Automatic Lego Sorting Machine

Final Report

Team 10A

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DISCLAIMER

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EXECUTIVE SUMMARY

We want to configuration, assemble, test, and repeat where required on an Automatic Lego Sorting Machine that sorts by Lego piece type for every single great piece (block, plate, rail, and so forth) and some particular pieces that bode well to structure for. The framework must NOT require human cooperation after Legos are stacked into the machine and until they can be put away in the wake of arranging.

The anticipated Milestones During the Project. First, Sort an agent test of LEGO pieces by hand to get the comprehensive view of this issue. Second, research Sensors and arranging strategies that could be utilized in this structure space. Thierd, model Sensor application and individual arranging methods. Then we need to do a framework Integration of all subsystems required to totally sort the Lego accumulation. Full framework testing and cycle as required. Last, delivery to the client

So, our project is a LEGO sorting machine. It will sort LEGOs by functionality and sizes. It is a challenging project. Our client is Pr. David Willy. Our sponsor is Northern Arizona University. The budget is 500$. The design will be simple and save to use. It will have cover pilt, scale and motors. those are the main parts. Also in will be connected by Arduino in order for all of them work in order. The Arduino will have coding that will make it work in our project. In the other hand we will have walls for separating the LEGOs one by one. The results going to be that we can separate LEGOs be Functionality and sizes. The machine will be easy to carry and it can fit in a table. However, in the report more details about our project. The report will give the needed details for the project and the CAD (the shape of our project). Also, it will have the prices of our parts that we need in order to finish the LEGO sorting machine. All in all, it is a challenging project that we will do our pest in order for us to finish it and make it a successful project

ACKNOWLEDGEMENTS

The tem were guided and mentored by the team's instructor and the client David Willy. Who supported us throughout the semester by providing us with the best feedback as the client also, as the team's instructor he leading us to solve problem that we faced throughout the design process.

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1. BACKGROUND

1.1 Introduction

Sorting of Legos is a tough task, as building the Legos is good time spending but sorting the Lego after build is an annoying thing. For that bins can use, and Legos have to sort by hand with respect to their size and functionality in order to find the parts quickly for next time. The other option is throwing the Legos into bin and take more time to find the perfect parts. So this problem need to sort out because large time consume in either case, whether sort the Legos or whether throw them and find the part in next build. This problem can be solved using an automatic process with the help of some sensors, and logic control. This is a common technique uses in all industries in different ways like arranging the boxes over the conveyor belt, making the assembly line.

Sponsors have shown interest in this project because it saves the time and effort that they spend on sorting legos . Furthermore, it provides a competitive idea that can apply to any shape of Lego and make the sorting in short period of time and make it perfect that it doesn't need to do any final amendments through hand. This project will provide benefits to the stakeholders, client and sponsors as well in a sense that the algorithm utilizes to do the automatic sorting will be advance and it can utilize for commercial purposes as well. So this project is important to do as it provide the ease in arranging any sort of Legos and save the time and also save from facing the annoying situation happens during the sorting of Legos manually.

1.2 Project Description

Following is the original project description provided by the sponsor. "Design an automatic Lego Sorting Machine that sorts by Lego piece type for all classic pieces (brick, plate, rail, etc.) and some specialized pieces that make sense to design for. The system must NOT require human interaction after Legos are loaded into the machine and until they can be stored after sorting."

Requirements given by the Sponsor:

- Can use standard wall power (120VAC, 60hz)
- Must be safe enough that a child can run the system.
- Must sort automatically by Lego type.
- Cannot exceed $500, unless further fundraising can be obtained.
- May be judged by a room full of kids or parents.

2. REQUIREMENTS

This sections contains the requirements for the project provided by the client. This section will organize the requirements in table and manage them according to their importance. The requirements given by the client are customer requirements and then after the customer requirement engineering requirements are developed. The engineering requirements will be given technical values related to the project. However, testing procedures will be present as well. These will explain how the engineering requirements will measure and test at the end. The House of Quality will be present that will relate the engineering requirements with the customer requirements and identify the priority list of engineering requirements. House of Quality provides the targeted as values as well engineering requirements need to be met at the end of completion of work.

2.1 Customer Requirements (CRs)

Customer requirements have obtained from the description provided for the project. Description has provided in simple way so customer requirements obtain the major works to do for the project. These requirements have simplified in the table to explain that these points need to fulfill by the project. Customer requirements are the most important aspect of project and these requirements need to understand before doing the project. CRs obtained for this project have given below in table 1.

Table 1: Customer Requirements

Customer Requirements
1. Portable Design
2. Long life
3. Easy to assemble
4. Separate legos
5. Cost
6. Safety

There are six customer requirements which have provided by the customer and to do this project. Both separate Legos and safety are on the top the list when it come to importance because this is the main goal of the project. As a household device, cost and portable design comes in the second place because it will not be very attractive if the cost is too high or the device has to sit in one place. Finally, easy to assemble and longlife comes in third place.

2.2 Engineering Requirements (ERs)

Engineering requirements are the technical values for doing the project. These technical values are the technical requirements of this project, these have developed in order to measure whether the objective of project has achieved or not. As the customer requirements cannot measure directly therefore ER's have developed so it can measure. Engineering requirements have given below in table 2.

Table 2: Engineering Requirements

Engineering Requirements	Targeted Values - Tolerance
1. Size	2x2x3
2. Safety	Enclosed
3. Sort by lego type	85%
4. Fully enclosed system	Enclosed
5. Lifespan	3 years
6. Normal power source	120V-15 Amp
7. Operating Sound	< 55 dB
8. Weight	< 51 lb
9. Cost	< $500
10. Factor of Safety	< 1.2
11. Fused	15 Amp

The technical values have given in order to test the values and check if these values have met or not.

2.3 Testing procedures (TPs)

1. Size:

Height, length and width of the device were measured by using a ruler. The height is 2 feet, the length is 2 feet and the width is 3 feet. The device or prototype will be set to measurements to meet the target.

2. Safety:

The safety of the device is measured by using OSHA limitation for safety standards.

3. Sort by Lego Type:

The sorting process will be based on the result of the machines sorting output. The number of lego pieces will be counted targeting 85% of the input.

4. Fully Enclosed System (OSHA):

A fully enclosed system is explained by OSHA enclosed systems standards. It states the a fully closed systems should be fully out of reach the user hands.

5. Lifespan:

The lifespan of the device is set by the client to be three years in use without any defaults. As a testing procedure, the device will be tested by calculating what it can handle as a household machine during three years period of time.

6. Normal Power Source:

Power source is the main point in powering the device. The device will be tested as simple as it looks like. It will be powered to 120V power source and it should handle 15 Amps. If the device works the it did pass the test.

7. Operating Sound:

The operating sound of the device will be measured by using OSHA limitation for average human residential boundary-noise limit which is less than 55 dB.

8. Weight:

The weight of the device was measured by using OSHA limitation for average human weigh that can be lifted without any injuries. which was less than 51 Ib.

9. Cost:

The cost of the advice is set after meeting with the client which is $500 USD or less.

10. Factor of Safety:

The factor of safety is a hard character to determine so it was suggested by the GTA and the client to by on the safe side which is less than 1.2.

11. Fused:

Powering the whole machine as a household device must be safe. So a fuse will be put to mearse the current through the device. if the fuse fails, the device fails. The fuse set up to 15 Amps tobe on the safe side of the house environment.

2.4 House of Quality (HoQ)

House of Quality is known as QFD as well, it is a matrix with different portions, and the purpose of HoQ is basically to make the relationship between the Customer Requirements and Engineering Requirements. In the matrix, a raw weightage assign to the customer requirements and then compare it with each engineering requirement and according to the similarity present in the customer requirement and engineering requirement a number grade assign to the corresponding box. In this way, the matrix generates and then technical absolute values, and relative values calculates. These values show which engineering requirement is most important and which requirement is least important. HoQ for this project has given in table 3. From the absolute technical importance, we can see that cost got the highest importance. For the project sake, the design process had to re arrange this particular category. So it had to go after sort by lego type and safety. Those three engineering requirements will be most focused on.

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Table 3: House of Quality (HoQ)

House of Quality (HoQ)	Team: Lego Sorting Machine Team 10 A , Section 001												
Customer Requirement	**Weight**	**Engineering Requirement**	1. Size (ft)	2. Safety (OSHA)	3. Sort by lego type	4. Fully enclosed system (OSHA)	5. Life (3 years)	6. Normal power source (120V) (15 Amp)	7. Operating Sound (>55 dB) (OSHA)	8. Weight (>51 lb) (OSHA)	9. Cost ($)	10. Factor of Safety	11. Fused
1. Portable Design	4		5	1		3				5			
2. Longlife	3			3			5	2			2	3	3
3. Easy to assemble	3		2	2	2	3	1			1	2		
4. Separate legos	5				5				2		4		
5. Cost	4		3	3	5		3	3	2	2	5	3	3
6. Safety	5		1	5	1	5		3		3	3	5	5
Absolute Technical Importance (ATI)			35	38	37	35	33	32	28	35	40	35	35
Relative Technical Importance (RTI)			4	2	3	4	5	6	7	4	1	4	4
Target ER values			2x2x3	-	85%	-	3	120	-	18lb	$500	1.2	
Tolerances of ERs			1 ft + or -	-	5% + or -	-	3	120	-	<25lb	<500	<1.2	
Testing Procedure (TP#)			Measure	-	Sum	-	-	-	Measure	Weight	-	-	-

3. DESIGN SPACE RESEARCH

As the design project need lot of research to see others work and take help from the sources to do the design project. For doing any design project, different sources need to search which can help like peer reviewed journal articles, engineering books, patent designs, existing designs, engineering reports, and website sources. Adding to that the team learned from class is breaking down the subsystems. These type of sources provide different kind of solutions from which some ideas can take and these ideas can help in implementing the design. Benchmarking is another way of doing the research, in benchmarking interview can conduct with professionals and take some help. The idea is to open different ways and to make creative design idea for the project.

3.1 Literature Review

3.1.1 Student 1(Sultan Alharbi)

3.1.1.1 Model Design and Simulation of Automatic Sorting Machine

Different sensors that can use to sort the Legos, and the main focus of this journal article is on proximity sensor, which use to do the sorting algorithms. Proximity sensor uses the electromagnetic field to detect the nearby objects. With the help of proximity sensor Legos will determine and the size of Legos will also manage through the proximity sensor. [1].

The created computerized sorting machine can consolidate adaptability and separate types of non-ferrous metal items and in the meantime move protests naturally to the bin as characterized by the direction of the Programmable Logic Controllers (PLC) with a capacitive closeness sensor to identify an esteem scope of articles. The outcome got demonstrates that plastic, wood, and steel were arranged into their individual and right position [1].

3.1.1.2 Introduction to Arduino

The textbook reference regarding the Arduino, as we have to build an automatic sorting machine so we have to use a microcontroller that will make the decisions and will pass the instructions to all parts of the device and send the tasks to perform. For the microcontroller, Arduino is one of the best option to use and this reference is explaining the use of Arduino and the working of Arduino and also providing the complete practice on using it and the coding of Arduino. A controller is such a small device which collectively perform many operations using a single chip, and the controller is small integrated circuit with memory, processor core and inputs/outputs [2]. We can use this reference in building the project for microcontroller because we have to understand the microcontroller and its programming as well before using it and this reference can use to learn the programming and working on controller [2].

3.1.1.3 Automation and Robotics

This is mechanical engineering textbook and this is useful for our project because in this textbook automation technologies have defined. In this textbook, different techniques have defined which can use for the automation in the robotics, these techniques include the proximity sensors and other related things. Some conveyor lines have defined in the series which are useful for building the project as the conveyor line process makes it possible to do the automatic of sorting for moving the LEGOS from one side to another side [3]. As the algorithms have presented in the book as well which can utilize for sorting in automatic condition. In chapter 5, robot grip mechanism has discussed, in which control system and the feedback systems have discussed and these controllers are strongly recommended to use in the automatic system and we can use these controllers in our project to develop an accurate and concise system of sorting the LEGOS [3]. So this reference is quite helpful for us in this regard.

3.1.1.4 Machine Control System Operation for Automatic Sorting

The framework and the machine control program for programmed eggs sorting into classes dependent on size and shape utilizing a specialized vision framework [4]. The foremost distinction between the considered machines for sorting eggs into classes and the current sorting machines, is the detachment of eggs into classifications by size incorporating substandard eggs in the stream. For capturing of eggs in the stream keen camera type NI-1772-EF00303A is chosen, and programmed partition of egg into classifications is conveyed by pneumatic actuators valve, which empowers twofold profitability increment. The program for shrewd cameras is made in the earth. The focal hub task control arrangement of the machine is the controller programming. Controller "OWEN PLC 110-160" supporting perception is executed in CoDeSys 2.3 condition. Trial confirmation demonstrated that the framework permits control of the machine activity units in powerful mode and programmed sorting of eggs in classifications in the stream [4].

So this article has used sorting machine and the phenomena used in this article can help us in using the LEGOS sorting like the conveyor used the egg sorting accordingly and we can implement similar sensors and camera applications in building design project.

3.1.1.5 Machine Vision and Object Sorting

This article is about the machine and the sorting of various items based on their shapes and sizes. A small scale generation line was developed and mechanized utilizing STEP 7 programming, and Simatic-300 based Programmable Logical Controller (PLC); both are fabricated by Siemens [5]. The machine vision part of the theory was done in NI LabVIEW, a graphical program improvement condition from National Instruments [5]. The correspondence between the PLC and LabVIEW was done utilizing OLE for Process Control, an extra for LabVIEW [5].

This reference is also helpful in building the project as it has used the Programmable controller for applying the sorting algorithms and therefore it can help us in building the sorting machine using PLC and using the software LabVIEW.

3.1.2 Student 2 (Fahad Alotaibi).

3.1.2.1 Mechanical Engineering Design

As the project is Automatic Lego sorting machine and for this project a textbook reference is using as a starting point to understand. This textbook is a good reference for helping in building the project because it has lot of details regarding the materials, springs, and gears, which can help in the project. As the project will sort Legos so materials will help in understanding the best materials for the Legos and identify the stress, materials can bear which are perfect to use for Legos, springs will use to move the Legos from one place to another place, gears will also help in moving the Legos for sorting them. In materials, material strength and stiffness is useful to select the best material for the Lego because the Legos must be strong enough to bear any external force or if drop down then don't get broken [6]. The selection of a material for a machine part or a structural member is one of the most important decisions the designer is called on to make. The decision is usually made before the dimensions of the part are established. After choosing the process of creating the desired geometry and the material (the two cannot be divorced), the designer can proportion the member so that loss of function can be avoided or the chance of loss of function can be held to an acceptable risk [6]. Hardness of the material is important factor as well to select the final material and it can learn from the reference that hardness can determine for different materials [6]. The resistance of a material to penetration by a pointed tool is called hardness. Though there are many hardness-measuring systems, we shall consider here only the two in greatest use [6].

Gears can better understand through this reference as all type of gears have explained in the textbook so it will be useful when implementing the project which gear can use to move Legos. This chapter addresses gear geometry, the kinematic relations, and the forces transmitted by the four principal types of gears: spur, helical, bevel, and worm gears. The forces transmitted between meshing gears supply torsional moments to shafts for motion and power transmission and create forces and moments that affect the shaft and its bearings. The next two chapters will address stress, strength, safety, and reliability of the four types of gear [6].

3.1.2.2 Proximity Sensors

The textbook related to the proximity sensors as proximity sensors can use in our project to determine the positions of LEGOS and carrying them from one point to another point. Proximity sensors works on the basis of rays which detects the distance from the object and in this way we can apply the sorting algorithm and get the required arrangement of LEGOS. For this purpose, proximity sensors textbook has taken as a reference to understand different kind of proximity sensors and determine which proximity sensor can use in our project and serve the purpose in its best way. In this book, different kind of proximity sensors have discussed which includes optical proximity sensors, ultrasonic proximity sensors, pneumatic proximity sensors, capacitive proximity sensors, inductive proximity sensors, magnetic proximity sensors and mechanical sensors [7]. All these sensors have different criteria and usage and their usage has defined along with their operational working and because of the detailed description of each sensor make it easy to determine which sensor is best to use for the project [7]. This source is quite useful in this project because we are going to use the sensors for building the project and it will be helpful for us to understand which sensor is best to use according to our requirements.

3.1.2.3 Lego Bricks Color Sorting Machine

LEGO Bricks Color Sorting Machine is a framework with capacity to sort LEGO bricks as per their color. This framework configuration utilizes Arduino Mega as a controller. In this task, PIXY sensor is utilized to recognize the color of the article after it was physically sustained by clients at nourishing slide [8]. In view of the sensor readings, the framework will consequently begin to sort them to their correct area or station. The best splitter space will move to one side or directly so as to alter the area for the drop [8]. The upside of this framework is the capacity of the framework to sort LEGO bricks dependent on its color, and contains a station for rejected article on the off chance that it doesn't meet the framework prerequisites, for instance color isn't identified or object isn't perceived. The framework sorts the item in quickest time and with no blunders. The exploratory outcomes bolster the objectives which is to build up the LOGO bricks color sorting machine with decreased sorting time and better quality in the field of robotics [8]. This source has complete LEGOS sorting solution and the machine presented in this article has developed for the LEGOS on the basis of color. So this solution can utilize for building the design of LEGOS sorting machine.

3.1.2.4 Automatic Color Sorting machine

Sorting of items is an extremely troublesome modern process. Nonstop manual sorting makes consistency issues. This paper portrays a working model intended for programmed sorting of articles dependent on the color [9]. TCS230 sensor was utilized to recognize the color of the item and the PIC16F628A microcontroller was utilized to control the general procedure [9]. The distinguishing proof of the color depends on the recurrence examination of the yield of TCS230 sensor. Two transport lines were utilized, each constrained by isolated DC engines. The primary belt is for setting the item to be broke down by the color sensor, and the second belt is for moving the holder, having isolated compartments, so as to isolate the items [9]. The exploratory outcomes guarantee that the model will satisfy the requirements for higher generation and exact quality in the field of robotic [9].

This reference has a complete design about sorting through different colors and this design can utilize for building the design of automatic LEGOS sorting, as this design has color sorting, and it can help us in finalizing our own design.

3.1.2.5 Color image based sorter for separating red and white

A straightforward imaging framework was produced to examine and sort wheat tests and different grains at moderate feed-rates [10]. A solitary camera caught color pictures of three sides of every portion by utilizing mirrors, and the pictures were prepared utilizing a (PC). Continuous picture procurement and preparing was empowered on a common PC under Windows XP working framework utilizing the IEEE 1394 information exchange convention, DirectX application programming, and double center PC processor. Picture obtaining and exchange to the PC required roughly 17ms per piece, and an extra 1.5ms was required for picture handling. After order, the PC could yield a flag from the parallel port to enact an air valve to occupy (sort) bits into an auxiliary compartment [10]. Hard red and hard white wheat parts were utilized in this examination to test and show sorter capacity. Basic picture measurements and histograms were utilized as highlights. Discriminant examination was performed with one, two, or three highlights to exhibit characterization enhancements with expanded quantities of highlights. The sorter could isolate hard red portions from hard white bits with 95 to 99% precision, contingent upon the wheat assortments, feed-rate, and number of grouping highlights [10]. The framework is a prudent and helpful instrument for sorting wheat and different grains with high exactness [10]. This source is also useful in our project because of the design for separating the red and white color and we can continue developing this technique on the basis of LEGOS.

3.1.3 Student 3 (Abdullah Almutairi)

3.1.3.1 BrickLink

It is a website that shows for me all the sizes and the shapes of the lago parts. The most important thing for us is the weight of the lagos. It will help us to find everything about the parts that we need to sort. However, a good source for us that will help [11].

3.1.3.2 The art of LEGO design

This source was the best start for our team. The start that give us a brief description about what we want to sort will help our team alot. All in all, we need to know what we are sorting in order for our team to success[12].

3.1.3.3 SolidWorks 2011 Assemblies Bible.

The book will give as much as we want to see more better by drowning every part. However, when we draw them it will be as clear as we want to see. For example, when we want to see the part better we will draw it and we will see the things that we want to change if it need to be changed[13].

3.1.3.4 Programming Arduino.

The book will make us know how to start with arduinos. It will give a good information about how to start with programming these things in order to make them work for our project. the book will help because we are a mechanical engineers not a programming engineers so, we need to learn how to do it. all in all, learning is what we do[14].

3.1.3.5 Automatic sorting system.

In extensive scale production of numerous gadgets and components, it is unreasonable to make every individual gadget Within amazingly close resiliencia. It is, in this manner, normal to fabricate a gathering of gadgets using generously a similar procedure and from there on test the individual gadgets for motivations behind ordering them into gatherings I whose qualities fall inside worthy breaking points or above or beneath such cutoff points. Such a training is particularly normal in the assembling of electronic segments, for example, curls, condensers, resistors, diodes, transistors, and so on.

For instance, at least four diverse sort of transistors may result from a solitary creation run. The main distinction in the different sorts of transistors coming about because of the creation run might be, for instance, an alternate scope of current intensification factors or a distinction in authority breakdown voltage or contrasts in one of the other transistor parameters which are viewed as basic. Albeit every one of the transistors is made utilizing indistinguishable procedures to the best degree conceivable, even little contrasts in the measure of pollution material diffused into the semiconductor body or a little warmth differential in the diffusing heaters can deliver distinctive gadget qualities. In this manner, it is known measurably that shifting rates of every one of a few diverse sort gadgets will be gotten from every creation run[15].

3.1.4 Student 4 (Husain Alkandari)

3.1.4.1 Actuators. In Hydraulics and Pneumatics - A Technician's and Engineer's Guide

Hydraulics and Pneumatics: A Technician's and Engineer's Guide serves as a guide to the hydraulic and pneumatic systems operations. It features mathematical content that has been presented in a style understandable even to beginners and non-experts. It has nine chapters that cover both hydraulic and pneumatic machinery, their fundamental principles including safety standards and regulations. The book also features abundant referencing, updated web links, and masterful tables for easier understanding of the concepts covered. The text is written to serve as an introductory reference for novices and students in pneumatics and hydraulics. It is also invaluable and can be used as primary reference for control, manufacturing, mechanical, and electrical engineers, operations managers, and technicians working with hydraulic and pneumatic equipment[16].

3.1.4.2 Adaptive Parameter Estimation for an Energy Model of Belt Conveyor with DC Motor

In this paper, a new energy model of belt conveyor with a DC motor is introduced. Then, an adaptive observer is designed for the model. In order to identify the four coefficients of the energy model , the feed rate *T* of the belt conveyor and the angular velocity *wm* of the rotor of the DC motor should be measured on-line. Then, based on the adaptive observer, a parameter estimation algorithm is derived. In addition, under a persistent excitation condition, the convergence of the parameters to the desired values can also be concluded. Simulation results show the validity of our methods[17].

3.1.4.3 Welding Fundamentals

Welding Fundamentals is designed to provide students with a strong understanding of the underlying theory and skills required for successful welding, with a strong emphasis on safety. It provides all of the information needed to help students develop proficiency with the most common welding processes (including GTAW, GMAW, FCAW, SMAW, and oxy fuel welding), thermal cutting, basic print reading and weld symbology, and joint design and fit up. The text also introduces students to weld inspection and testing[18].

3.1.4.4 Tomato sorting based on shape, maturity, size, and surface defects using machine vision.

In this study, an image processing technique was developed to sort tomatoes according to 4 quality criteria: maturity, defects, shape, and size. The software developed in this study evaluated tomato shape by its eccentricity, tomato size by its 2-D image area, tomato maturity by its mean color, and tomato defect by its fullness parameter[19].

3.1.4.5 Motors for Makers
This book explains how DC motors work. It also shows to connect servos to mega arduino specifically. The torque and speed play a large role in selecting the motor. This is used as how to select and use motors for this project [20].

3.2 Benchmarking
For doing the benchmarking, different searches have done and different projects have seen which have done before related to this project. Some existing designs have found as well which are similar to this project. The basic purpose of doing this benchmarking is to find similar designs, which have found over the google. These designs have analyzed and some of the design ideas have found useful for this project.

3.2.1 System Level Benchmarking
In system level benchmarking such similar designs have searched which fully applied to the project. As the name stated system level benchmarking, so the full complete device comes under the system level. Some existing designs have presented in this section.

3.2.1.1 Existing Design #1: Lego Sorting Using TensorFlow Arduino [21]
The LEGO bricks begin a chute as a gathering, and after that slide down onto a moderate moving transport to disperse the gathering. Next, a second, quicker moving, transport further isolates the bricks. With a good space between one brick and the following, they're channeled into a region where they can be captured. The Arduino with TensorFlow at that point chooses what sort of brick it is and pivots another chute to the relating container, where the brick is saved. Garcia's initially kept running of the machine precisely arranged 89% of the bricks, and that can probably be improved with better TensorFlow preparing. It has shown below in figure 1.

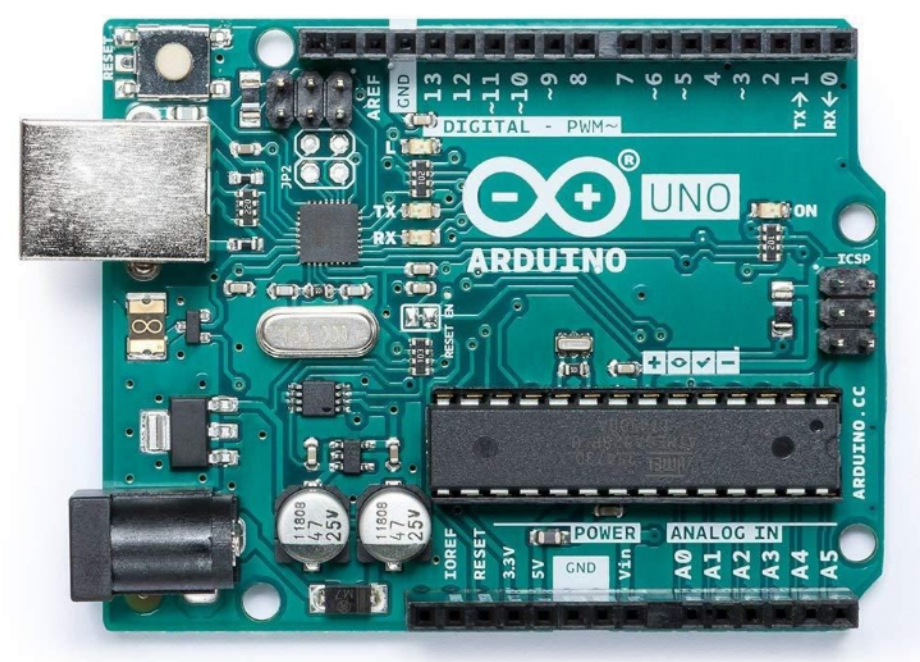


Figure 1: Arduino Design [21]

3.2.1.2 Existing Design # 2: Elaborate Lego Sorting Machine [22]

Utilizing Python code, repurposed mechanical weight sensor machine sorts in excess of 38,000 shapes in 100 conceivable hues and shades[22]. The pieces are pulled up the belt on a stepping stool, slide down a chute, are captured and afterward taken to their fitting canisters on another transport line. It has shown below in figure 2.

Figure 2: Elaborate Sorting [22]

3.2.1.3 Existing Design # 3: Lego Parts Solver

The sorter runs bricks down a transport line, shunting them into containers dependent on size and shape, and even tile and pivot styles. The mechanical subtleties of the construct can be difficult to parse, however essentially, Chow step by step expands the span of the openings a brick may fail to work out, dumping littler ones first, and after that bit by bit abatements the tallness of the boundaries to permit level pieces through while uneven ones get expelled[23].

3.2.2 Subsystem Level Benchmarking

Sub-system level parts are defining like some important basic parts that will play important role in the project will use. Like sensors, catcher etc. that will play important role in the project.

3.2.2.1 Subsystem #1: Sensors

There are different kind of sensors that can use in this project. Sensors detect different conditions and respond if something has happened or not. On one hand, Proximity sensor is one of its kind which detect the nearest hurdles. On the other hand, Arduino can also be used as a sensor and sending unit at the same time in this project.

3.2.2.1.1 Existing Design #1: Proximity Sensors

Proximity sensor is a sensor that can detect the nearest hurdle, so it detects any object is present in nearby or not. This is important because it will help us control the process start/stop different part of the design when needed to organize the flow of the process. This sensor can use in our project to detect the Lego bricks, and identify the location because of its sonar beams. This existing design can help in the project for finding the Legos[24].

Figure 4: Proximity sensor [24]

3.2.2.1.2 Existing Design # 2: Ultrasonic Sensor

Ultrasonic sensor is a sensor which detect the object far from its location. This sensor can be used in the project in the idefing what type of Lego it is and send a signal to the control system. It uses the ultrasonic rays which goes and then come back to the source and detect the object present in the way. In this way ultrasonic sensor can use for sorting the Legos by finding the Legos and then sort them on the basis of their shape.

Figure 5: Ultrasonic Sensor [25]

3.2.2.1.3 Existing Design # 3: Infrared Sensor

This sensor can also use to find the location of object without touching it, in this way this existing design can help in making the project so that Legos shape can recognize easily. This sensor can use in multiple ways, like detecting the object, placement of object, recognizing the shape as well.

Figure 6: IR Sensor [26]

3.2.2.2 Subsystem #2: Conveyor Belts

From the team's researches we agreed that conveyor belts could be used in the design for its multiple uses. From the function model we could use a conveyor belt to aligne, separate and transport Logos.

3.2.2.2.1 Existing Design #1: Powered-in Conveyor Belt.

One idea was to buy a conveyor belt this when we found the powered-in conveyor belt. We will just has to find the right place to install it in the design.

Figure 7: Mini Conveyor belt [27]

3.2.2.2.2 Existing Design #2: Controlled conveyor belt.

fdhjvbfdvbdfn

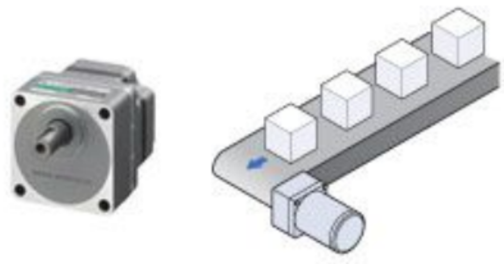


Figure 8: Stepper motor powered belt [28]

3.2.2.2.3 Existing Design # 3: Metal conveyor belt

The idea why we chose this type of conveyor belt because it has low friction on the legos pieces. It will allow the Legos to move when they contact the barriers and separate the legos one by one.

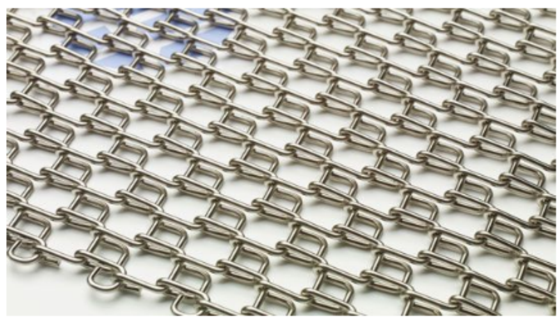


Figure 9: Aluminum grid conveyor belt [29]

3.2.2.3 Subsystem # 3: Motors

Another subsystem that will use in the project for the movement. In order to move the conveyor belts, the device needs motors. This subsystem will take over moving the conveyor belts.

3.2.2.3.1 Existing Design # 1: Stepper motor

A stepper motor could be used in the sorting part because it can receive signal from the controller. Also, it can rotate both sides and can be controlled. From the decomposition model the both the aligne/separate and transport sub-functions required the use of a motor.

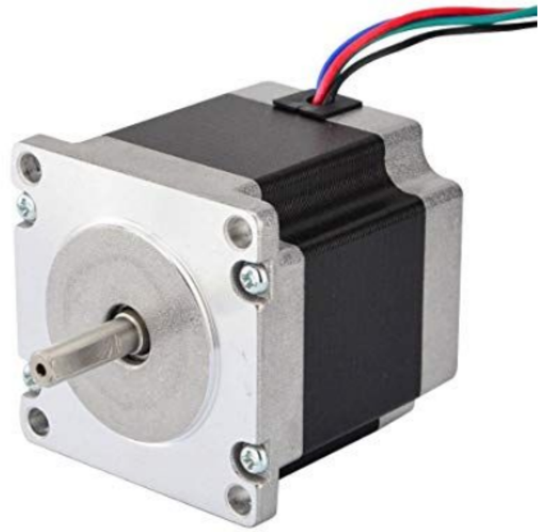


Figure 10: Stepper motors [30]

3.2.2.3.2 Existing Design #2: DC motor

A DC motor is very helpful in moving an object in one direction and usually uses to move heavy object. We could use it to move the conveyor belt and control the speed and the torque. Using a DC motor to move the conveyor belt will help us accomplish one of the requirements separating the Legos.

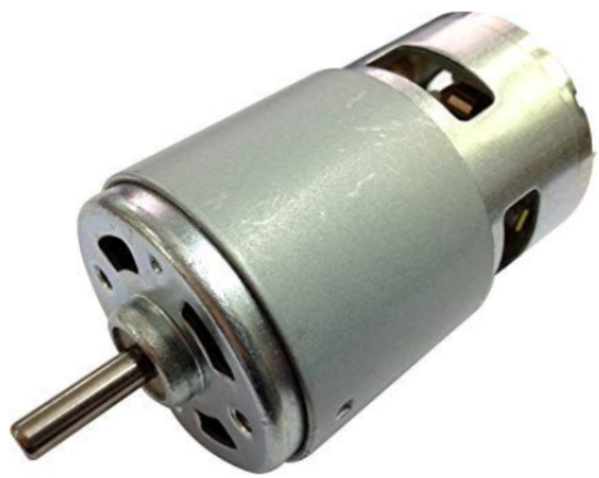


Figure 11: DC motor [31]

3.2.2.3.3 Existing Design # 3: Electric Motor

Th

Figure 12: Electric motor [32]

3.3 Functional Decomposition

As the project divided into multiple functions so that's why it has named functional decomposition. In this part of the project, different sub parts of the project will describe that will possible present in the design and will perform the operation. In this section two design tools will be presented the Black Box model and functional model. The Black Box model describes the input and outputs of the system and functional model defines what is happening inside the product. In this process we are taking a complex design problem and breaking it down into its smaller, easier to solve sub-functions. Also, it will help us get a better idea of the main function of the system.

3.3.1 Black Box Model

This is a model in which inputs and outputs of the device shows like what is going as an input to the device and what is getting from the device, without any consent of what is happening inside the device and that is why it has named the Black Box model. The black box model has three shapes inputs, first is hand and random Legos/non Legos entering the system as materials, second is electrical energy and human energy entering the system as energies, and third is on/off and empty reservoir entering as signals. Also, has three shapes outputs, first is hand and sorted Legos/non legos leaving the system as materials, second is sound and heat leaving the system as energies, and third is on/off and full reservoir exiting the system as signals. Black box model helped us idefing the main function of the system and helped us knowing what are the inputs flow and the outputs flow .

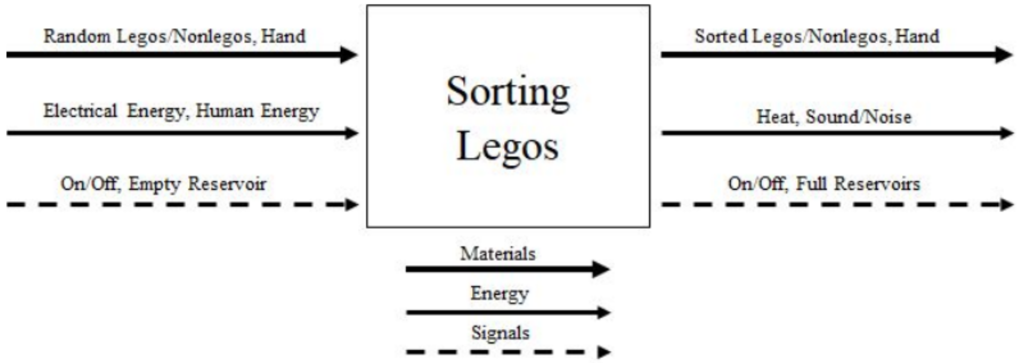


Figure 13: Black Box Model

3.3.2 Functional Model

Functional model shows the complete system from the inside of product in steps like what is happening with the input at first and then what is going to happen next and so on in a verb-object form. In this way all the steps and sub parts shows in the functional model and that's why it has named functional model. Also, helped us focus on what has to be accomplished rather than how. The functional model complete process has shown that the four main sub-functions that we should focus on are aligne Legos, Arduino, transport Legos and sort Legos.

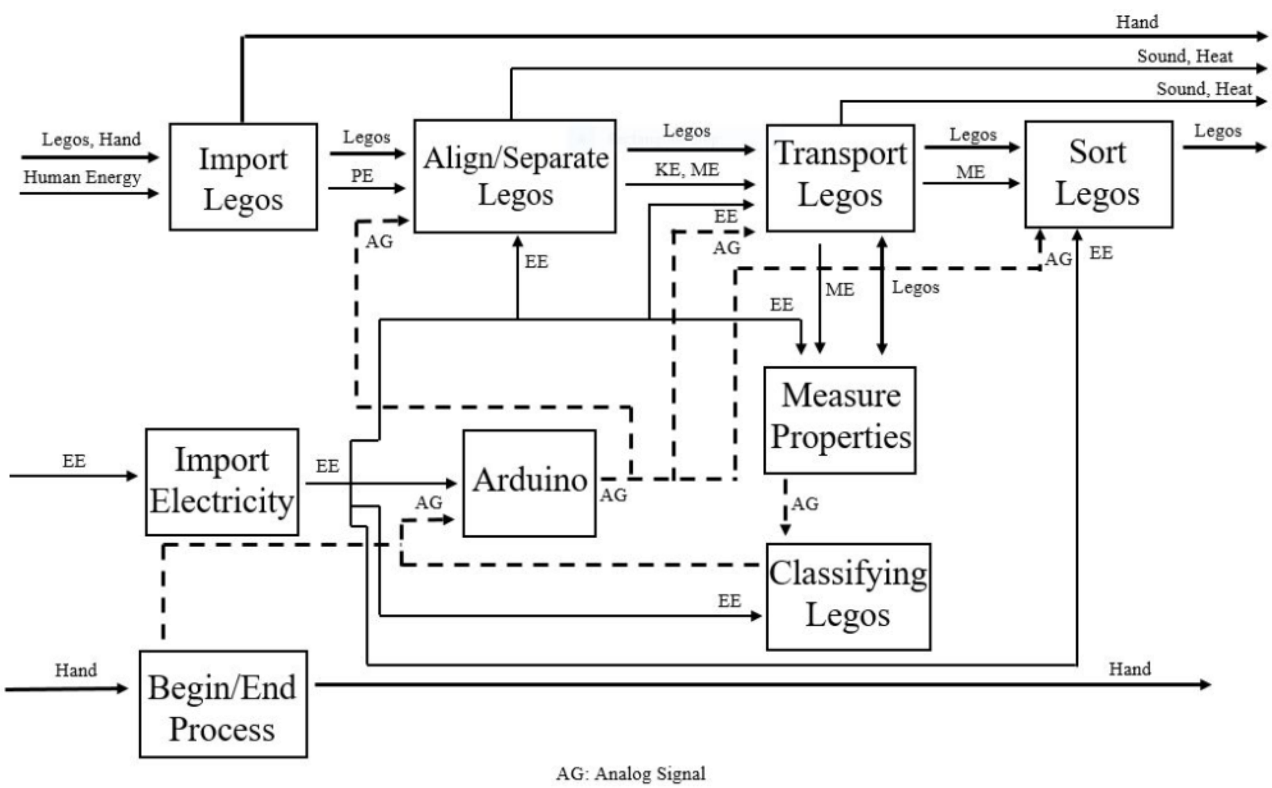


Figure 14: Functional Model

4. CONCEPT GENERATION

In this section different ideas are presenting that have generated by the team members. These design ideas have created by the team and sketch them as well for better understanding. In this way final design will select from these developed design ideas.

4.1 Full System Concepts

4.1.1 Full System Design #1: Box on the Wide belt

This is a wide belt in which the Legos will place randomly and it will move forward to the next belt for sorting as it has shown below.

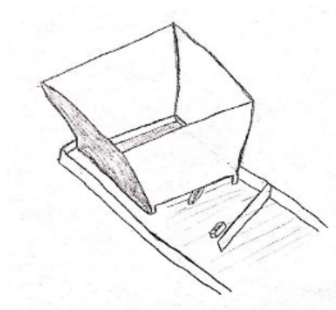


Figure 15: Wide Belt

Advantages:

- Randomly movement
- Easy movement

Disadvantages:

- Slow process

4.1.2 Full System Design #2: Belt with Hurdles

In this design idea, there are breaks present in the belt that make the que of the Legos and arrange them in one-line shape to make it easy to move.

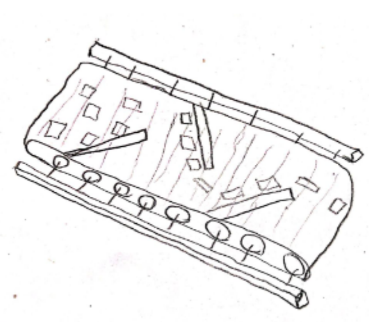


Figure 16: Belt with Hurdles

Advantages:

- Large Lego to put

Disadvantages:

- Slow process

4.1.3 Full System Design #3: Weight

This is the idea that check the weight of each Lego and differentiate it from others and move to the space associated to that weight and it has shown below:

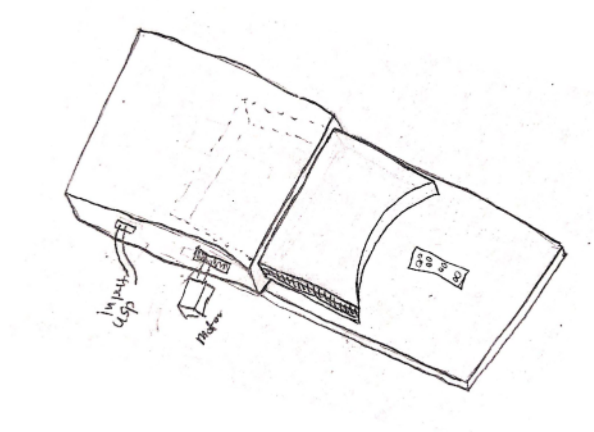


Figure 17: Weight Sensor Idea

Advantages:

- Fast process
- Economical to use

Disadvantages:

- Not efficient

4.1.4 Full System Design #4: Boxes

In this design there are boxes formed with the link from center box and all the Legos have their own box so each design will get its own box so lot space and it is easy as well to store the Legos and within small space. As the design has shown below

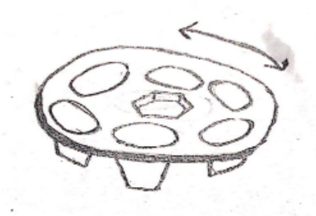


Figure 18: Boxes

Advantages:

- Large Space

- Easy to use
- Sorting is easy

Disadvantages:

- Slow Process

4.2 Subsystem Concepts

In this portion different design ideas will generate related to the project and these ideas will be for the sub system of the project. Lego Sort Level. In this subsystem, Lego will differentiate on the basis of its size and shape.

4.2.1 Subsystem #1: Align/ Separate Legos

4.2.1.1 Design #1: Nozzle down

In this design idea, a nozzle shape has made with the wide open to make easy for the Legos to go inside and then narrow down for reducing the number Legos to move forward, in this way Legos get in a line easily as the idea has shown below.

Figure 19: Nozzle Down

Advantages:

- Fast
- Easy to narrow down

Disadvantages:

- Chance of obstacle

4.2.1.2 Design #2: roulette

There is a Roulette in which the Legos goes, spin through the walls of the Roulette and then move to the next stage one by one, when the wall push it to move forward. The idea has shown below as well.

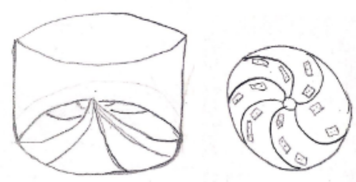


Figure 20: Roulette

Advantages:

- Fast

Disadvantages:

- Costly
- Chance of breaking

4.2.1.3 Design #3: Slide box

In his idea, we have a slide box that makes the Legos go to the next step by just throw it into the slide without any electrical or kinetic energy to move the Legos. The idea has shown below as well.

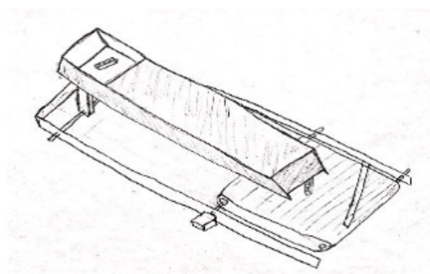


Figure 21: Slide Box

Advantages:

- Fast

Disadvantages:

- Chance of breaking

4.2.2 Subsystem #2: Transport Legos

4.2.2.1 Design #1: Straight Belt

The design idea states that it is good to use the straight belt which make a long que of Lego and move straightly without any interaction.

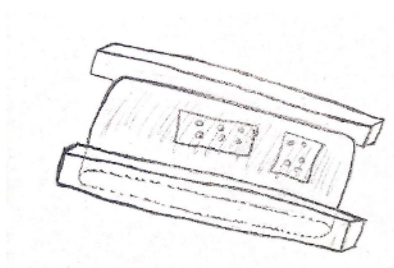


Figure 22: Straight Belt

Advantages:

- Fast
- Straight

Disadvantages:

- Less Legos to put in it.

4.2.2.2 Design #2: Round Belt
In this design idea, there is nozzle shape belt which make a long que and provide large space to the Legos as the idea has shown below.

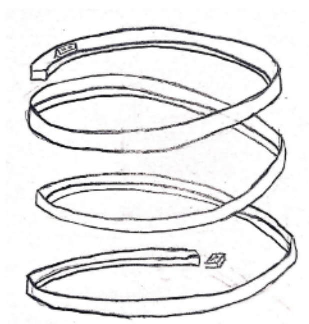


Figure 23: Round Belt

Advantages:

- Large number of Legos

Disadvantages:

- Time taking

4.2.2.3 Subsystem #3: Hand Grabber
Hand grabber might be a useful idea, because we are going to create a robot to transport the Legos to the next step. As shown in the figure below.

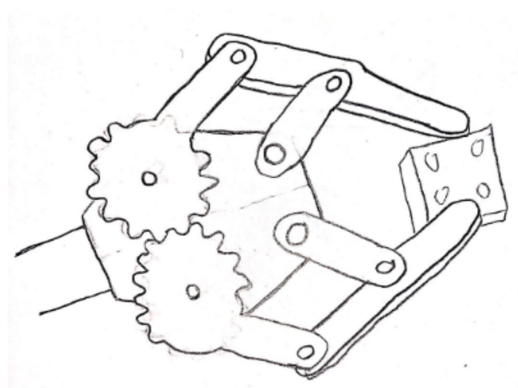


Figure 24 : Hand Grabber

Advantages:

- Easy to use
- Safe time

Disadvantages:

- Costly
- Needed more maintenance

4.2.3 Subsystem #3: Classify Legos

4.2.3.1 Design #1: Scanner

This is the idea that scan the Lego and differentiate it from others to find its location where it need to go according to the associated space and the idea has shown below.

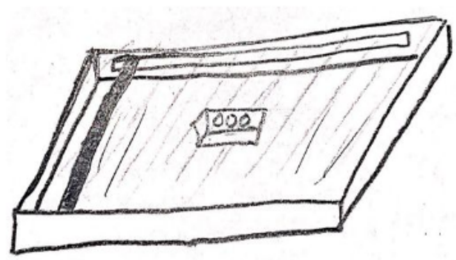


Figure 25: Scanner

Advantages:

- Easy to operate
- Economical

Disadvantages:

- Less efficient

4.2.3.2 Design #2: Camera

Another option we have decided is the use of camera to do the differentiation between the Legos and recognize the Lego so it can move to its associated space.

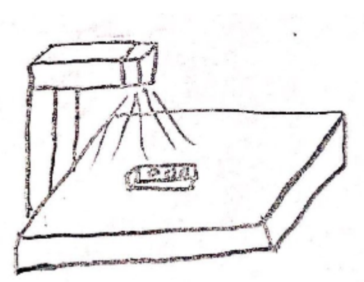


Figure 26: Camera

Advantages:

- Accurate
- Speedy

Disadvantages:

- Costly

4.2.4 Design #4: Sorting Legos

4.2.4.1 Design #1: Round Box

In this design, all the Legos will sort out in one round shape area with the hands outside it and these hands store the Legos. One hand will store one kind of Lego and other hand will store second kind of Lego and in this way all the Legos will sort in this round shape. The design has shown below.

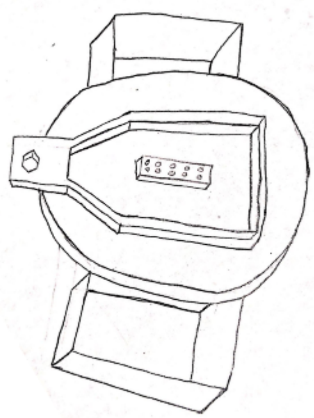


Figure 27: Round Box

Advantages:

- Easy to use.

Disadvantages:

- Less space
- Slow Process
- Sorting is difficult

4.2.4.2 Design #2: Multiple Branches Tree

In this design, Legos have lot of space to store so different Legos store in different portions of the branches, so this design can manage multiple shapes, multiple colors and multiple sizes as well as the design has shown below.

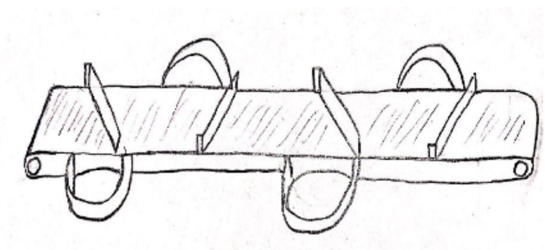


Figure 28: Tree Design

Advantages:

- Large Space

Disadvantages:

- Slow Process.
- Sorting is difficult

5. DESIGN SELECTED

In this section final design will going to select from the concepts which have generated in the previous section. There are different ways to select the design from multiple designs but it is difficult to select the best design by simply checking the design so there are some methods available which can help in choosing the design like decision matrix, and Pugh chart. These design ideas use the customer requirements and then test each design with each requirement to and then the best design select.

5.1 Technical Selection Criteria

Criteria for selecting the design depends on the efficiency and the requirements they are fulfilling. The basic criteria for selecting the design is that test it with the requirements and see if all the requirements are following by the design or not. If all the design is following by the requirement the design is acceptable otherwise the design is not acceptable. In this way selection of design happens. The technical criteria of design engineering requirements and engineering requirements can measure as well so technical criteria for the design is engineering requirement that need to meet by the design to count as a final design.

5.2 Rationale for Design Selection

There are different design ideas which have generated, and to select these design ideas, Pugh chart and Decision matrix have used.

Pugh Chart

Pugh chart has used to check for each requirement against each design and then assign a plus sign if the requirement is present in it. And if the requirement is not present then it assign a negative sign. And at the end sum up the plus sign and minus sign. So the design with higher plus sign will count as the final design.

Table 4: Pugh Chart

LEGO SORTING	Weight	Design # 1	Design # 2	Design # 3	Design # 4
1. Portable design	8	+	+	+	D
2. Long life	7	+	-		D
3. Easy to assemble	6	+	+	-	D
4. Separate Legos	5	+	+	+	D
5. Cost	4	+	S	+	D
6.Safety	1	+	+	-	D
Pluses		6	4	3	Na
Minus		0	1	2	Na

From the Pugh chart, we have the best design as design #1 which has 8 plus and 0 minus sign that's why it has count as final design. Now check it with decision matrix.

Decision Matrix

Decision matrix is a matrix in which each requirement test against each design and then assign a score, and there is a raw score for each requirement so multiply the assign score with the raw score for each requirement and then add up to make the total. The highest total score is count as the best design.

Table 5: Decision Matrix

Decision Matrix	Portable design	Long life	Easy to assemble	Separate Legos	Cost	Safety	Total
Weight	8	7	6	5	2	1	
Design # 1	6x8=40	6x7=42	2x6=12	7x5=35	5x2=10	5x1=5	144
Design # 2	6x8=40	6x7=42	2x6=12	7x5=35	5x2=10	1x1=1	122
Design # 3	4x8=32	4x7=28	3x6=18	4x5=20	3x2=6	1x1=1	105

So from the decision matrix the best design is Design 1.

5.3 Analytical Summaries

All the team members have done the technical analysis and the technical analysis have presented below.

Person 1

The problem addressed is 'weight measurement of Lego-parts using Arduino' for autonomous sorting of Lego parts. The solution needed should be robust, low-cost and efficient, therefore, following approach has been used to solve the problem. This is an example problem, whose solution can be used in future for many advanced projects.

- $V1 = Vcc \times (R_{sensor}) / (R_{sensor} + R1)$ ------------(A)
- This V1 would be read by the analogue input of the arduino. As the Arduino has built-in 10bits ADCs, so we need to calculate the corresponding voltage values using some calculations of ADC.
- For example, lets say X = binary string of the Vi converted by ADC,

  $Vin = (dec(X) \times 5)/1024$ (because Vref = 5V)

- Now this calculated value of Vin can be used to find the value of R_{sensor} using equation (A).

Once the R_{sensor} is found, we can then use the value of R to check for its corresponding value of Force applied (as per the transfer function given in the datasheet or interpolated using manual calibration of the sensor).

Person 2: Abdullah Almutairi

LEGO Sorting Machine system design utilizes Arduino Mega as the central controller. Arduino IDE was employed to write and consequently compiled and upload to the board. The entire needed libraries are incorporated. Arduino boards are deemed to be small computers that are utilized for construction of homemade IoT devices, and an extensive variety of additional electronic projects. For the LEGO Sorting Machine, the Arduino editor was used, which also acted as a tool fundamental for uploading the sketch to the underlying Arduino board. However, the Arduino will read the weight and send signals in order to sort the LEGOs in the right place. All in all, the device that called Arduino will be the brain of our project.

Coding will be utilizing weighing scale in terms of function within a relatively broader project through using this Instructable as the main basis, of the requirements emanating weighing fractions of the underlying a gram to the corresponding numerous grams. Moreover, this will entail obtaining the fundamental terminals of the corresponding sensor.

Person 3: Analysis

Analysis about the actuator part which is the last part and do the division between the Legos so it will sort them. The analysis will determine the motor on the basis of torque, speed require, angle needed and cost and will also focus on the bin size that will store the Legos.

$$T = \frac{V*\omega*k}{R}$$

Put the values in the above equation as

$$T = \frac{110*0.2*100}{200}$$

$$T = 11\ Nm$$

Now calculate the mass that can carry with this torque

$$T = mgL$$

$$L = 0.3\ m$$

$$m = \frac{11}{9.81*0.3}$$

$$m = 3.737\ kg$$

So the above torque can easily lift the weight of 3.7 kg, that's means the Lego weight and the plate weight will be 1.70 kg. it means for heavier weight around 5 kg, we need to torque

$$T = 5 * 0.81 * 0.3$$

$$T = 14.71\ Nm$$

So the motor which can provide the torque of 20 Nm is enough to perform a good job in this project. And to determine the speed from the torque we can use this conversion

$$T = 9.5488 * \frac{P}{\omega}$$

$$P = V\,i$$

$$P\ = 110 * 2.5$$

$$P = 275\ W$$

$$P = 0.275\ kW$$

$$20 = 9.5488 * \frac{0.275}{\omega}$$

$$w = 7.6164\ rpm$$

So we need the speed of around 10 rpm for the motor, so a motor has found with the similar characteristics which can use in the project.

- DC 12V Reduction Motor Worm Reversible High Torque Turbo Geared Motors 2-100RPM [3]
- Cost of this motor is $11.59 [3].

For holding the bins, we have the length and width

$$W = 2\ in$$

$$L = 4\ in$$

$$H = 1\ in$$

And the bin can make for the size as

$$Bin\ Width = 4\ in$$

$$Bin\ Length = \ 5\ in$$

$$Bin\ height = \ 6\ in$$

So with these dimensions each bin can store as

$$volume\ of\ one\ lego = 2 * 4 * 1$$

$$volume\ of\ one\ lego = 8\ in^3$$

And the volume of bin is

$$bin\ volume = 4 * 5 * 6$$

$$bin\ volume = 120\ in^3$$

$$So\ total\ Legos\ it\ can\ stored\ in\ a\ bin = 15$$

Assume some free spaces present left while holding the bins so reducing the number, it can easily store 12 bins.

Sultan Alharbi: Analysis

Analysis about the conveyor belt that will going to use in the machine to move the Legos for sorting purpose.

$$Friction\ Coefficient\ for\ rubber\ in\ rolling\ with\ plastic = 0.70$$

Legos weight totally accumulated over the belt is around

$$Legos\ accumulated\ Weight = 25\ lb.$$

Calculating the rolling resistance as

$$RR = W_{GV} * C_n$$

$$RR = 25 * 0.70$$

$$RR = 17.5\ lb$$

Rolling resistance is around 17.5 lb. Now calculate the force that will face on the wheels for the conveyor to move it

$$F = RR * a$$

Assuming that the acceleration for the conveyor belt is 0.25

$$F = 17.5 * 0.25$$

$$F = 4,3750\ lbf$$

So the force need required to move the conveyor belt is 4.375 lbf, and the stress applied to the rubber of conveyor belt is

$$Stres = \sigma = \frac{F}{A}$$

Now the area of the belt is

$$Area = L * W$$

Length of the conveyor belt

$$L = 15\ inches$$

$$W = 6\ inches$$

$$Area = 15 * 6$$

$$Area = 90\ in^2$$

Calculate the force

$$F = F_{rr} + F_{body}$$

Mass of conveyor belt is

$$F_{body} = m * a$$

$$F_{body} = 25 * 0.25$$

$$F_{body} = 6.250\ lbf$$

Now calculate the total force acted on the wheel as

$$F = F_{rr} + F_{body}$$

Where

1. F_{rr} = rolling resistance force
2. F_{body} = force on belt directly

$$F = 4.3750 + 6.250$$

$$F = 10.6250\ lbf$$

Calculating the stress

$$stress = \sigma = \frac{10.6240}{90}$$

$$stress = 0.1180 \frac{lbf}{in^2}$$

Now calculate the strain

$$strain = \frac{\Delta L}{L}$$

$$\Delta D = 0.001\ in$$

$$D = 15\ in$$

$$Strain = \frac{0.001}{15}$$

$$Strain = 6.6667 * 10^{-5}$$

Now the strength can calculate as

$$strength = \frac{stress}{strain}$$

$$Strength = \frac{0.1180}{6.6667 * 10^{-5}}$$

$$Strength = 1.7700 * 10^{3}\ psi$$

The strength required for the conveyor belt is around 1.770x10^3 psi, but the rubber has strength higher than this value, that's why rubber is fine to use for the conveyor belt.

And for passing the Legos to the division part we can use slits in front of Legos to make the proper line that will pass the Legos one by one to the sorting part.

5.4 Design Description

The final design has selected and the final design is that it has a LEGO holder which will hold the LEGOS, all the LEGOS will insert into it so this is basically the input part, second part is separate wall, separate will separate the LEGOS and pass the LEGOS one by one, there is a conveyer belt on which the LEGOS will transfer from one side to other side for sorting purpose. Separate walls are present on the conveyor belt so the conveyor belt will keep moving and the LEGOS will keep moving as well but the separate walls will pass the LEGOS one by one. There is a motor which will rotate the belt and the motor will attach to the end point of conveyor belt. When the LEGOS will pass through the conveyor belt, it will automatically push through the pusher to move into the storage. In storage part there are three different things, first is storage compartments, second is storage holder and third is large motor which rotate the storage holder and all the storage compartments fix over the holder so storage compartments also rotate when the motor will run. This is the complete design description and the final CAD model has shown below in the figure.

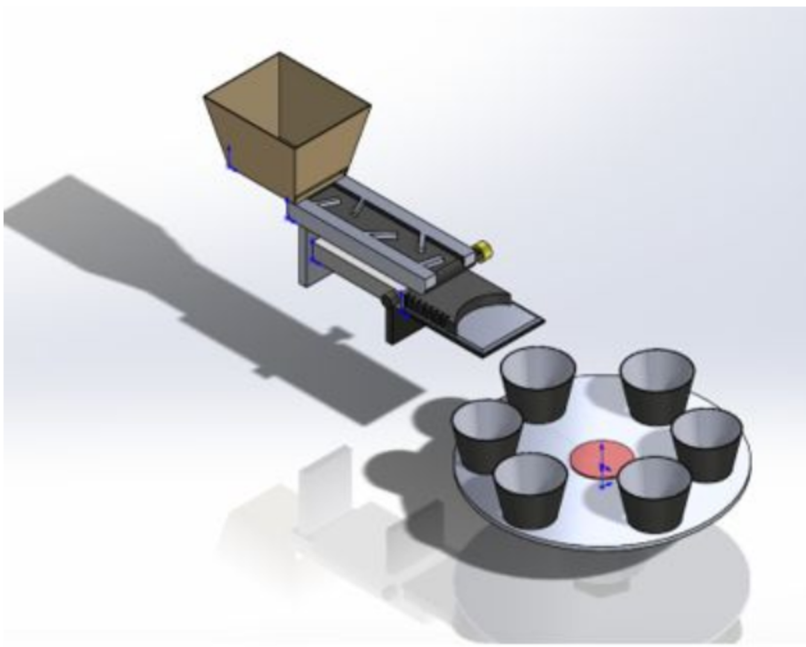


Figure 29: CAD Model

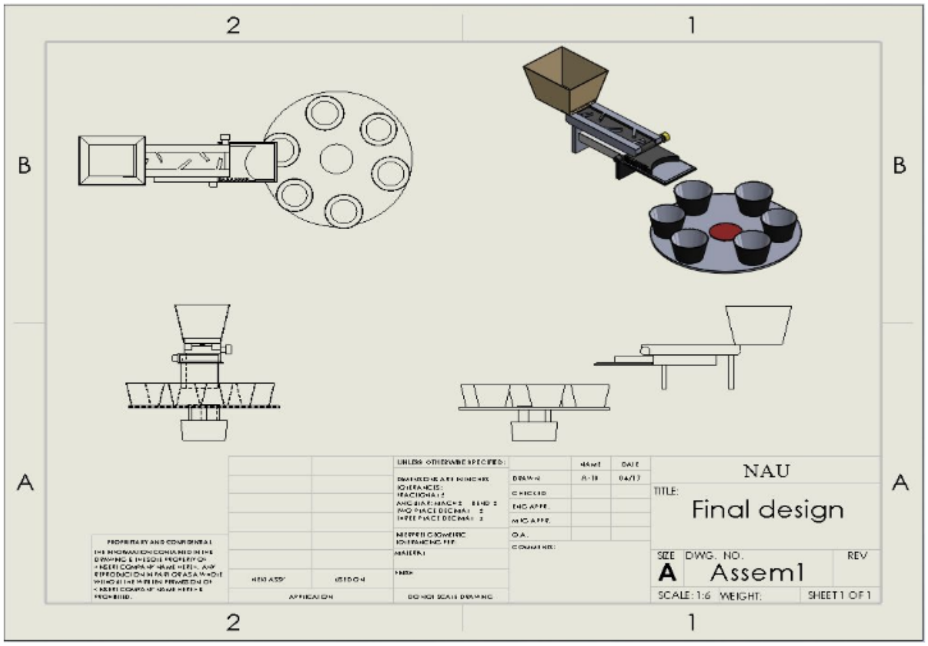
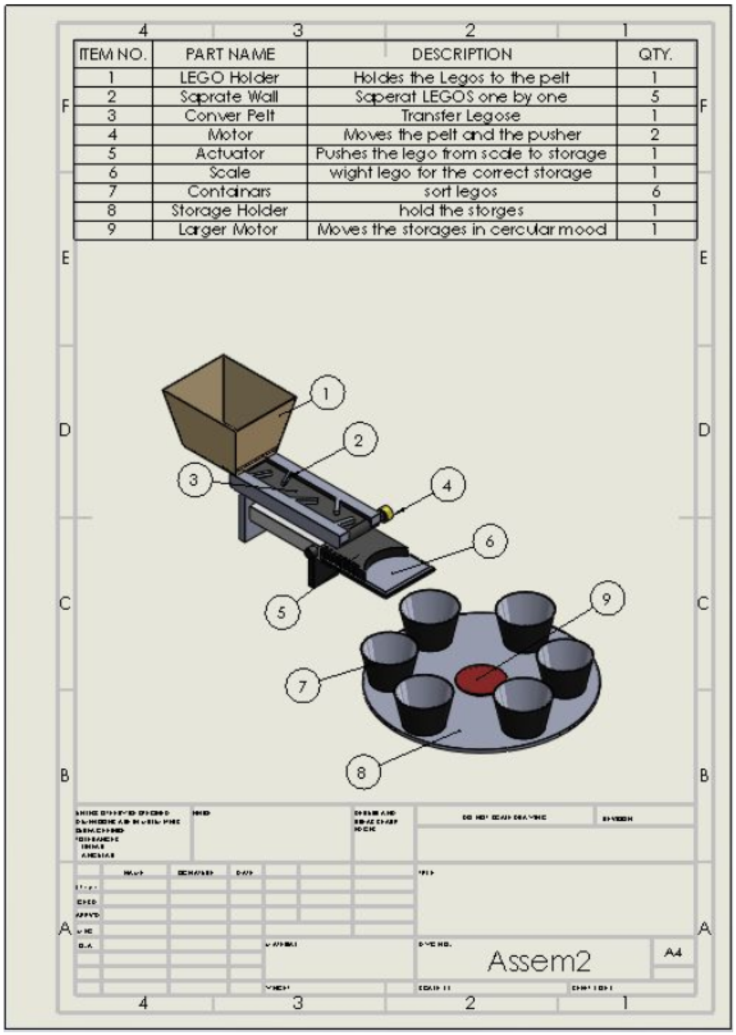


Figure 30: All Side views front, top and right of Design CAD model

And the details about the parts has shown in the table given below in Figure 31.



ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	LEGO Holder	Holdes the Legos to the pelt	1
2	Saprate Wall	Saperat LEGOS one by one	5
3	Conver Pelt	Transfer Legose	1
4	Motor	Moves the pelt and the pusher	2
5	Actuator	Pushes the lego from scale to storage	1
6	Scale	wight lego for the correct storage	1
7	Containars	sort legos	6
8	Storage Holder	hold the storges	1
9	Larger Motor	Moves the storages in cercular mood	1

Figure 31: List of part for the design

6 IMPLEMENTATION PLAN

For implementing the device, the overall material has selected for the device is aluminum because the aluminum is strong as it has described in the analysis because aluminum is lightweight so it will make the device easy to carry and strong as well. For manufacturing the device, we will purchase the Aluminum sheet and will cut it down into the pieces and will make the shapes as required for the design. For the motor to move the storage cell, 12V DC reduction motor will use because of its high torque it will capable to rotate the complete storage compartment and storage holder. Arduino will use to control the complete device, Arduino will be the main controller to control the motors, storage cell, selection of the LEGOS will perform the through the Arduino as well. Wood will use to put the stand belt in order to put the conveyer belt in moving around the stand. Plastic storage compartments will use to store the LEGOS. For moving the conveyor belt, motor will use a small motor with the input of 12V. And the belt will make of rubber whereas the 3D printing will use the plastic. Scale will make using the aluminum as well to scale the LEGOS.

Table 6: Bill of Materials

Part #	Part name	Qty	Description	Function	Material	Dimensions	Cost per ea.	Link to Cost estimate
1	Arduino Kit	2	Program the system	Program the	Alminum	5.8" x 2" x8.3"	$16.90	h... https://www.eb.../232964282593 ...lete-Tutorials-Breadboard-UA005/dp/B07D3RZZNN/ref=asc_df_B07D3RZZNN/?tag=hyprod-20&linkCode=
2	DC 12V Reduction Motor	1	Motor with high torque	Rotate the bins	Alminum	12 V	$12.00	https://www.ebay.com/itm/DC-12V-Reduction-Motor-Worm-Reversible-High-Torque-Turbo-Geared-Motors-2-100RPM-/232964282593
3	Wood	2	Base stand	Hold the device	Wood	4 x 8 ft	$11.35	https://www.google.com/shopping/product/11617222143144898586?lsf=seller:8740,store:11461729596472276026&prds=oid:1227650078679224(
4	Plastic Storage	1	First storage of legos	Prepare legos for conveyor belt	Plastic (3D Print)	8" x 10" 13"	$22.00	NAU
5	Conveyor belt motor	2	Rolling belt	Rotate the belt	Alminum	12V	$40.00	
6	Belt	2	Transport the legos	moving legos	Rubber	1/2" x 5/8" x 1"	$1.37	https://www.mcmaster.com/#6391k215/=1ci4g6v
7	Load Scale	4	determine the weight	Weighting the legos	Alminum	34 mm x 34 mm	$7.99	https://www.amazon.com/Onyehn-Resistance-Half-bridge-Amplifier-Electronic/dp/B07HCXJHZF/ref=asc_df_B07HCXJHZF/?tag=hyprod-20&linkCo
8	3-D Printing	6	Containers	Store the lego after weight them	Plastic (3D Print)	5"x 6"x 4"	$40.00	NAU

Bill of materials
Project 10A
Team: Automatic Lego sorting machine

And the Gantt chart for the implementation has shown in the following figure.

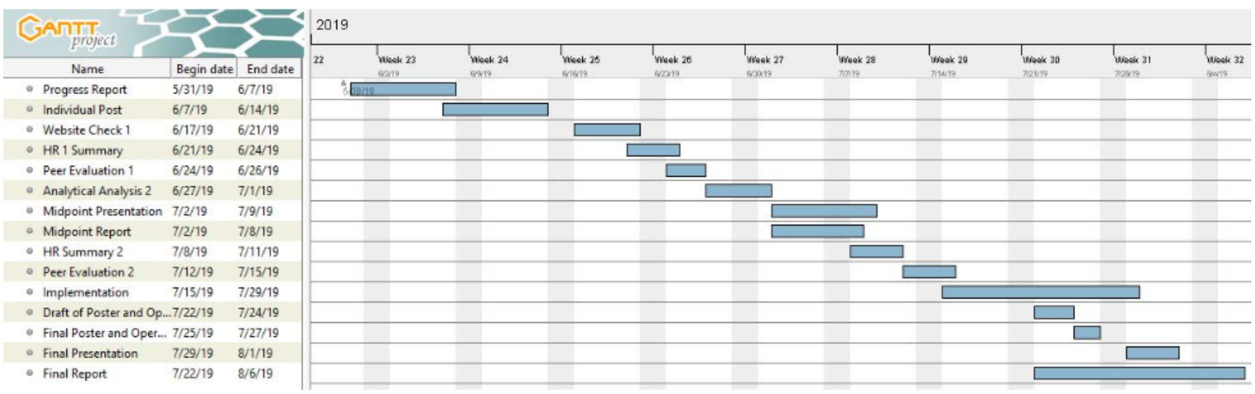


Figure 32: Gantt Chart

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