Autonomous Waste Sorter Design Project

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Abstract: In this design project, main aim is to sort waste materials according to the ASME 2010 STUDENT DESIGN CONTEST competition criteria. There are four types of wastes which are glass, plastic, ferrous metal and non-ferrous metal. Totally twelve different wastes are separated. Afterwards the wastes are sent to their corresponding bin. Moreover, in order to meet the criteria of the contest, it is focused to optimize the size of the robot and the energy requirement. For this project, the control system includes Programmable Logic Controller (PLC), encoders, a linear actuator, a motor driving system and sensors. Therefore, completion of control system is very crucial. Mechanical parts of the system include mainly a four bar mechanism to take the waste into the three different bins, wheels to move the robot, a skeleton which includes the main base, and a V-shaped hopper which is used for carrying the wastes onto it. The magnetic switch and proximity sensors for metals are used to separate ferrous and non-ferrous metals. For this purpose, a magnetic switch is placed underneath the V-shaped hopper together with the proximity sensor that is used to detect metal wastes. The encoder is used for measuring the length of the plastic and glass bottles so that separation can be done. As a result by combining the sensor data and encoder steps counting data, the types of each waste are detected. After detecting wastes, the taking in mechanism starts to pick up wastes from the hopper, and put all of these wastes into corresponding bins. Finally, all wastes are sorted correctly according to their types. The production of this design is done as a prototype. This project has important contribution to the solution of the recycling problem which is one of the today's essential real-world problems. This design project provides an innovation in recycling and sorting problem since, there is not such a robot design in literature review which identifies, sorts and separates the recyclable wastes. This design is a brand new application in its field.

Keyword: Queues, sorting, waste treatment, sensors, PLC control, proximity sensor, direct current (DC) motor, step motors.

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1. INTRODUCTION

This design project is about recyclable waste sorting problem which is the subject of 2010 ASME Student Design Contest. Our aim is to design, build, and test a system capable of rapidly and accurately sorting the four waste materials into distinct waste containers. This system must operate autonomously and be capable of both material identification and waste handling.
Students will be provided with a semi-rigid waste container (a containing twelve waste products), specifically:

1. Three empty plastic bottles D = 75mm (-+20mm) L = 220 mm (-+20mm)

2. Three empty aluminum cans D = 65mm(-+20mm) L = 120 mm (-+20mm)

3. Three empty steel containers D = 75mm(-+20mm) L = 110 mm (-+20mm)

4. Three empty glass containers D = 60mm (-+20mm) L= 95 mm (-+20mm)

Fig. 1. The types of wastes (plastic, non-ferrous, ferrous, glass bottles, respectively)

1.1 Sorting and Working Principles

Our aim in this design is to identify, handle and sort some kinds of wastes such as ferrous-nonferrous wastes, glass, and plastics. In order to do that, we use a kind of robot which has only one arm, one long hopper, one inductive sensor, one capacitive sensor, one magnetic switch, one encoder and Programmable Logic Controller (PLC) for control mechanism. These parts are connected to the main machine, and there are four bins for each type of waste. Firstly, the capacitive sensor defines whether a waste exists or not. Then, the inductive sensor and magnetic switch are used for detecting non-ferrous and ferrous wastes. The encoder is used for sorting glass and plastic bottles, since the capacitive will give sign "on" , but the inductive sensor and the magnetic switch will give "off" signal, at this time encoder is used for counting steps while translational motion of robot passing the waste. The lengths of the plastic bottles are much larger than the glass bottles ones, so this remarkable difference can be used for sorting these bottles by counting step signals from encoder and separating them into different containers. Therefore, sorting logic is defined as follows:

(i) Capacitive sensor is "on", inductive sensor is "on" but magnetic switch is "off" concludes that the waste is non-ferrous material.

(ii) Capacitive sensor is "on", inductive sensor is "on" but magnetic switch is "on" concludes that the waste is ferrous material.

(iii) Capacitive sensor is "on", inductive sensor is "off" but magnetic switch is "off" and encoder gives larger value than the limit concludes that the waste is plastic material.

(iv) Capacitive sensor is "on", inductive sensor is "off" but magnetic switch is "off" and encoder gives smaller value than the limit concludes that the waste is glass material

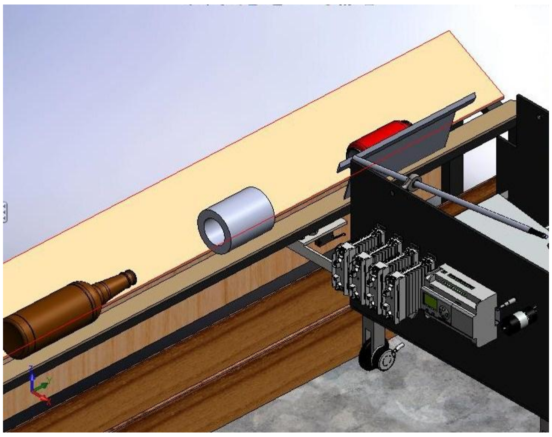

Fig. 2. The wastes on the V-shaped hopper and the robot

The hopper is used for arranging wastes, the arm is for picking the wastes, and these four bins are lying through the translational motion of robot. At the beginning of the process, the wastes are poured onto hopper by hand. After finishing the pouring of the waste process, the robot starts to work.

Firstly, the capacitive sensor gives the information that there is a waste here by giving signal "on". At the same time, the inductive sensor and magnetic switch detect non-ferrous and ferrous metals. If inductive sensor gives "on" but magnetic switch gives "off", this means that a non-ferrous waste exists here; on the other hand both the inductive sensor and magnetic switch give "on" signals, this means that there is a ferrous waste here. After all wastes are detected, the robot arm begins to collect wastes, and put them into correct bin by the help of the sloped surface driven by linear actuator and geometric design of robot. All wastes are collected by the robot arm. The robot arm picks these wastes into the machine one by one. At the end, the wastes are put into their containers, and the operation of the machine is completed.

2. PROPERTIES OF THE DESIGNED SYSTEM

First of all, this machine is considered as a robot and mainly, the system has 3 degrees of freedom. One of them is the translational motion of the robot along the hopper. The second one is related to the arm mechanism to be used for the process of taking the wastes from hopper to the inside of the robot to separate. The third one is the translational motion of the sloped surface driven by the linear actuators placed underneath of the sloped surface.

2.1 The Degrees of Freedom

If it is needed to be more precise, a detailed explanation can be given about the degrees of freedom of the mechanism listed above. Firstly, the robot moves to the right or to the left by the aid of a strong direct current (DC) motor. The necessary torque is calculated afterwards. Specifically, this torque is calculated by putting the friction coefficient of the ground and weight of the robot (all parts inside the robot plus the part on the robot and the skeleton) into the perspective. According to this torque value, suitable DC motor is selected.

The other important point of the arm mechanism of the robot is that the selection of the dimensions of the links of the inverted slider-crank mechanism as an arm. These links of the mentioned mechanism is selected for mainly carrying the waste with the maximum weight. However, in addition to that, selected links should not have contact with the sloped surface. Since the wastes are taken one by one, the heaviest parts are the ferrous wastes (steel parts), which are dominant in this process considering the durability of the mechanism. The third degree of freedom is about the translational motion of the sloped surface. This sloped surface driven by the linear actuator is used as sorting glass and plastic wastes. When the capacitive sensor gives signal as "on", but the inductive sensor and the magnetic switch give signal as "off", this means that the type of waste recognized is either plastic or glass. Since it is known that the length of the plastic wastes are much larger than the length of glass wastes, this remarkable difference is used for sorting by counting the step signals given from the encoder which is placed on the shaft of the driven wheel of the robot. So, the process of sorting the plastic and glass bottles are done by this principle.

2.2 The Hopper Design

The hopper design is also crucial for the system. Since it carries all the wastes, it should have the necessary strength. Moreover, its length is determined by adding the maximum lengths of the wastes plus a clearance value so that when they are poured to the hopper they are arranged along the length of the hopper and they do not overlap. This is very important when identification process is put into the perspective. However, it should also be noted that its length may be 2m maximum. Hence, overlap actually is inevitable.

For the hopper, the following conditions have to be considered:

- It should be enough wide not to let waste to fall down during pouring,
- It should be in a geometry not disturbing the arm,
- It should have enough alignment to guide waste in appropriate manner.

2.3 The Control Mechanism

The control of the slider crank arm mechanism, driven wheel DC motor, arm motor, encoders, linear actuator is achieved by PLC. For the inductive sensor and capacitive sensor to be used in our mechanism, the range of sensor is not significant since its head will be on the underneath of the long hopper part. Therefore, accuracy may be increased. The key point is actually when using sensors, motors, encoder and linear actuator, computer interaction should be achieved. To be more specific, our system includes a main computer and all the motors, sensors, encoder, magnetic switch and linear actuator are controlled by the main controller that is PLC. In order to connect motors and sensors to the computer, PLC is easy to implement and allows us to do any changes in the algorithm. Therefore, these kinds of control systems or derivatives can be used to obtain accurate results.

PLC algorithm is written by first considering the cases like if capacitive sensor is “on”, the inductive sensor is “on” but the magnetic switch is “off”, the case is that the waste is non-ferrous material such as called “M2”. After defining the cases as mentioned above, the actions are taken into consideration in the second part of the algorithm. For example, in the case described above, the sloped surface is stationary and only the slider crank arm mechanism works to take the waste into the robot.

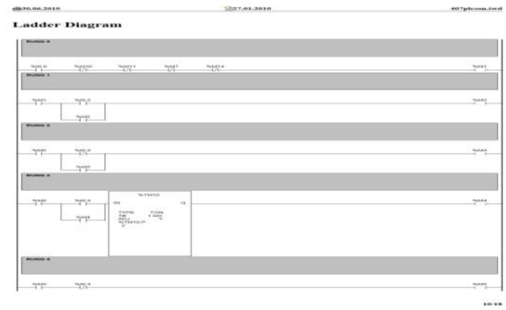

Fig. 3. PLC algorithm (first part)

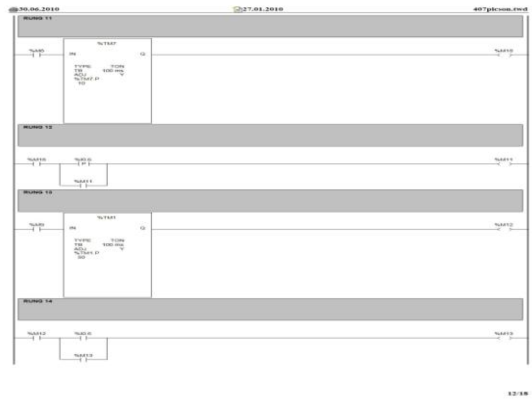

Fig. 4. PLC algorithm (second part)

2.4 The Motions of the Slider Crank Arm Mechanism

The slider crank arm mechanism has two different motions such as inward and outward motion. These types of motions are done according to the detection of the waste material. If the waste material is plastic, the arm mechanism does outward motion and if the waste material is non-ferrous and glass, the arm does the inward motion to the robot. The material of the waste is detected as ferrous then arm does not move and the ferrous waste stays on the hopper since the weight of ferrous wastes can damage the arm mechanism, which is undesirable.

For the arm, the items given below have to be satisfied:

- It should be, in a position in its turn, can lay within the given geometry restrictions,
- It should cover whole waste range, not skipping some small wastes,
- It should not, in a position in its turn, intersect with other components.

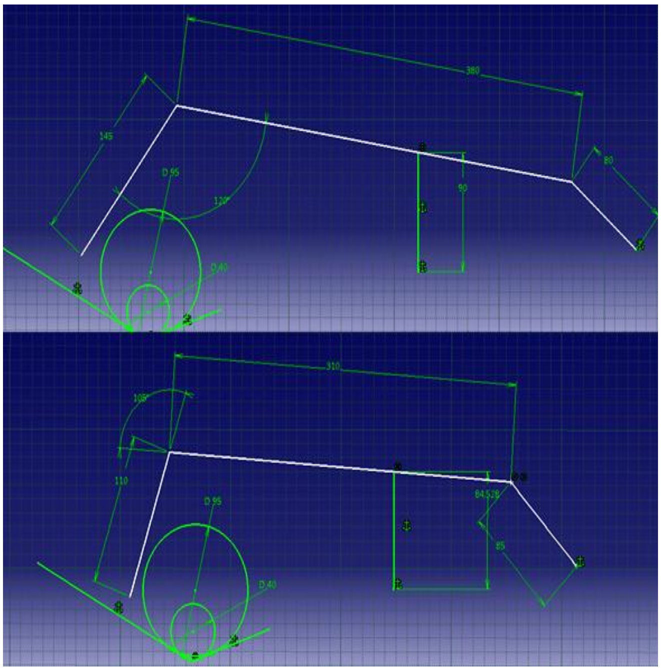

Fig.5. Geometric design of inverted slider crank arm mechanism

2.5 Motor Selection

The choice of the suitable motors is also vital. The most critical motor is the one located under the base plate to drive the robot. It is chosen by considering the total torque acting on the wheels. The strongest motor is the driving motor as stated at the beginning of the mechanism. There is also other motor namely, the DC motor actuating the arm mechanism, this motor does not have to apply huge torques as the main driving motor since the weight of the wastes is very small when compared to the total weight the robot.

3. ENGINEERING CALCULATIONS OF THE GEOMETRIC DESIGN

3.1 Inverted Slider Crank Arm Mechanism

The arm mechanism is the most crucial part of the robot since it is used for taking the detected wastes and sending to the correct container. For the arm, four-bar and inverted slider crank are offered mechanisms by Dr. Eres Söylemez. Inverted slider crank is the first candidate since its motion curve seems more appropriate.

Table 1.Position Analysis of Arm Mechanism in Excel

			x (mm)	**y (mm)**	**Prismatic joint**	
x_{fixed}	345,4		0	0	-354,995	97,00723
y_{fixed}	70,4	**A_0**	40,35838	-110,884	-318,793	79,99453
crank	118	**A**	-345,4	70,4	-335,805	43,79277
slider	495	**B_0**	-407,639	99,64843	-372,007	60,80547
coupler arm	105	**B**	-488,274	32,39576	-354,995	97,00723
α_3	65	**C**	-457,556	58,01583		

In Excel, as seen in Table 1 and Fig. 1, parametric model of inverted slider crank is created. By playing with parameters, a suitable motion curve is generated. Since, there is no limitation about the design of the long hopper, it is achieved according to the design requirements of the arm mechanism.

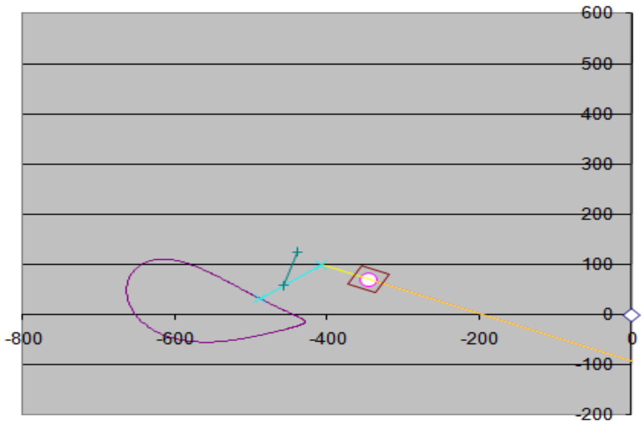

Fig. 6. Simulation of arm mechanism at Excel

3.2 Sloped Surface Mechanism Actuated by Linear Actuator

This mechanism is used for separating glass bottles into their specified container. This mechanism is actuated by a linear actuator which is controlled by PLC according to taken data from sensors and encoders. If the control logic which is mentioned before for the glass bottles is satisfied, then linear actuator becomes active and sloped surface mechanism moves toward to the long V-shaped hopper and arm mechanism takes the glass on the sloped surface and the glass bottle moves along the sloped surface and falls into the container. The sloped surface mechanism's design should be calculated according to hopper and arm mechanism design in order to get high accuracy. So, in Excel Macro the sloped surface mechanism is calculated and the obtained results are as follows:

Fig. 7. Simulation of sloped surface mechanism at Excel

The figure given below shows the side view of sloped surface mechanism design.

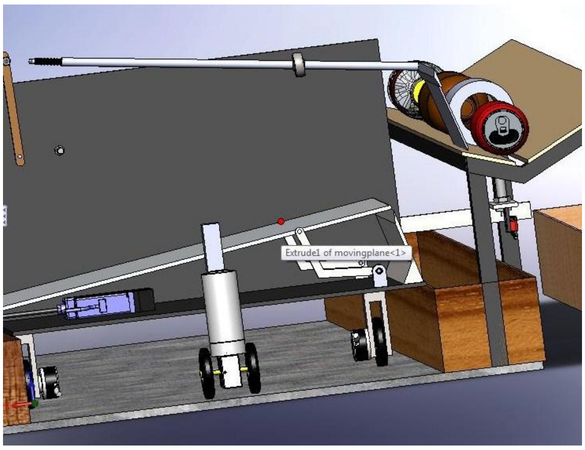

Fig. 8. Side view of sloped surface mechanism

3.3 Shaft Design of Wheels

Total weight is taken as 300 N and there are 5 wheels of the robot. From static analysis of forces on the wheels, it is taken that the heaviest part that exerts force as 90 N. These wheels are taken as the most critical part of the wheel shaft design.

$F_w = 90$ N, $d_s = 5.25$ mm, $L = 19.56$ mm,

$f = 0.5$, $d_w = 62$ mm.

The material properties are taken as: AISI 1080

$S_{ut} = 615.4$ MPa, $S_y = 375.8$ MPa, $E = 200$ GPa.

(S_{ut}: Ultimate Tensile Stress, S_y: Yield Stress, E: Modulus of Elasticity)

After determining the torque, moment and direct force on each shaft on the wheels, bending and shear stresses are evaluated. Von Misses Stresses are evaluated to find alternating and mean components of the shear and bending stresses. Moreover after determining the design factors (size, temperature, reliability, and so on), the process for finding safety factor begins. (Budynas and Nisbett 2006)

$$\sigma a1 := \sqrt{\sigma abending^2 + \tau a^2 \cdot 3} \quad (1)$$

$$\tau m := 16 \cdot \frac{Tw}{\pi \cdot ds^3} \quad (2)$$

$$\sigma m := 0 \quad (3)$$

$$\sigma m1 := \sqrt{\sigma m^2 + \tau m^2 \cdot 3} \quad (4)$$

$$Se1 := 0.5 \cdot Sut \quad (5)$$

The endurance strength limit is calculated as:

$$S_e = k_a.\ k_c.\ k_d.\ k_f.\ S_{e1} \quad (6)$$

$$S_e = 1.853 \text{x} 10^2 \text{ MPa} \quad (7)$$

$$n := \frac{1}{\left(\frac{\sigma a1}{Se} + \frac{\sigma m1}{Sy}\right)} \quad (8)$$

At the end, it is defined that the safety factor (denoted by n) should be at least 2 and after calculations are done we obtained that n = 2.542.

So, this design for shafts of wheels is safe enough to satisfy the needs of the design.

3.4. The Design of Structural Members

The structural members carry sweeper motor for arm mechanism, spherical bearing connection, PLC controller box and relays. Since the exact location for the arm connection point to the structural members should be determined in detail, more durable body frame is satisfied and space minimization is provided, it is better to use special designed laser cut 0.5 mm thick sheet metal.

6. CONCLUSIONS

Before deciding to use this design, it is thought about lots of different designs' workability. At the beginning of the concept selection, there are lots of alternative concept designs. Firstly, it is tried to use some mechanical ways to separate the wastes. But in order to use these mechanical ways, huge amount of space for the machine is needed and large amount of energy is required for running these mechanical systems. According to these design specifications, the space is strictly limited, and it is only permitted to use dry cells as energy sources in the system so it should better to give up thinking of usage of mechanical ways to separate the wastes. Secondly, it is tried to use some piston arrangement to separate the wastes but in this design, it is needed lots of small pistons, and compressors to run these pistons, also the system needs lots of energy to run these pistons. It is known that dry cells are not powerful enough to run these compressors, also compressors occupy large amount of space. Another disadvantage of that system is that these pistons are hard to find, and it is too expensive. Finally, we tried to find a system which occupies small amount of space and also economic. In order to fulfill these conditions, we decided to use a kind of robot.

In a nut shell, the robot has some specialties. These specifications are weight, time, energy, user friendliness, accuracy, and space occupation. (Dieter 2000) It is chosen that the materials of the system with considering these specifications. There are a few motors in this system. These motors should not be heavy, should occupy small amount of space, and should consume small amount of energy and should satisfy torque and revolution requirements. Also, the process has to be completed in five minutes so the robot should make the process quick. Our system has to be user friendly. In our design, the user will only pour the waste, push the button, and wait until the wastes separated. The system has to occupy small amount of space. A robot can easily fulfill all of these specifications.

Further effort is going to be made in order to apply for patent of this design project and to provide automation of the robot for industrial needs. Since, Autonomous Waste Sorter Design Project provides an innovation to the sorting problem in recycling industry; we hope that this new and original project is going to be patented.

7. REFERENCES

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Appendix A. NOTATIONS

d: Diameter (mm)

L: Length (mm)

A: Cross Sectional Area (mm^2)

E: Modulus of Elasticity (GPa)

S_y: Yield Strength (MPa)

S_t: Tensile Strength(MPa)

S_{ut}: Ultimate Strength(MPa)

S_e: Endurance Limit(MPa)

n: Safety Factor

K: Yield Strength Modification Factor

F: Force (N)

M: Moment (N.m)

T: Torque (N.m)

σ: Tensile Stress(MPa)

σ_m : Mean Tensile Stress(MPa)

σ_a: Alternating Tensile Stress(MPa)

τ: Shear Stress(MPa)

τ_m: Mean Shear Stress(MPa)

τ_a: Alternating Shear Stress(MPa)