying the product, power consumption, friction, operating time, and life of the conveyor system are a matter of concern. Based on the results of the current study, power demand savings can be achieved in long belt conveyor systems through increased idler roll size, using relatively narrow idler spacing, and operating such systems at relatively high belt speeds (Youssef,2016).

Use of "Kevlar" Aramid Fibers in Conveyor Belts Research shows the improvement of splices in "Kevlar" reinforced belts. Various splice configurations have been examined and it has been shown that splice strengths greater than the parent belt are possible (Roberts et al.,2008).

Mohit et al. (2018) showed in their research that the presence of carcass material in the conveyor belt is effective, and the deformation of carcass material belt conveyor is less compared to the simple conveyor belt. There are four cases shown in which the first is simple belt conveyor, second is simple carcass material, third is banana fiber carcass material and fourth is pineapple fiber material. The minimum deformations are found in pineapple fiber.

This system is designed in such a way that it optimizes the various operational parameters of interest while considering the economic value as well. The materials used in this are in consideration of market availability and cost-effectiveness. For this reason, instead of pineapple fiber we have used regular conveyer belt material like rubber and polyester cloth.

3. Methodology and Setup

The following steps are followed in the construction of the system:

3.1. Design of a conveyer system: Design and simulation was done in Solidworks 2019.

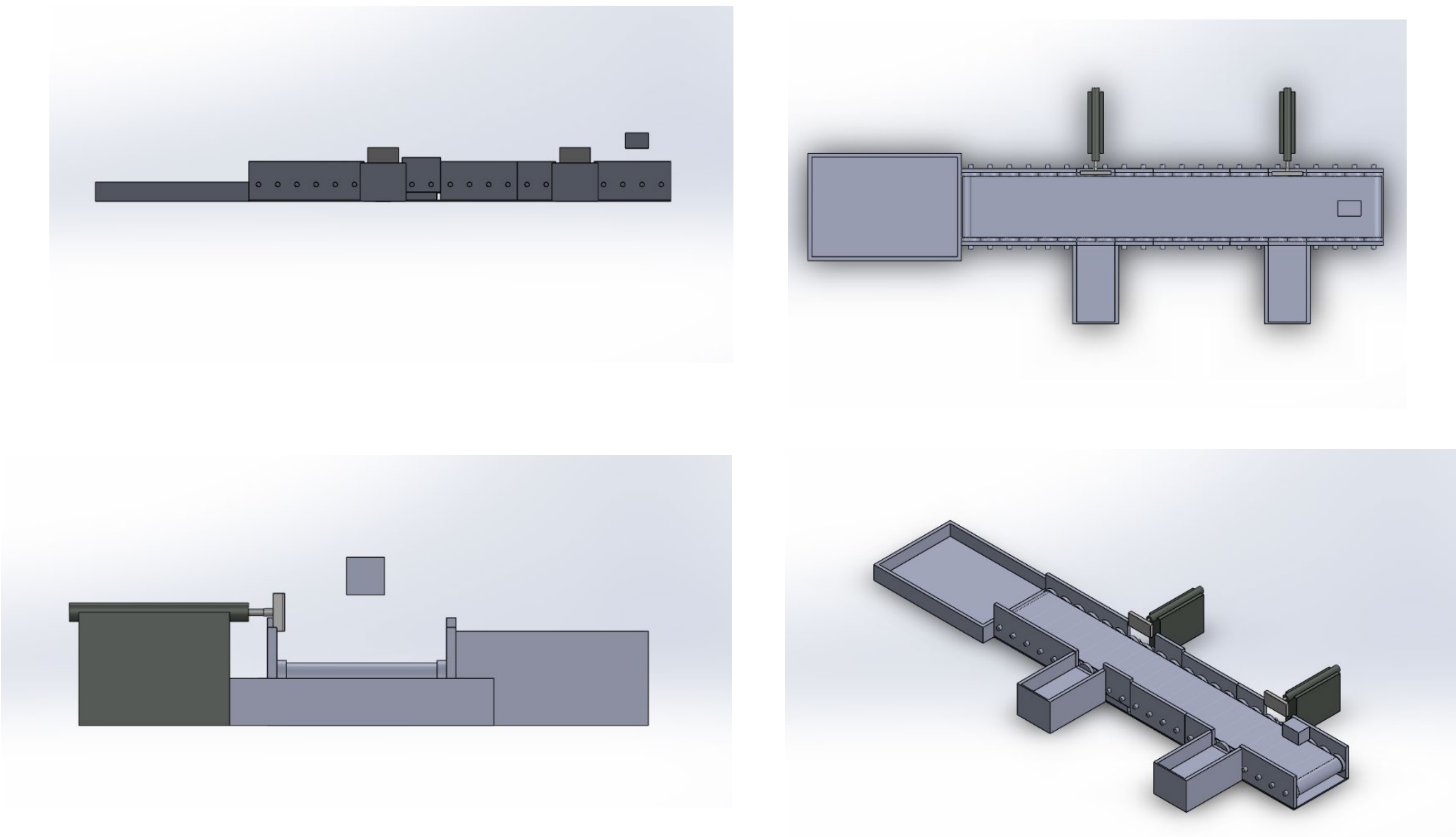

Figure 2: Solid model views of the conveyer system.

3.2. Integration of different sensors: Sensors will do checking process. Sensors are used instead of having a human being to determine the product quality. Accuracy, Precision, Wide operation range, High response speed, High reliability, Low cost are the prime factors to choosing a sensor (Iseramen 2018). Different types of sensors can be used for justifications of products.

1. Load cell: To check the product weight
2. Infra-Red (IR) sensor: To check the size
3. Image processing: To check the pattern
4. Magnetic sensor: To check materials
5. Ultrasonic sensor: To check product defect
6. Temperature sensor: For thermographic test.

In the first portion of the conveyor, the Load cell is used as a pressure sensor which is placed idler roller under the conveyor belt. Whenever the product passes over the load cell it takes the data and sends it to the control unit. In the next portion, an IR sensor is used for height measurement. When the product is 3cm ahead of IR it takes the data and sends it to the control unit.

3.3. Data analysis in control unit: Arduino Uno is used as the control unit in this system**.** Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. (Prakash and Pradip 2013). Again, in the case of factory purposes, Arduino Uno will not suffice due to load capacity shortage of port connections. After receiving data from sensors Arduino will function according to its program.

3.4. Feed-back action programming: If the load cell reads the data out of the range of the Arduino program, it will send a signal to the actuator to operate the pneumatic cylinder. The same action will take place for the IR sensor. If the product is in the range of the designated parameters, it will pass through the conveyer belt without any interception.

3.5. Implementation of the pneumatic cylinder as robotic actuator: From the control unit, it gets the signal to operate stroke over conveyer and its pushes of the faulty products. It operates by using the air pressure of the air compressor which is available in the MIST automobile laboratory.

3.6. Reservation of faulty products for further action: The faulty products are reserved in an arranged manner so that from there they can be taken to a further workstation for further action.

In this following flow diagram, our system action is introduced:

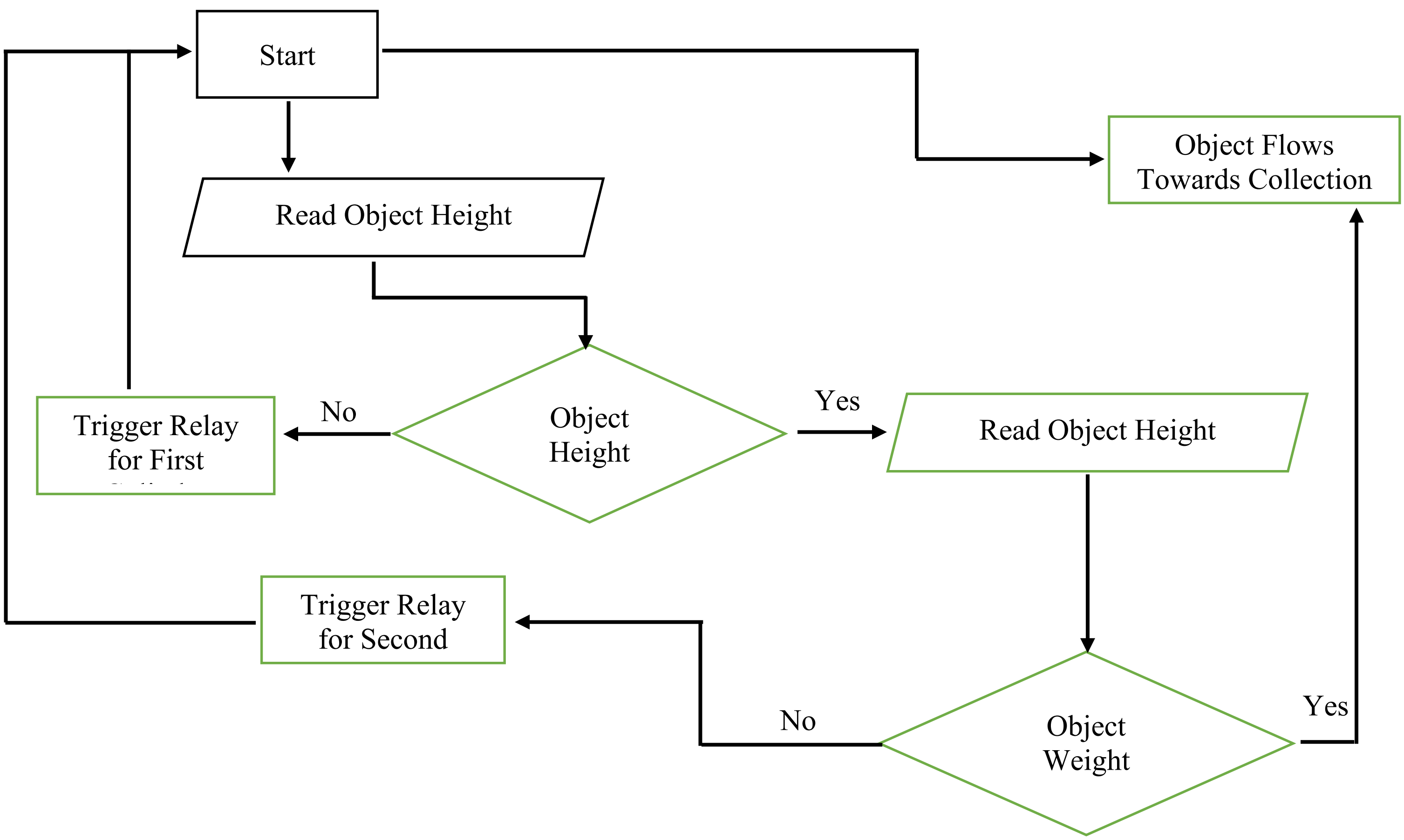

Figure 3: Flow diagram of the system.

4. Data Collection

Components with specifications we have used in our system:

- DC motor: 100 rpm
- Conveyor belt: Width 3 inch and l8inch
- Airline pipe: 0.5 mm diameter
- Pneumatic Bore Cylinder: Stroke 3inch and Bore 1inch
- Pneumatic Valve: 24V DC operable
- Relay module: Dual channel, 5V
- Power supply: 24V, 5A rated
- Voltage converter: (24v-12v)
- Load cell: Max 400gm to 1000gm

5. Results and Discussion

We have done our design and simulation in SolidWorks showed in figure 5.

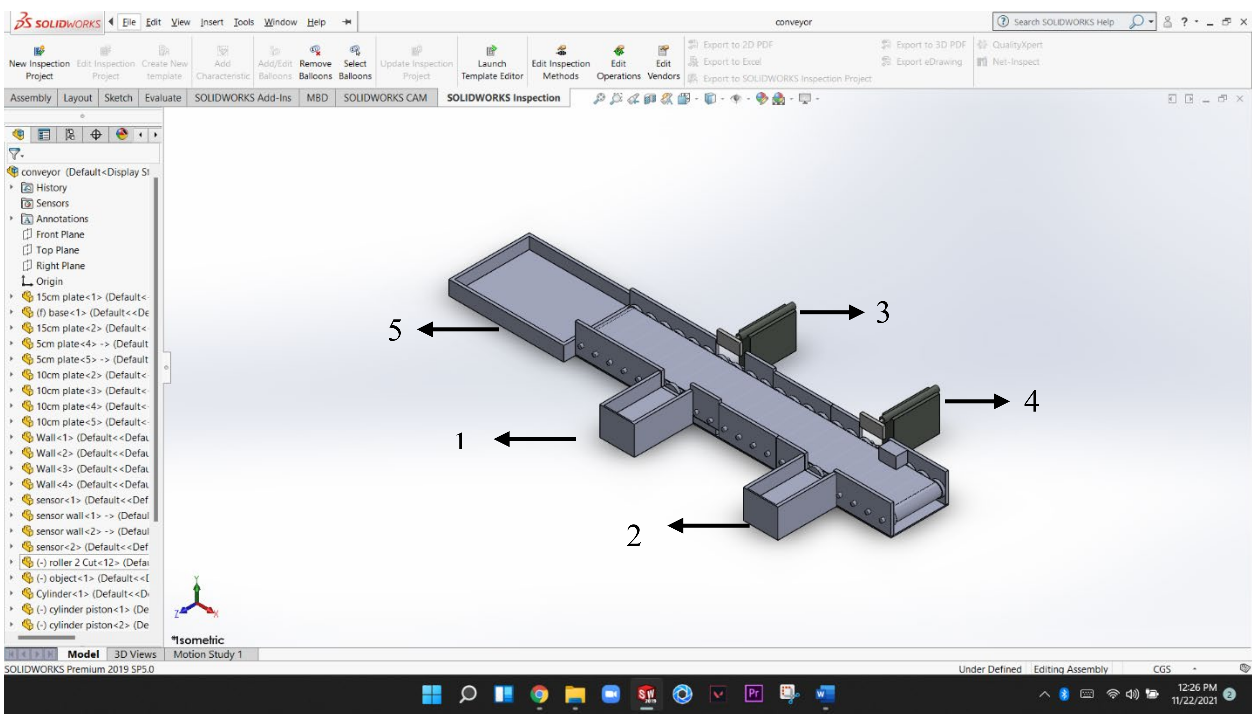

Figure 4: Solidworks Design

The design was created using SolidWorks 2019. The conveyor system filters the products according to the range of height and weight range. Products that are not of the specified dimension are pushed in drawer 2 by Pneumatic cylinder 4 and the product's weights more or less than the range are pushed outside in drawer 1 by Pneumatic cylinder 3. The products with perfect shape and weight only will pass the Pneumatic cylinders and will reach drawer 5.

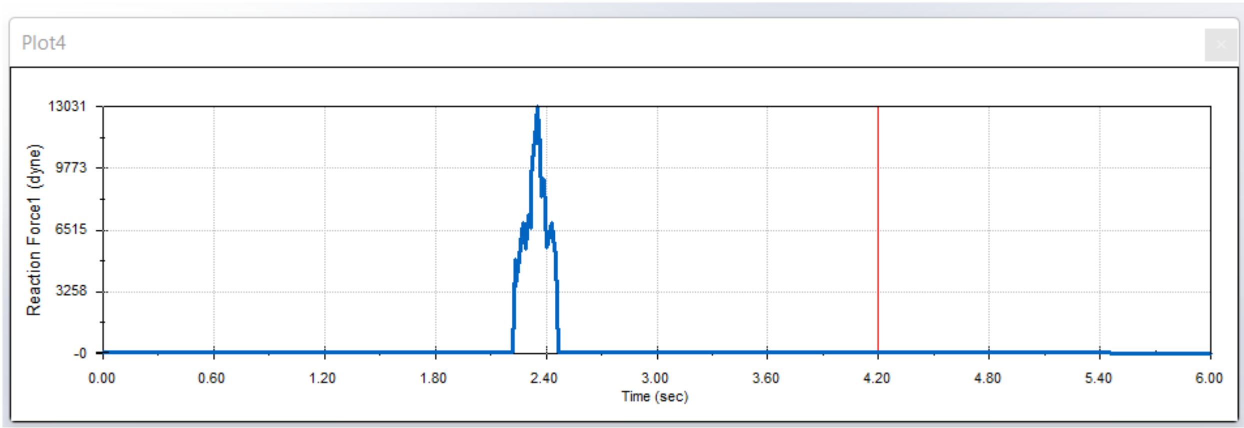

Figure 5: Reaction Force Vs Time graph

This is the reading that the pressure sensor will detect. The weight limit will be checked from this reading and will be allowed to pass the Pneumatic cylinder or will be pushed in drawer 1. For the correct reading, the IR sensor over the cylinder will be turned off for a specific time so that the product passes the cylinder without being pushed out. The same will be done to measure the IR sensors to measure the dimension. In case of obstruction, the system will take it as anomalies and will activate the sensor on the cylinder for a specific time so that the cylinder can get activated for a specific amount of time which is showed in following graph in figure 6.

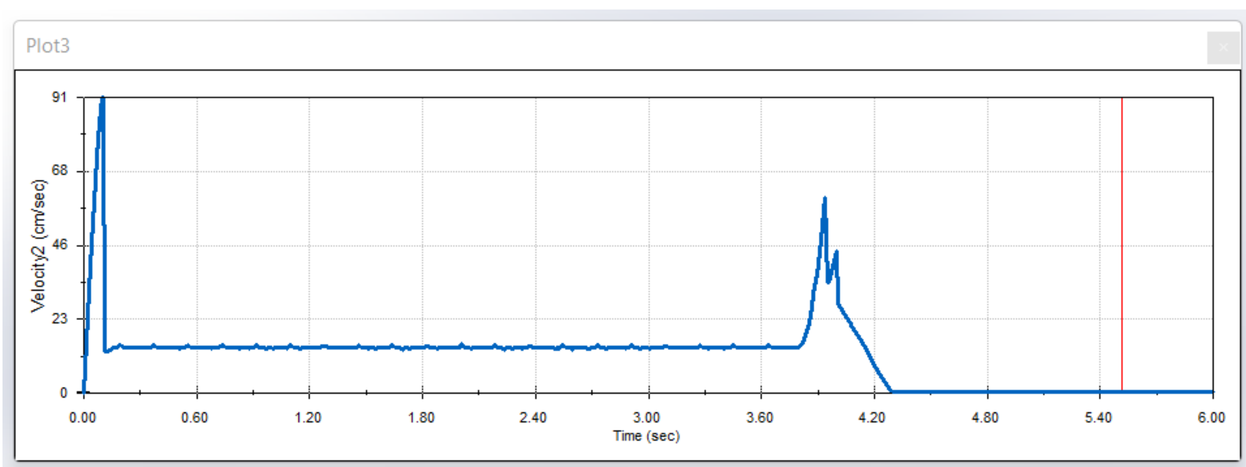

Figure 6: Velocity Vs Time graph

This is the speed that the product will face. The acceleration at the beginning is for the drop while the product is placed. The second anomaly was when the product was placed in the reservoir.

Circuit board for this conveyer system is designed from KiCad to control the system which is indicated in the figure 7.

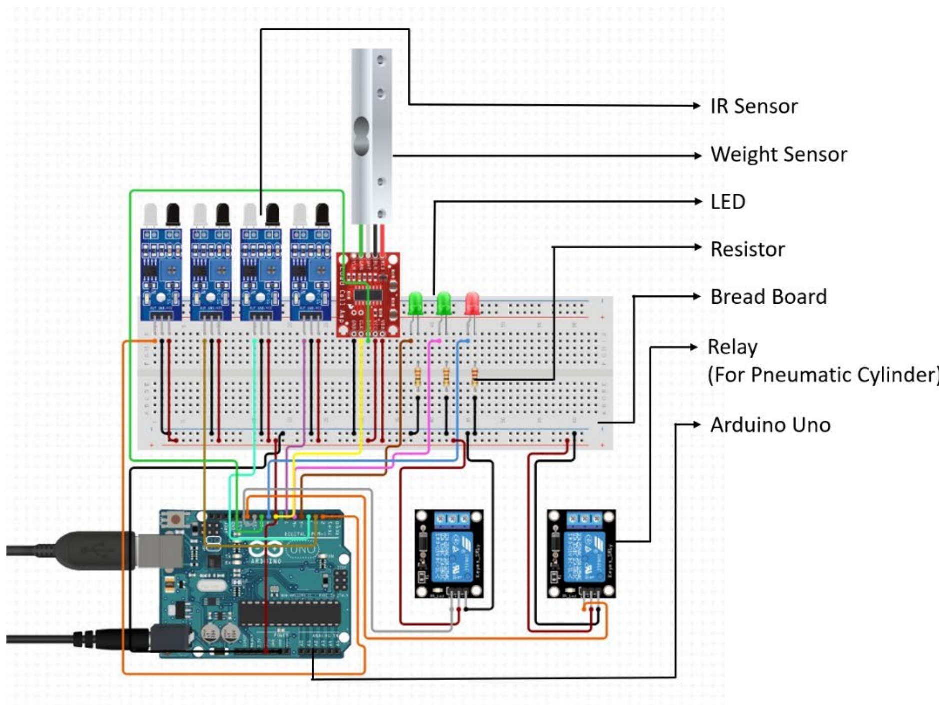

Figure 7: Circuit Board design

So far from the simulation and prototype system, our conveyer belt is successful at an interval of 7cm in each product. This interval is required for neat data collection and operation. In further research, this interval needs to be reduced which enhances the capability of the conveyor system.

5.1 Numerical Results

This conveyor system can measure the weight of the product in the range of 400 to 600 gm. The accuracy rate is 96%. Height of 3 to 5cm can be measured in and the accuracy rate is 98%. After sorting the faulty products, 2.5second is required to take off from the conveyer. Pneumatic cylinder operates in 200 milliseconds under5bar air pressure. These values are obtained from simulation analysis and physical observation.

5.2 Proposed Improvements

The system we have worked with it is a single segment of production processing. This smart system can be developed with
further enhancements. Scope of improvements are:

5.2.1. Smart packaging: by using a programmed servo motor we can package our products in different subdivisions, i.e., 400gm products in 1st box,500gm products in 2^{nd,} etc.

5.2.2. Using robotic arm for further operation: Faulty products are reserved in a box. A pick and place 3 degrees of freedom (DOF) robot can take the faulty product in another workstation i.e., under a lathe machine or any nondestructive test.

5.2.3. Using the system for loading and unloading the heavy weapon: This system can be used for loading tank or artillery big guns.

5.4 Validation

Bassey et al. (2018) mention his findings from the experimental analysis that the time it takes the product to move from the entrance sensor to the exit sensor covering 0.8m is between 15.7second to 16.3second. At 0.096 meters

between IR and photodiode sensors, the response time to display on LCD is approximately 1.0 seconds. Therefore, showing that the belt around the rollers is running at a speed of 0.05m/s, which is the designed speed.
Other than the total length of the conveyer the ratio of timing by Bassey et al (2018) in our simulation is nearby to our data given in numerical analysis. Due to idler roller friction, voltage up-down, different types of conveyor belts, this finding may vary.

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Biography

Lieutenant S. M. Mahabub Ul Alam Shuvo is a final year undergraduate in the Department of Mechanical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh. He has started his undergraduate study in 2017. Mr. Shuvo is currently serving as Lieutenant in Bangladesh Army and conducting his final year thesis on "Design and Development of Robotic Manipulator and Conveyor System for Automated Industrial Process". His research interests include designing, simulation, and material handling.

Lieutenant Shamim Ahmed is a final year undergraduate in the Department of Mechanical Engineering, Military Institute of Science and Technology, Dhaka, Bangladesh. He has started his undergraduate study in 2017. Mr. Shamim is currently serving as Lieutenant in Bangladesh Army and conducting his final year thesis on "Design and

Development of Robotic Manipulator and Conveyor System for Automated Industrial Process". His research interests include designing, simulation, and material handling.

Muammer Din Arif, Ph.D. is an Assistant Professor in the Mechanical Engineering Department of Military Institute of Science and Technology (MIST), Dhaka, Bangladesh. He earned his B.Sc. in Mechanical Engineering from Michigan Technological University, USA; M.Sc. in Mechanical Engineering from IUT, OIC, and Ph.D. in Manufacturing Engineering from IIUM, Malaysia. Dr. Arif has served in various universities and industries in Bangladesh. He has published several peer-reviewed journal articles, conference papers, and book chapters from his research. His research activities include Renewable energy, Chatter modeling and control, and Data-driven manufacturing process modeling. He has an affiliation with IEB (Bangladesh) and the American Order of the Engineer.