ABSTRACT

MEENAKSHISUNDARAM SRINIVASAN, SATHISH. Timer Based Automated Object Dispenser System Design with Programmable Control. (Under the direction of Dr. Yuan-Shin Lee).

This thesis presents a new approach to automated object dispensing and their working procedures. A programmable controlled hardware assembly includes the design of movable components of mechanisms, stepper motor, timer and actuator. This machine is designed to accommodate different types and sizes of objects with a small change in the components of the machine.

The methodologies for sorting and dispensing are presented with various mechanisms, and three different models are proposed. The evaluation and validation of these models are done to select the best working concept, and a prototype system is built. A software program is developed based on the working algorithm of the system to control the stepper motor and actuator in the system. The program is real-time based so that the objects can be scheduled according to selected time intervals. The user interface prompts the user to select the objects and the timing sequence on which these objects are to be dispensed. Based on the inputs from the user, the system responds and starts working. A communication interface is developed in the programmable environment which interlinks the output of the sensors placed in the system and updates the system's working status to the user. The system status includes working status of the system with individual components working status, status of the object dispensed and the object's availability for future dispenses. A prototype model of the proposed concept is developed and tested. The presented techniques can be possibly used for both manufacturing industry and health care systems.

Timer Based Automated Object Dispenser System Design with Programmable Control

by
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APPROVED BY:

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Chair of Advisory Committee

DEDICATION

To my father Srinivasan, my mother Usha and my brother Venkatesh.

BIOGRAPHY

Sathish Meenakshisundaram Srinivasan was born in 1984, hailing from Madurai, India, which is well known as the Temple City. He received his Bachelors of Engineering in Mechatronics from Thiagarajar College of Engineering, Madurai, India in the year 2006. He worked with Tata Consultancy Services as Assistant Systems Engineer from July 2006 to April 2008. He then decided to do MS in Industrial Engineering with a concentration in Manufacturing and joined North Carolina State University, Raleigh, USA in August 2008. He works as a Research Assistant to Dr. Yuan-Shin Lee in the field of Manufacturing and Automation.

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Chapter 1

Introduction

1.1 Motivation

Sorting objects and dispensing the right objects at the right timing is very important for many different applications. These applications are used in a variety of industries ranging from food processing, textiles, pharmaceuticals and manufacturing industry with discrete components. For example, a tablet dispensary is useful for hospitals and homes. Particularly, older people need medication regularly and they sometimes forget to take their pills or tablets, due to shortness of memory. The purpose of this thesis is to design and develop an object dispensing machine to dispense tablets according to the prescription of a doctor. A software program in the computer acts as the brain of the system, controlling stepper motors and actuators. Once the objects are dispensed the system reminds the user, with a LED illuminator or buzzer sound. Details of the design and development are presented in this paper.

In the medical and pharmaceutical industry, the applications of sorting and dispensing objects are of great use. The importance of proper medication for patients is stressed widely. This proposed system can be used as an automated medicine or tablet dispensing system which dispenses tablets at specified intervals and time period to the patients. The problems of improper medication according to the National Council on Patient Information and Education are listed below:

(a) Patience Compliance

- Almost two-thirds of Americans currently use medicines: Forty nine percent use prescription drugs and thirty percent use non-prescription medications.

- The No.1 problem in treating illness today is the patient's failure to take prescription medications correctly, regardless of patient age

- Two-thirds of all Americans fail to take part or all of their prescription medicines.

(b) Effects of non-compliance

- Twenty three percent of nursing home admissions are due to non-compliance.
- Ten percent of hospital admissions are due to non-compliance.

(c) Prescriptions

- About fifty percent of the 2 billion prescriptions filled each year are not taken correctly.

- One third of patients take all their medicine, one third take some, one third do not take any at all (that is, their prescription is never filled).

In order to avoid these problems and improve the patient compliance, there are many products available to make it easier for the patients to remember their medication and take their medicine at the right timing. There are some models available that require lots of work from the patient side. The patient needs to sort the tablets according to the prescription and load them in proper chambers. This involves lots of work from the patient. The application of sorting and dispensing of objects can be applied in many industries, among them a few are listed here:

(a) Applications in the textiles industries

In the textiles and garments manufacturing industries, the buttons involved in the manufacturing of clothes need to be sorted and dispensed according to the type and size. There are a variety of buttons depending on the cloth color and design. These buttons need to be stitched with clothes. They are dispensed according to the requirement based on the speed of the processing materials. This would be of great use in the garments manufacturing industry.

(b) Application in food processing industries

In the food processing industries and the confectionery manufacturing industries, the assorted mix of their products involves sorting, dispensing and packing of the items at the right time. There is a huge need of these applications in food processing industry where sorting and dispensing of different food items is involved.

(c) Application as pet feeding machine

In many occasions, the pets have to be left in a home for a long time during a family outing or a vacation. The dispensing system can be used as a pet feeding machine, where the discrete food items can be loaded so that the machine operates and dispenses the food to the pets on a timely schedule. The size of the pet food is a constraint here. If the size of the food is big, accommodating them needs changes in the dimension of the parts of the machine. This machine can feed for different number of days and periods so long as the food lasts.

1.2 Research scope and objectives

This research will focus on designing and building a timer-based automated dispensary system with programmable control, which can be used in different industries to dispense objects with the right quantity at the right timing. The hardware and software program components which control the system are discussed in detail. A software program is developed by using a Visual Basic platform with a user friendly interface. This system works according to the inputs specified by the user. The timer activates a stepper motor control which positions the actuator at the required position and activates the dispensing mechanism. The actuator pushes the dispensing mechanism and delivers the required objects. The controller also keeps counting the number of cycles with a counter. The system is equipped with sensors and control logic to send out communicative message, when the system detects errors or runs out of tablets.

1.3 Thesis outline

The rest of the thesis is organized as follows. Chapter 2 presents the literature review. Chapter 3 explains the methodologies for object sorting and dispensing. Chapter 4 discusses the object sorting and dispensing models. Chapter 5 presents the details of the sorting and dispensing system design. Chapter 6 presents the development of programmable control for the automated object dispenser system. Chapter 7 presents the experiments and results. Chapter 8 provides the conclusion and some possible future research directions.

Chapter 2

Literature Review

In this chapter, some literature review of object sorting and objects dispensing techniques are presented.

2.1 Objects sorting

Objects sorting deals with the separation of objects based on their parameters. The parameters may be physical or geometric parameters like material, shape, size, color etc. An example of objects sorting is the coin sorting and counting machine which sorts the coins based to the coin size and dispenses vouchers corresponding to coins [Mol06]. All the coins are fed into a hopper from where it passes through a rotating chamber containing holes of the sizes of different coin. The holes are arranged in ascending order in such a way that small coins fall out of chamber first through the small holes. The coins of bigger sizes are then moved towards the other end where they fall out through the corresponding holes. Finally, if there are any exceptions in the coins left, they will be collected at the end.

Sorting can also be possibly done using color as the parameter. A color sensor is used to determine the color of the object and take corresponding action depending on the identified color. If an object of particular color is to be deposited, a stepper motor rotates and directs the movement of the conveyor in that direction. Sorting the objects can also be done based on the height of the object [SC01]. This is done using a height regulator through which the objects are allowed to pass. The height regulators act as hindrance to the objects and cause the objects to fall from the conveyor.

2.2 Vision based sorting

Software based automated sorting is of primary importance in industries today. The sensors and cameras are used as the source to collect the object's parameters. Image processing techniques combined with artificial intelligence are used to identify the objects. The advantages of these systems are high speed sorting, higher efficiency, high accuracy and the elimination of human involvement. An example of identifying pistachio nuts in industries using acoustics signals and a multilayer feed forward neural network classifier is discussed in [OMO09].

Some example applications of vision based sorting in industries are discussed in [CKY06]. Computer vision algorithms were used to determine the color of the fish and sort them fast. This allows non-destructive testing method. A computer vision based surface detection of apples was discussed in [LWG02]. The system captured the image of apples and further processing was done based on the results obtained by image processing technique.

A real time counting and sorting using visualization of fluorescence excitation was discussed in [KWWL08]. In [YZ08], a mechanical sorting using computer vision and VC++ software is presented. The image of parts moving at a conveyor is captured using camera and the image was processed to determine the shape, based on which the sorting was done. In [JRHS00], robotic sorting was presented to sort a random pile of papers using vision and the Hough algorithm. The algorithm detects the edges and grabs the paper using a vacuum picking mechanism. Another example of vision based sorting of parts moving in a conveyor was discussed in [MCG00]. The sensing and gripping of objects in sorting was handled using a fuzzy technology neural classifier.

2.3 Tablet dispenser and methods

Drug dispensing device serving with limited space availability was discussed in [Tak00]. Tablets and pills were arranged in a case and the case was dispensed according to the prescription. In [Kim03], the packaging of tablets and pills is done as the tablets are dropped into the bag which is sealed and packed. Figure 2.1 shows this method. A high speed counting and dispensing discussed in [Gel04]. It uses the storage compartments with a predefined number of tablets. When a request was made, the tablets were dispensed from the storage compartments without the need for counting. This eliminates the delay time needed for counting.

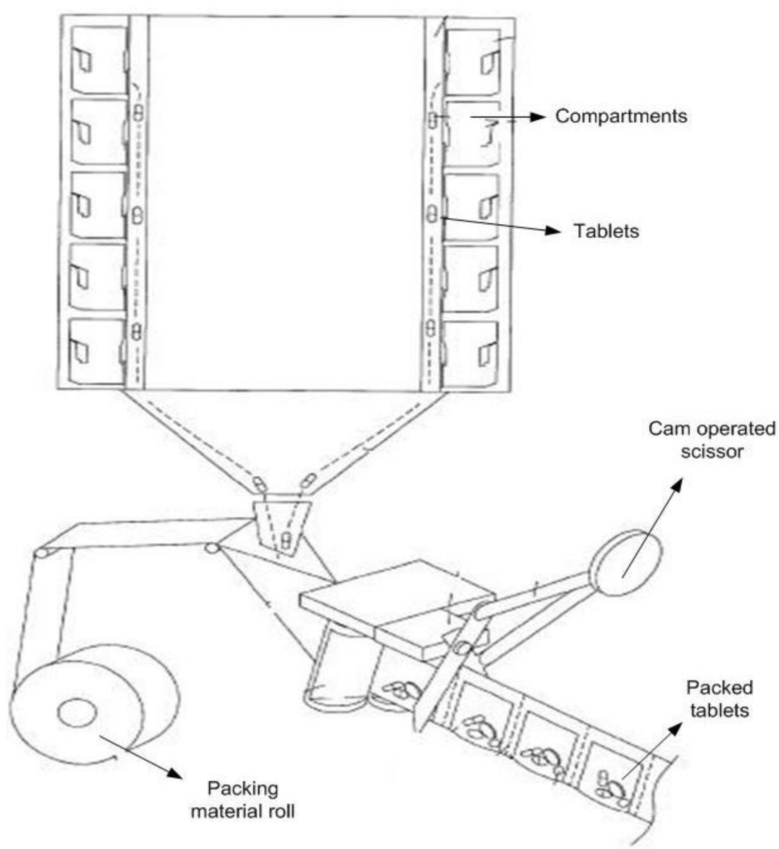


Figure 2.1 Tablet dispensing and packaging [Kim03]

Another type of tablet dispenser is discussed in [Spa94]. This contains plurality of frames and housing for the tablets with vial manipulator assembly, a motor, a control and a printer to print the prescription. In [Wei91] a dispenser with non-reversing method was discussed. There is a rotating disk which can hold only one tablet during its rotation. When the disk rotates the tablet falls into the opening through the orifice, by gravity. The disk rotates in one direction so it becomes non reversible for tablet due to gravity.

In [Gir08], a small hand-held tablet dispenser with dual lever mechanism is implemented. It can handle only one type of tablet. This is specially designed for candy or mint. This works with force given by pressing the lid at the top which opens the lever at the bottom, and thereby dispensing one tablet at a time. In [Har76], a tablet dispenser is implemented with vertical cylindrical stack of tablets pushed at the bottom by the reciprocating pusher. In [Koo95], a tablet dispenser is developed with a rotator at the bottom. In [Var08], a tablet dispenser with a rotating component carrying one tablet for each rotation is discussed. The problem with this model is that it cannot work with tablets other than the circular shape. In [EJ03], a tablet dispenser is implemented with a motor on which the compartments were moved. When the compartment reaches the desired position it opens and dispenses the tablets to a collecting cup. In [Lew86], tablet dispenser primarily working on the principle of operation of a cam is discussed. It contains rotating chambers with space for multiple pills or tablets. Once loaded it rotates and dispenses tablets at one chamber. The problem with this is that the tablets need to be loaded according to the sequence of the prescription of tablets. Skipping one dosage of tablets may result in error and confusion.

In [Pea06], a vacuum pill dispenser with a counter was discussed. In this design there is a rotating vacuum disc with a counter housing which can load tablets by vacuum suction cup and the rotation places them on the pill separator which slides the pill though the opening. There is a counter placed against the pill separator to detect the pill and count the number of pills. In [KJ08], a vacuum method was used in the heavy pharmaceutical industries.

In [Boy97], a tablet counter and dispenser is used in object dispensing based on vibrational dispensing method controlled by a microprocessor. This system uses a concave shaped, slope with number of descending steps to separate the tablets and control the flow as required. This is suitable for different types of tablets. The vibrational speed can be varied according to the requirement.

2.4 Summary

In this chapter we reviewed the works related to sorting, dispensing and packaging. Discussions were focused on the techniques of vision-based sorting, mechanism-operated sorting and vacuum-based sorting and other conventional methods used in sorting. In the following chapters we will present the details of developing a timer-based programmable control method for object sorting and dispensing.

Chapter 3

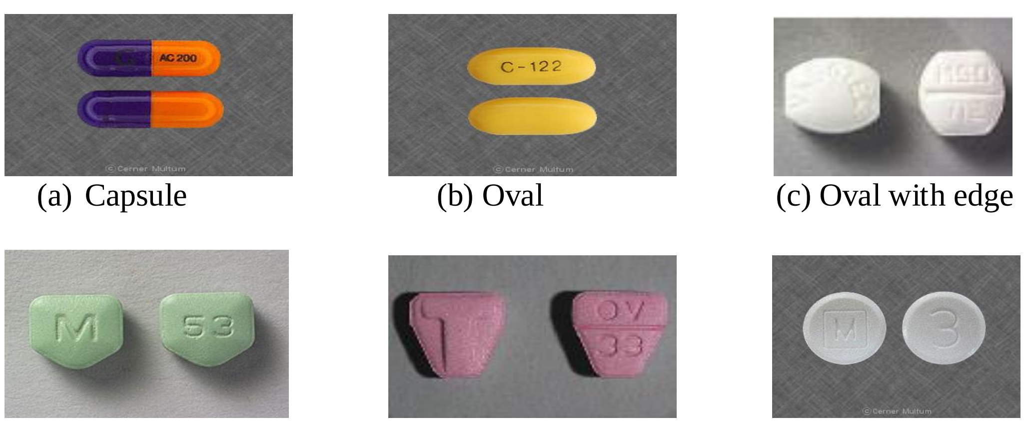
Methodologies for Object Sorting and Dispensing

While designing a system for object dispensing, many factors need to be considered. The ease of use, assembly, reusability and simple design are some of the factors to be considered in designing a system. Our objective is to design and develop an object dispensing system by taking advantage of the logical and programmable control with a software program.

3.1 Important factors considered in the design

- The system should be simple in its working mechanisms. For example, a system without gears is much simpler in implementation than a system with gears.

- The size of the system should be small with fewer components and easy for assembly.



(a) Capsule (b) Oval (c) Oval with edge

(d) 5 sided (e) Triangular (f) Circular

Figure 3.1: Pictures of different shapes and sizes of tablets

- The system should be very easy to be used from the user's perspective.
- The cost of manufacturing should be low to make the product affordable.

This system consists of both the hardware and software components. The hardware components involve designing of components based on its working principle. The software part consists of the Visual Basic program which drives the hardware components. The most challenging part of the design is to dispense the right object. The main aim of designing such a system is to load the system with tablets and to dispense the tablets according to the prescription and the schedule given by the user. This eliminates the patient's burden in remembering the dosage. The major difficulty was dispensing one correct tablet from the bin. An analysis was done by analyzing different dimensions of tablets. There were around 670 different tablets available in a database provided by a hospital. Designing a common mechanism that accommodates all the different variety of tablets is a challenging task. Some examples of different shapes of tablet are shown in Figure 3.1.

Table 3.1: Classification of tablets based on axial shape and tube shape

Axial Shape	Tube Shape	Number of Varieties	Percentage
Bar Shaped	Bar Shaped	5	0.75
Rectangle	Rectangle	14	2.10
Diamond	Diamond	6	0.90
Hexagon	Circle	15	2.25
House- shaped	Diamond	3	0.45
Octagon	Circle	3	0.45
Octahedron	Ellipse	3	0.45
Oval	Circle and Ellipse	306	45.95
Pentagon	Pentagon	8	1.20
Round	Circle	273	40.99
Shield	Kite	4	0.60
Sphere	Circle	4	0.60
Square	Rectangle	5	0.75
Trapezoid	Rectangle	7	1.05
Triangle	Triangle	8	1.20
U-Shaped	Rectangle	2	0.30
Total		**666**	**100.00**

Considering all these different shapes and sizes, the tablets were categorized into groups based on the shapes. There were fifteen different types of shapes. Table 3.1 shows the different types of tablets available. It also shows a list of tube shapes that can be used to accommodate them.

The range of the height was in a permissible range to accommodate with few changes to the system design. The height of tablets is chosen as a base for further design. Table 3.2 shows the distribution (in %) of tablets with respect to the tube shape. By classifying these tablets according to the thickness and shapes, different tablets can be adopted into several different tubes in the design.

Table 3.2: Tube shape and percentage distribution

Tube shape	**Axial shapes covered**	**Percentage of tablets**
Bar shaped	Bar shaped	0.75
Rectangle	Rectangle, Trapezoid, Square	4.20
Diamond	Diamond	1.35
Circle	Hexagon, Octagon, Oval, Round, Sphere	67.27
Ellipse	Octahedron, Oval	23.43
Pentagon	Pentagon	1.20
Kite	Shield	0.60
Triangle	Triangle	1.20
Total		**100.00**

Table 3.2 shows eight major tube shapes with various dimensions required to accommodate the range of different shapes of tablets. Table 3.3 shows the classification of tablets based on the Z dimension i.e. the height of tablets.

Table 3.3: Classification of tablets based on their dimensions and shape.

S.no	Axial Shape	X (dimension in mm)	Z (dimension in mm)	No. of varieties
1	Oval	9	3	15
2	Rectangle, Concave Rectangle, Pentagon, Oval, Round, Bar-Shaped	4 -15	4	27
3	Bar-Shaped, Oval, Trapezoid, Rectangle, Concave Rectangle, Hexagon, Diamond	3 - 15	5	93
4	Oval, Bow-Shaped, Concave Rectangle,House-shaped,Octahedron,Pentagon,Round,Hexagon,Sphere,Square	6- 15	6	116
5	Oval,Trapezoid,Hexagon,Diamond,U-Shaped,Rectangle,Pentagon,Shield	7 - 21	7	135
6	Oval, Round, Rectangle, Diamond, Trapezoid, Bow-Shaped, Square	8- 20	8	124
7	Rectangle, Oval, Hexagon, Triangle. Round, Round, Octagon	7 - 10,15,16, 18 - 20,23	9	55
8	Oval, Triangle, Diamond, Round	10,13-22	10	54
9	Oval, Triangle, Round, Pentagon	11,22	11	22
10	Round, Hexagon, Oval	6,10,12	12	13
11	Round	13	13	4
12	Oval, Round	7,14	14	4
13	Round, Oval	16	16	2
14	Oval	19	19	1
15	Round	20	20	1
	Total			666

In pharmaceutical industries, a counting mechanism is used but the mechanism which they use is very complex. They use a vibrational mechanism on which the tablets move and fall one by one. The limitation of these mechanisms is that it is for the same size objects. In our case we are dealing with variety of tablets in different sizes and shapes so these previous mechanisms cannot be used.

The other mechanism that was taken under consideration is the vacuum suction method where one can just load the tablets with their boxes and the suction cup will suck one tablet from the correct box and deliver it to the collecting cup at the other end. The suction force changes with the different size and weight of the tablet.

Another possible solution is the vision-based technique. Vision-based sorting needs a good resolution camera with good lighting with objects moving in a conveyor. The camera captures the image of the objects moving in the conveyor. The image is processed using the software which makes analysis from the frame and color pixels and decides course of action. This is used in most of the fast lane processing industries like food processing where the conveyor is used to sort the items. Vision-based systems typically are more expensive to build.

We focused our efforts on looking for a simple but effective mechanism which can solve the problem of sorting and dispensing. There were a few mechanisms found to be helpful and they are discussed in the following sections.

3.2 Simple mechanisms used for sorting and separating

An example of simple oscillating mechanism is shown in Figure 3.2. The oscillating movement picks up the parts to be separated one by one and feeds the parts in the other direction. In [SC01], several simple mechanisms that can be used for the purpose of sorting and feeding were discussed. In Figure 3.2, one can see the angle and the dwell at both ends of the stroke that controls the timing and allows the next part to be loaded.

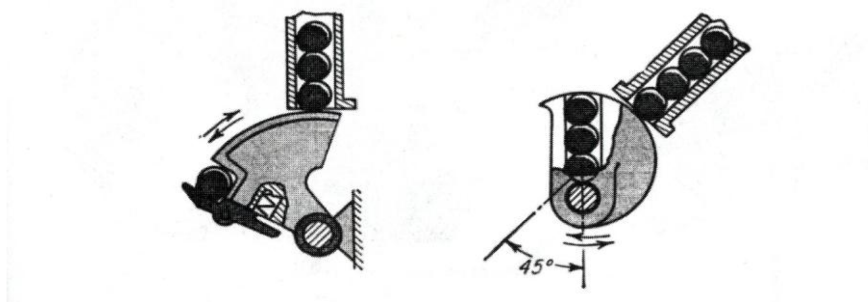


Figure 3.2: Feeding device mechanism [SC01]

Figure 3.3 shows examples of reciprocating and oscillating mechanisms for separating parts. The circular objects slide in an inclined tube due to gravity. This can be coupled with reciprocator and oscillating mechanisms to separate an object from the lot. Figure 3.3 (a) shows the reciprocating mechanism used to separate parts. In Figure 3.3 (b), an oscillating mechanism is used.

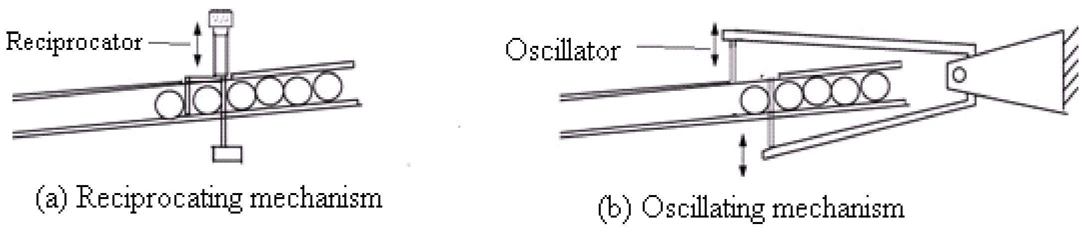


Figure 3.3: Separating device mechanism

Figure 3.4 shows a mechanism of two counter rotating wheels to mix two alternative objects. In Figure 3.4, the rotating wheel has grooves, which can load an object and drop it when it rotates. This design works fine with objects that are cylindrical in shape. In [Booth05], mechanisms for automatic feeding and orienting of objects were discussed. Objects falling under gravity are given higher priority, as there are variations in the tablet weight.

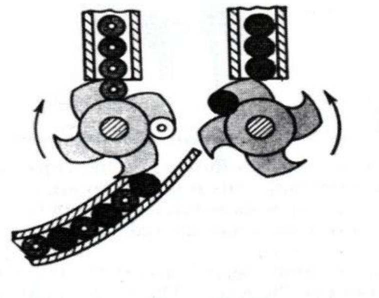


Figure 3.4: Mixing different parts mechanism [SC01]

Figure 3.5 shows a simple sorting mechanism based on the size of the spherical object. In Figure 3.5 (a), a spherical object is allowed to roll over the rails with varying distance in between the two rails. When the object reaches a point where the gap between the rails is equal to the diameter of the object, it falls in the chamber placed below. Figure 3.5 (b) shows another mechanism with a trap door and gate. The spherical object pushes the gate based on its height. This helps to decide the path in which the object should travel. If the object does not touch the gate, it falls through the trap door. If it touches the gate, it moves forward along the other path as the trap door is closed. This mechanism is best suited for spherical objects. Objects can be sorted at a time into two categories using this method.

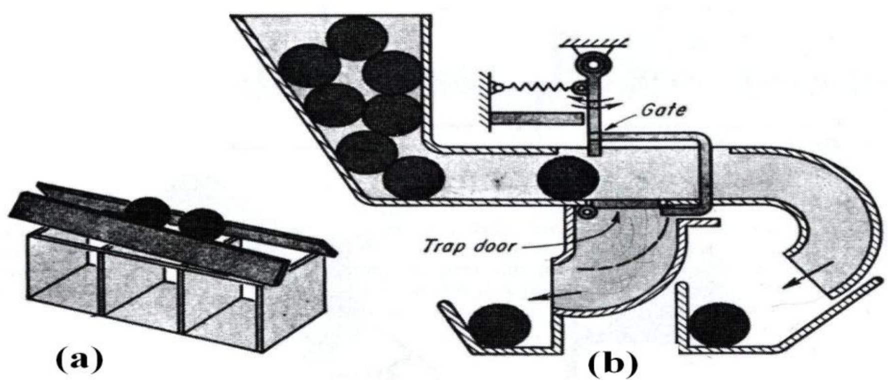


Figure 3.5: Simple sorting mechanisms [SC01]

Figure 3.6 shows a simple mechanism to sort objects based on its height. The objects are placed in a rotating cross platform to pass through height regulators that act as obstacles, to push the parts from the cross platform and falls into a collector.

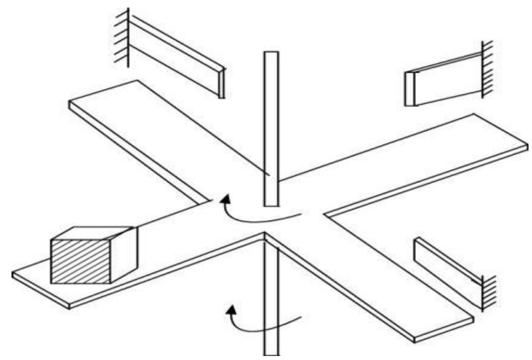


Figure 3.6: Sorting by height mechanisms

Figure 3.7 shows four-bar-linkages mechanisms for sorting. Figure 3.7 (a) shows a mechanism where the parts are separated in a moving conveyor. This is similar to the oscillating and reciprocating mechanism seen earlier. Figure 3.7 (b) shows a mechanism to separate the group of cylindrical components using a hopper which tilts to separate the objects. Figure3.7 (c) shows a mechanism for separating cylindrical objects based on the gravity.

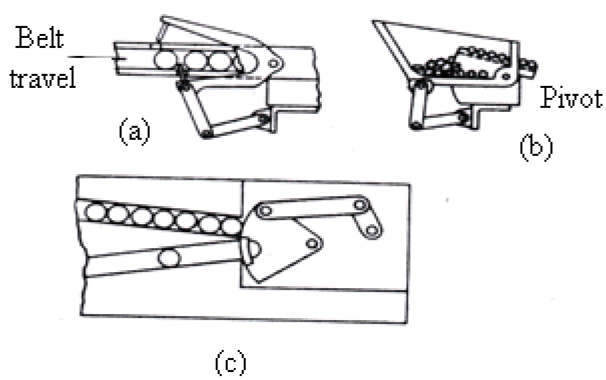


Figure 3.7: Simple separating mechanisms [SC01]

The problem with these mechanisms discussed above is that they do not deal with objects of different sizes and shapes. Based on the different tablet shapes and thickness, we are trying to figure out a mechanism to perform the sorting and dispensing.

3.3 Summary

In this chapter the basic working principles and methodologies for dispensing of objects are discussed. In designing a prototype system, we consider the tablet shape and its thickness as the parameters to be considered for sorting and dispensing process. In this thesis, we will develop a prototype system which can handle different types of tablets. In the following chapters, we will discuss the details of constructing such a prototype systems for object sorting and dispensing.

Chapter 4

Design and Analysis of Object Sorting and Dispensing Models

In this chapter three different design models for the object sorting and dispensing are proposed. A comparison of the three models is done with the key features and parameters. A validation and analysis of the models are done based on the task variables. The best model is recommended for construction.

4.1 Models designed for object dispensing

The basic requirement for the design is that the system should be simple and feasible. The model should meet the specifications considered for design. The idea behind designing various models is to look for different ways to achieve the goal of better dispenser design. Both the positive and negative points of the designs are considered and evaluated. A model may seem to be simple but the components involved in them may be too costly. Similarly a model may seem to be more complex but the components can be relatively cost effective. There should be a right mix of the components and technical feasibility. In this paper three design models are proposed based on the technical feasibility and other approaches. They are:

1. Slider model;
2. Geneva mechanism model; and
3. Gear-driven model.

Details of the three different design models are discussed in the following sections.

4.1.1 Slider Model

This design model is based on a slider mechanism, as shown in Figure 4.1. It contains a small slider which can accommodate the object that needs to be dispensed. We designed a casing for the tablets where the tablet can comfortably placed and the actuator can push the casing, which is called slider. A detail of the design is shown in Figure 4.1. The sliders are designed depending on the sizes and shapes of the objects. A slider is pushed by an actuator from its position and thus the objects falls. When the slider is pushed away by the actuator, it also blocks the movement of the other objects in the tube.

In this model an actuator and stepper motor are used as the main driving components. As shown in Figure 4.1, the slider is designed in such a way that it can hold a tablet in the small opening at its center. A push of the slider moves the tablet towards the other end when the actuator is powered. The slider slides in along the guides which prevents the slider from unwanted movement. A spring is installed at the end of the slider which is compressed when the actuator is powered and slider is pushed to move the tablet. This spring action can bring the slider back to its original position when the actuator is disconnected from power. A slider serves the following purposes:

1. The slider serves as a predetermined position where the tablet sits when it slides through the cylindrical tube.
2. The slider prevents any unexpected movement of other tablets in the cylindrical tube when actuator is pushing the current tablet.
3. The slider helps the actuator to push the tablet and comes back to the original position with the help of a spring action when the actuator is reversed.

This slider is placed in between two plates, and the plate at the bottom is designed especially for blocking and allowing tablets to fall at particular position of the slider. This is designed to work with a stepper motor and one actuator. The slider motor turns the actuator towards the required position. The actuator pushes the slider, moves the tablet from the cylinder and blocks the movement of other tablets in tube. The thickness of the slider should be equal to the thickness of the tablet so that by replacing the slider of different thickness, it can accommodate tablets of different thickness. The basic circular plate is connected to several cylindrical tubes as shown in Figure 4.2.

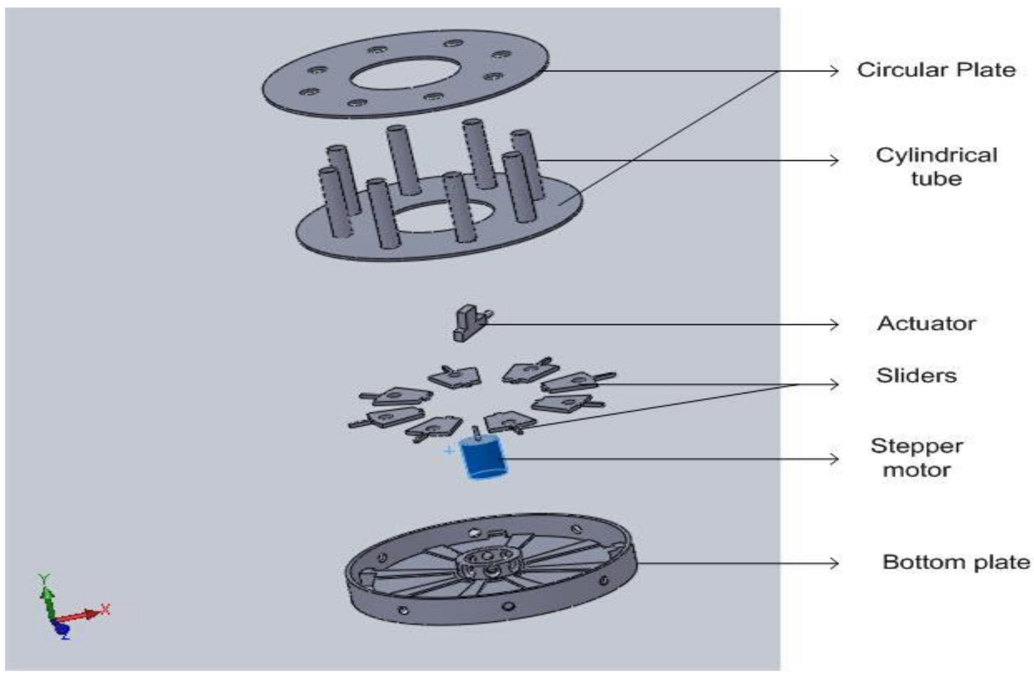


Figure 4.1: Slider model assembly

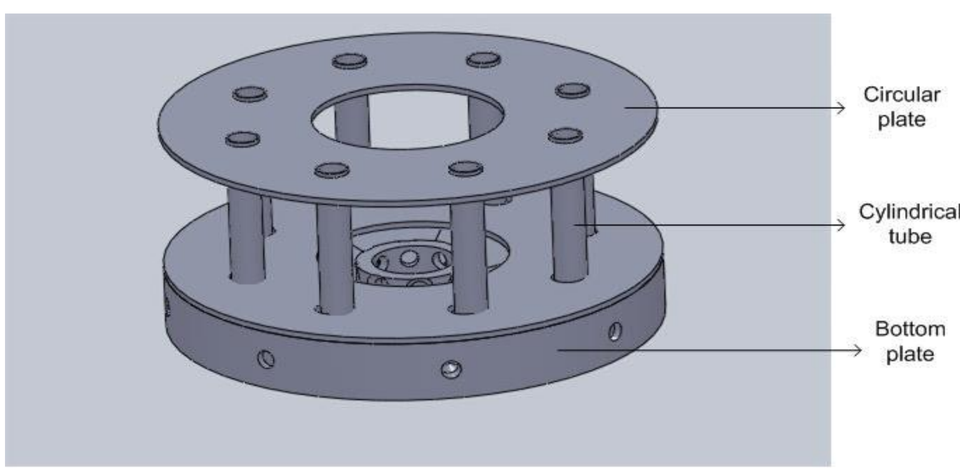


Figure 4.2: Slider model assembly

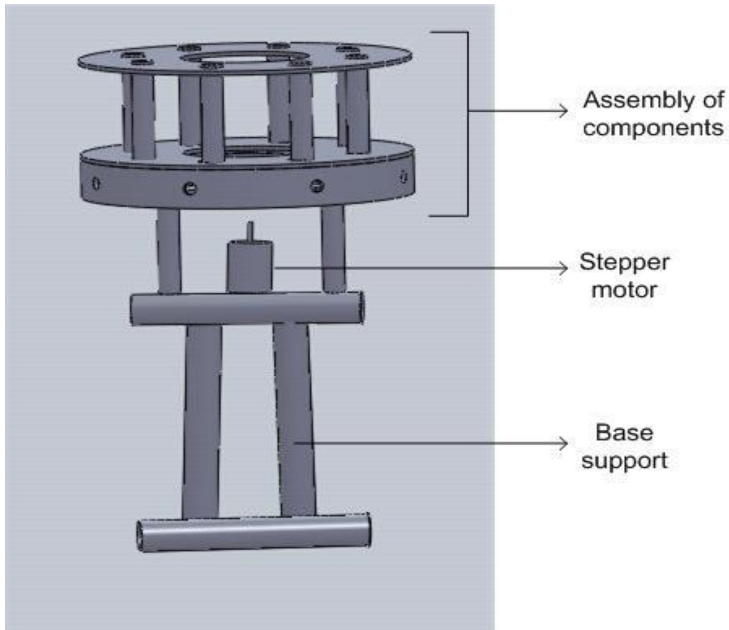


Figure 4.3: Slider model assembly

In this design model, the slider has opening equivalent to the size of the tablets (see Figure 4.1). The height of the slider is equivalent to the height of the tablet. Thus the slider can accommodate only one tablet at a time. When the actuator pushes the slider, it moves away from its resting position by compressing the spring. It also blocks the movement of any other tablets in the tube above. When the actuator is released, the spring enforces slider back to its original resting position. It also loads the next tablet from the cylindrical tube. The spring gets compressed when the actuator is activated. The assembled structure of the model design is shown in Figure 4.3.

4.1.2 Geneva mechanism model

In the second design, a model of the Geneva mechanism is shown in Figure 4.4. The idea is to provide an alternative for the actuator. There may be some possible failures which may prevent the first design model of actuator from working properly. The cylindrical tube containing the objects can be closed at one end with a wheel. In the second design model with Geneva mechanism, the wheel contains a grove and rotation of the wheel can be controlled using a stepper motor. The engaging and disengaging of stepper motor with the wheel will be a tough task. The opening and closing of the wheel dispenses the object. If there is any problem in opening and closing at the right time, it results in the failure of dispensing the object.

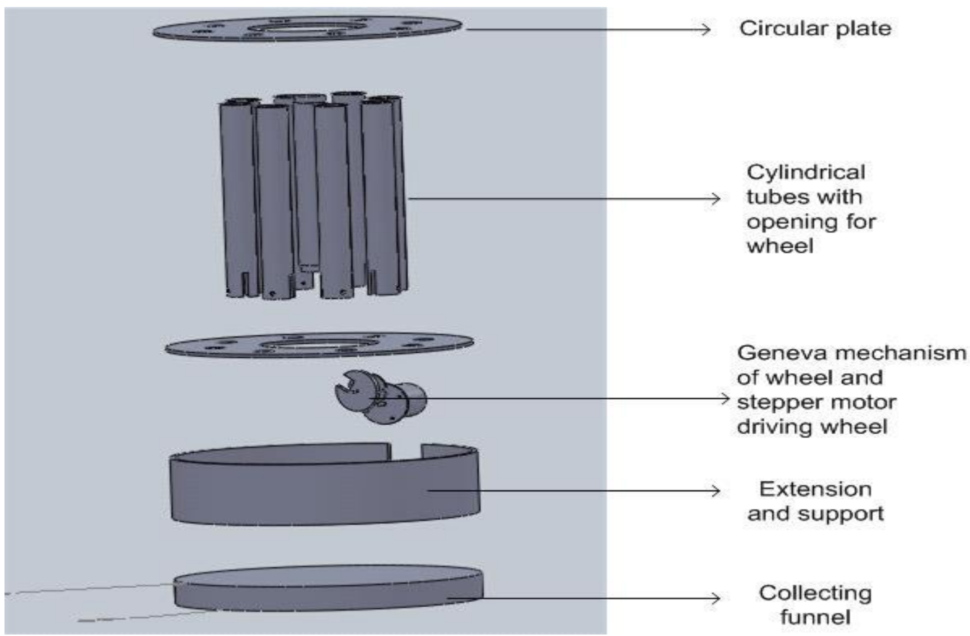


Figure 4.4 Geneva mechanism assembly with components

In the second design model with Geneva mechanism, a wheel is designed instead of slider which is fixed with the cylindrical tube containing the entire tablet as shown in Figure 4.4. The Geneva mechanism wheel has a small slot which can hold a tablet, as shown in Figure 4.4. The slot size is equal to the size of one tablet. The wheel is rotated 180 degrees so that it drops the tablet from the slot and it is rotated back to its original position to load next tablet. The challenge of this model is to use one stepper motor for the rotation of the plate which contains all the eight cylindrical tube containers and to use another stepper motor for the rotation of the wheel. To use one motor for all the wheels, we need to have a proper mechanism to engage and to disengage the wheel properly with the motor. We cannot attach the motor permanently to a wheel as it also needs to operate the other wheels too. As shown in Figure 4.5, a Geneva mechanism is used in the design. The Geneva mechanism helps to rotate the wheel without getting fixed to a stepper motor. However, the Geneva mechanism may cause the error of positioning the wheel away from the cylindrical tube. This may result in error while loading tablets. To exactly position the rotating Geneva mechanism is a real challenge. The wheel needs to be fixed and free from rotation, when it is not engaged with the Geneva wheel. This involves designing a special stopper to stop any unwanted movements. The rotational direction also needs to be streamlined for one direction. To stop the movement of wheel, it needs gears to hold a lever and control the movement. This makes the system more complex. When replacing a wheel, the lever also needs to be considered. This adds even more problems to the design. The exact engagement of wheels with Geneva wheel will become challenging when the circular base plate is rotating 360 degrees.

The engagement and disengagement of the wheels is shown the Figure 4.5. Due to the drawbacks of Geneva mechanism and the wheel alignment position problem, this model was not further considered in this paper.

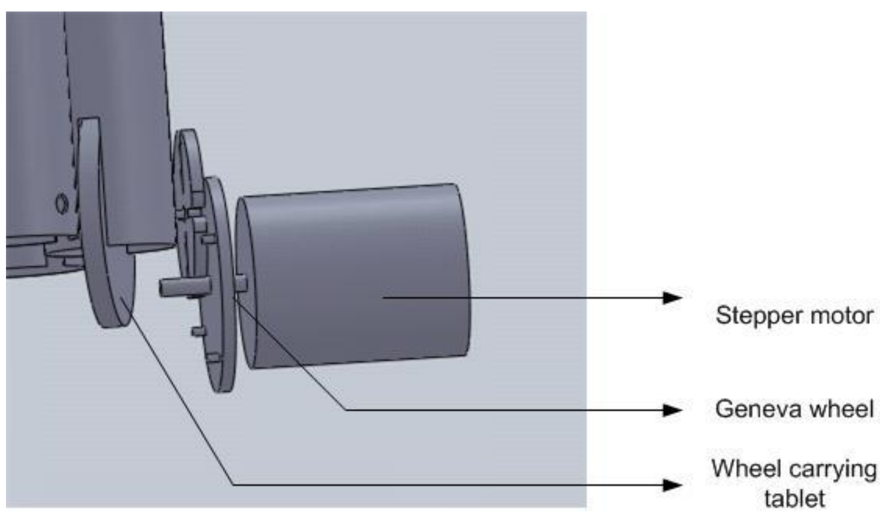


Figure 4.5: Geneva wheel alignment

4.1.3 Gear-driven model

The third design model is to modify the second model by addressing the above mentioned problems. The Geneva mechanism is replaced with gears as shown in Figure 4.6. The rack and pinion gear is used and the rack is attached to a stepper motor. The operation of the stepper motor controls the rack and it makes the wheel to rotate 180 degrees to drop the object, as shown in Figure 4.6.

As shown in Figure 4.6, the rack and pinion gear arrangement is considered as a replacement of the Geneva mechanism. The rack is connected to the stepper motor which makes it move. The wheel is attached with the pinion. The wheel is turned 180 degree by the rotation of the stepper motor through rack and pinion gear. When the rack moves away, the wheel is disengaged and thus the circular plate can be rotated using the other stepper motor. The working is explained in following three stages. In the first stage the stepper motor runs and pushes the rack towards the other end in order. This is shown in Figure 4.6.

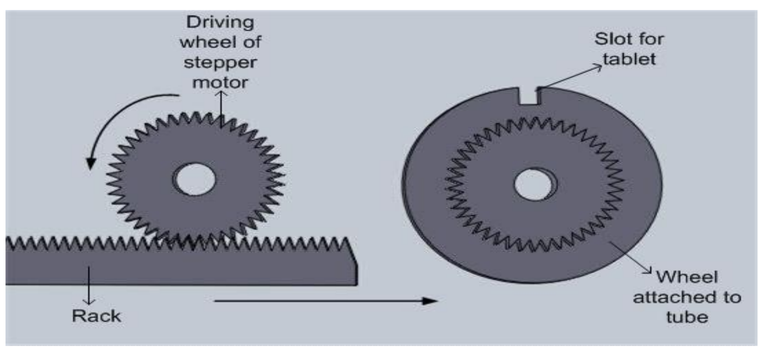


Figure 4.6: Rack and pinion arrangement

In the second stage, the rack starts to get in touch with the wheel and the wheel starts rotating. This rotation is done for 180 degrees so that the tablet which is seated in the position falls out. Figure 4.7 shows the stage two operation where the rack starts to touch the gear of the wheel.

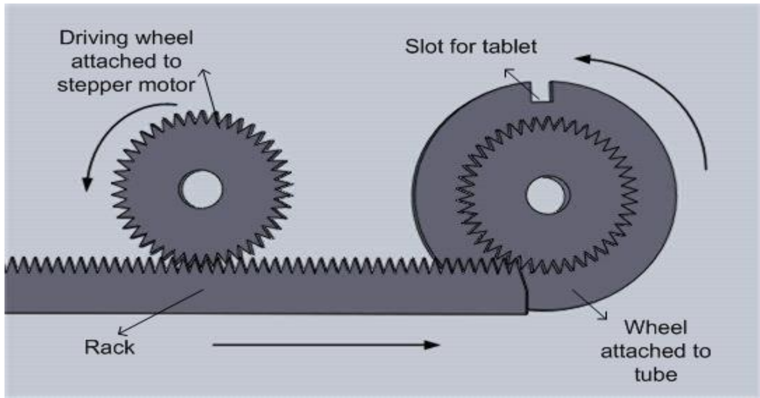


Figure 4.7: Rack and pinion arrangement

In the third stage the rack completes its motion and the wheel has rotated 180 degrees. Thus the tablet falls down easily. This is shown in Figure 4.8.

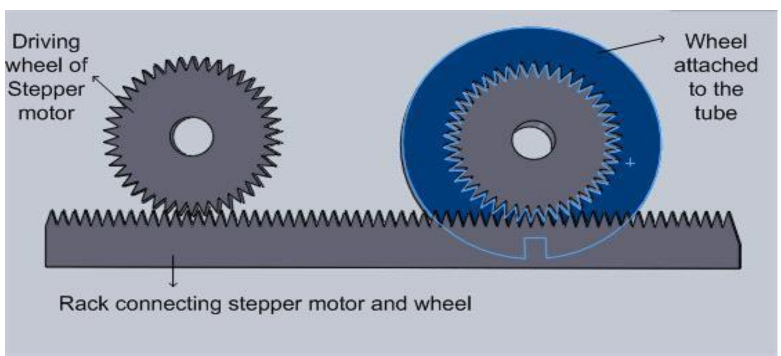
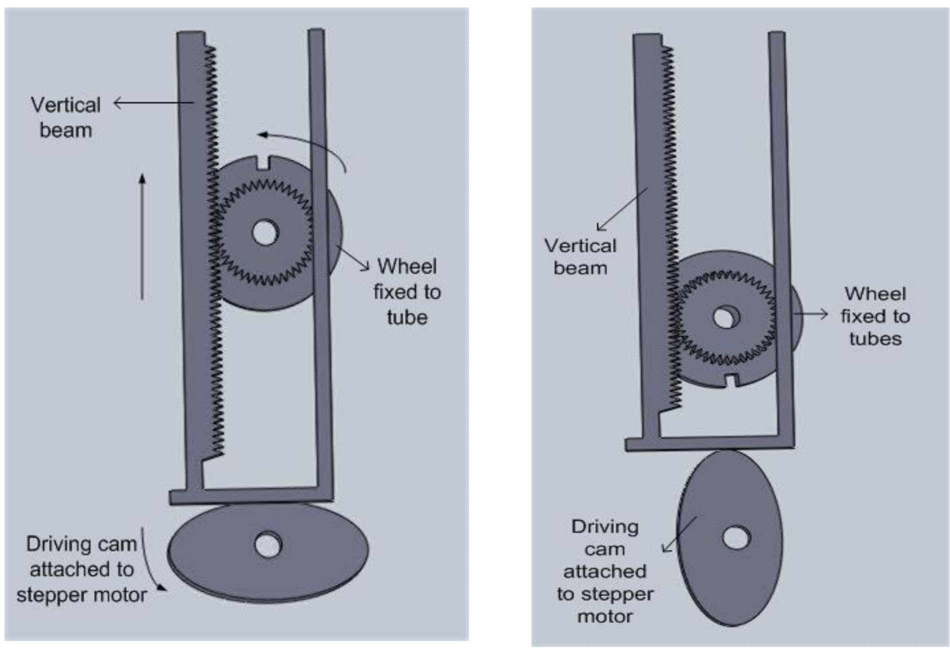


Figure 4.8: Rack and pinion arrangement

There were a few more problems like arresting the movement of the wheel when it is away from the stepper motor end. The wheel motion needs to be arrested to load the next tablet. The position of the slot is critical to load the next tablet. To design a lever, the gear mechanism is redesigned so it acts as a movement arrester for the wheel and as the driver for wheel, as shown in Figure 4.9. This is done using the gear is transferred into a vertical beam where the wheel is attached. The vertical beam can be moved up and down based on which the gears drive the rotation of the wheel, as shown in Figure 4.9. The cam is used to make the beam move up and down. The cam is designed according to the distance that needs to be moved and cam rotation is done using the stepper motor as usual. This system is better than the Geneva model as it has the gear which aims in the precise motion of the wheel. The model also arrests the wheel from the unwanted movement. The detailed diagrams of the stages are shown in Figure 4.9. The challenges with the third design model are the difficulty of manufacturing of the small gears, racks and pinion.



(a) Wheel in loading position (b) Wheel rotated 180 degree

Figure 4.9: Gear driven model component

4.2 Analysis of the three dispenser models

Among the three different models, we plan to identify one best model and construct a working prototype. We need to decide which design is the most efficient, reliable and simple to construct.

4.2.1 Comparison of three models

The comparison chart in Table 4.1 shows the features of all the three models. The main features to be compared are the design and working mechanism. If the design is simple and has a good working mechanism it is given a high priority. Complex or difficult models are given lower score. The feasibility of working with different sizes of tablets is considered as a better design. The number of components required to assemble in the system is also considered. The model with fewer components is given a higher priority. Interchangeable parts are another key feature to be considered. If there is good inter replace ability then it needs less components to accommodate different tablet sizes. Based on these parameters the three models are compared and the comparison is shown in Table 4.1.

Table 4.1: Comparison of three models

Features	Model 1 Slider model	Model 2 Geneva mechanism model	Model 3 Gear driven model
Working mechanism	Simple	Moderate	Complex
Feasibility of working with different size of tablet	Yes	Yes	Yes
Total number of components	39	36	28
Interchangeable of components	Yes	Yes but not to a great extent	Yes but not to a great extent
Gears	No	No	Yes
Stepper motor	1	2	2

1.2.1 Evaluation of models

Part merit rating is calculated for parts used in the assembly based on the individual components [Carl04]. Part merit is calculated with the feeding merit, insertion merit and fastening merit, as shown in Table 4.2. The merit is the numerical value from 0 to 10. Merit is assigned to each part for each of the three assembly events. Zero represents that the event being very difficult to accomplish and ten represents that it is very easy to complete. The part merit can be formulated as follows:

Part Merit

$$= \frac{\sqrt{Feeding\ merit^2 + Insertion\ merit^2 + Fastening\ merit^2}}{\sqrt{3}} \qquad (1)$$

Combined Average Merit (CAM)

$$= \frac{Sum\ of\ part\ merits}{Sum\ of\ parts} \qquad (2)$$

Product Assembly Merit (PAM)

$$= CAM \left\{1 - \frac{Sum\ of\ redundant\ parts}{Sum\ of\ parts}\right\} \qquad (3)$$

From Equations (2) and (3), CAM and PAM ratings are used to evaluate the models finally. Table 4.2 shows the CAM and PAM rating of the slider mode. Table 4.3 shows the CAM and PAM rating of the Geneva mechanism model. Table 4.4 shows the CAM and PAM rating of the gear driven model.

Table 4.2: CAM and PAM rating of the slider model

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Circular Plate	1	8	9	8	8.35	0
Circular Plate	1	8	9	8	8.35	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0
Cylindrical tube	1	9	8	9	8.68	0

Table 4.2 Continued

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Bottom Plate	1	8	9	7	8.04	0
Stepper motor	1	8	9	8	8.35	0
Actuator	1	8	9	8	8.35	0
Funnel	1	8	9	8	8.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Size Converter	1	10	10	9	9.68	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Slider	1	9	9	9	9.00	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Spring	1	9	8	8	8.35	0
Base	1	10	8	9	9.04	0
Sum	**39**					
			CAM		**8.82**	
			PAM		**8.82**	

Table 4.3: CAM and PAM rating of the Geneva mechanism model

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Circular Plate	1	8	9	8	8.35	0
Circular Plate	1	8	9	8	8.35	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Cylindrical Tube	1	9	8	9	8.68	0
Geneva Wheel	1	8	7	7	7.35	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	6	7	6.68	0
Wheel	1	7	8	7	7.35	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Stepper Motor	1	8	9	8	8.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0

Table 4.3 Continued

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0
Size Converter	1	9	10	9	9.35	0
Sum	**36**					
			CAM		**8.12**	
			PAM		**8.12**	

Table 4.4: CAM and PAM rating of the gear driven model

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Circular plate	1	8	9	8	8.35	0
Circular plate	1	8	9	8	8.35	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Wheel with gear	1	6	7	7	6.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Fixing clamp for wheel	1	8	8	7	7.68	0
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0

Table 4.4 Continued

Part Name	No.	Feeding	Insertion	Fastening	Part Merit	Redundant Part
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0
Size Converter	1	9	9	9	9.00	0
Stepper motor with gear	1	8	8	9	8.35	0
Rack	1	7	8	7	7.35	0
Sum	**28**					
			CAM		**7.83**	
			PAM		**7.83**	

Table 4.5: Comparison of CAM and PAM rating for the three different models

S.No	Model	Parts	CAM	PAM
1	Slider Model	39	8.82	8.82
2	Geneva Mechanism Model	36	8.12	8.12
3	Gear driven model	28	7.83	7.83

Table 4.5 shows the overall CAM and PAM evaluation of all the three models. If the CAM and PAM ratings are the same, it indicates that the design is optimized with non-repetitive parts. A model is considered as a better design, if it has a higher CAM value.

Validation of the three models is also done based on the following features. The working feasibility is considered for 40%, components involved in the system constitute for 25%, interchangeability of components for 10%, efficiency and reliability of the system for 15%, and other parameter like manufacturing cost, construction, assembly of the components are considered for 10%. Based on these parameters the three models are compared and shown in Table 4.6. Figure 4.10 shows the pie chart percentage distribution of the features.

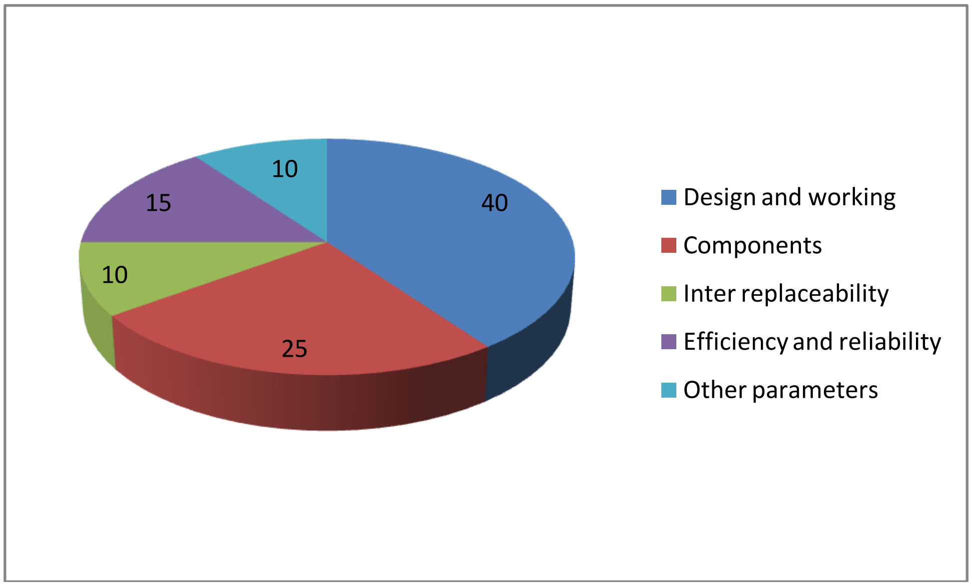


Figure 4.10: Pie chart of parameters for validation

As shown in Figure 4.11, based on the validation, the first model with the slider is a better design than the other models. The problem with the Geneva mechanism model (the second model) is that the wheel component needs to be replaced and it requires the second stepper motor. In the third model with gears, the mechanism is simple but the manufacturing of the gears and the interchangeability are challenges. The slider model scores high because of the simple mechanism design of the actuator. The slider can also be easily replaced easily. The slider model is selected and considered as the best model design for prototype.

Table 4.6: Comparison of model based on the features and construction

Features	**Slider Model**	**Geneva mechanism model**	**Gear driven model**
Design and working	38	30	35
Components	21	23	24
Inter replace ability	10	7	7
Efficiency and reliability	15	10	10
Other parameters	9	6	6
Total	**93**	**76**	**82**

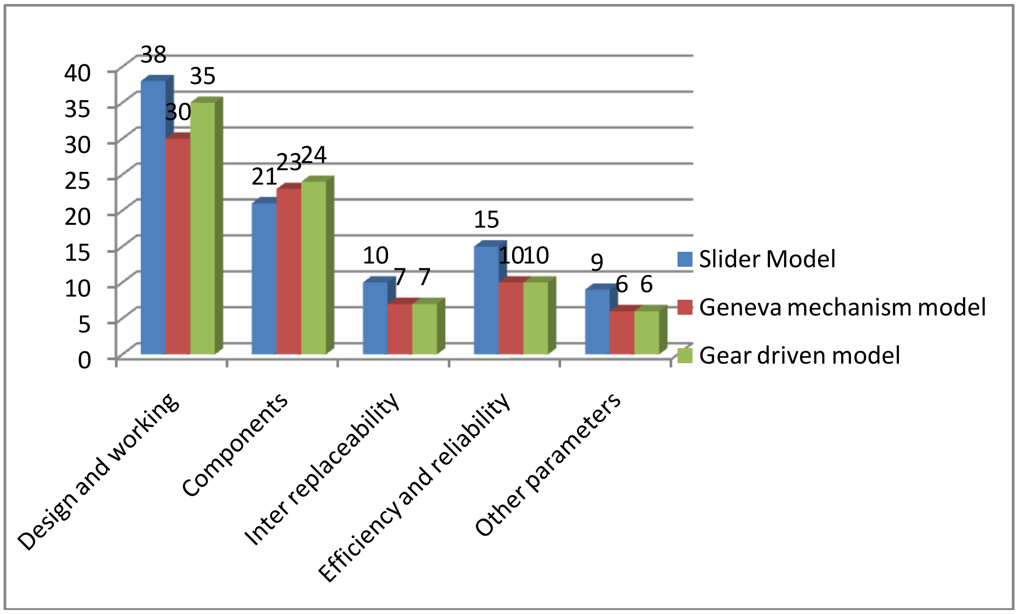


Figure 4.11: Overall comparison of the models

4.3 Summary

In this chapter we presented three different design models for object sorting and dispensing. Comparisons of the different models are discussed. Based on the analysis, the model with the simplest feasible mechanism is selected. In the next chapters, details of constructing the selected slider mechanism and the development of the automated control system are discussed.

Chapter 5

Sorting and Dispensing System Design

5.1 Working mechanism of the slider model

The working mechanism of the slider model is shown in Figure 5.1. The slider rests on the bottom plate between the guides. The slider has a small opening at the center in which it can carry a tablet. The opening at the center is usually based on the shape of the tablet. If a tablet is hexagonal shaped, then the opening should be hexagonal to accommodate the tablet. If the tablet is round, then the opening can be a circular one. The circular opening at the center can also accommodate other shapes of tablets like square, rectangle and hexagon. The slider carries the tablet based on its size and the slider width need to be equal to the width of the tablet. As shown in Figure 5.1, the slider is pushed away from its position to release the tablet. The plate has slots which allow the tablet to fall on the gravity. When the slider is pushed the spring is compressed on one end of the slider, as shown in Figure 5.1. The length of the spring should be greater than or equal to the slider extension.

In Figure 5.1, the slider movement with an actuator is shown. Figure 5.1 shows the original positions of the actuator and the slider. The slider is moved by the actuator against the spring. This happens when the actuator is powered. This leads to the movement of the slider and the tablet is pushed from its original position. When the actuator is deactivated, the slider is pushed back to its original position by the spring.

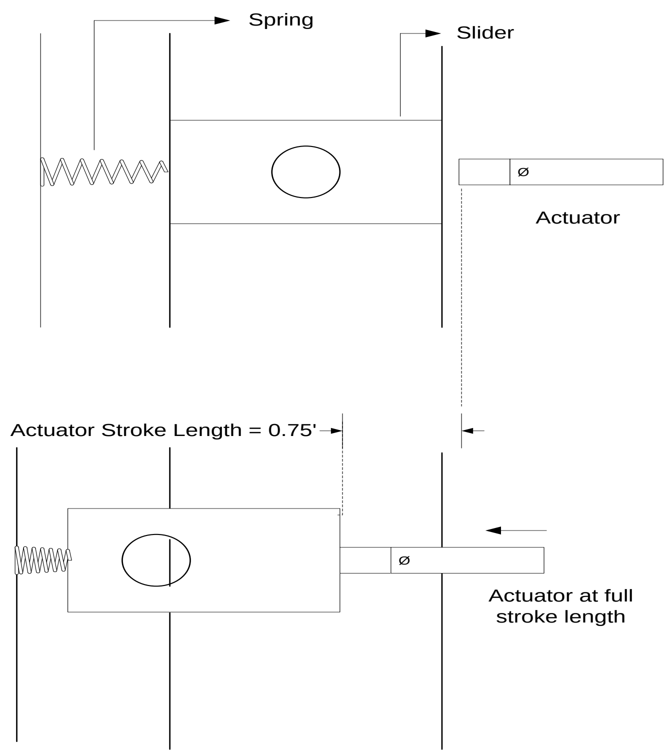


Figure 5.1: Mechanism of the slider

5.2 Design of components

The components used for the slider mechanism are listed in Table 5.1. The detailed design and description of all these components are discussed in the following sections

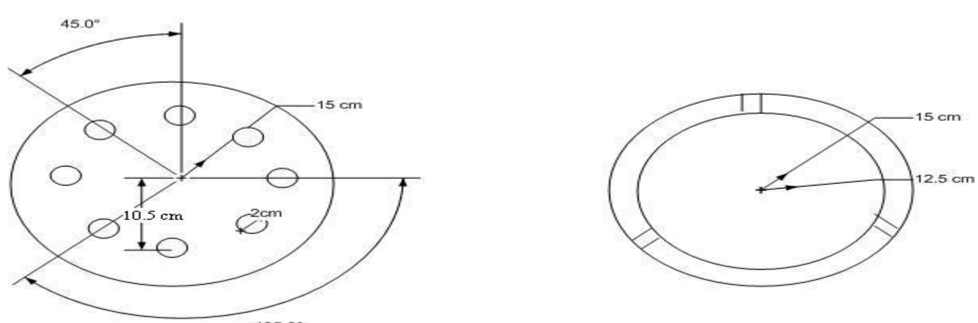
Table 5.1: List of components for the slider model

Components	Required numbers
Circular plate with 8 slots for cylindrical tube	2
Cylindrical tube	8
Bottom plate with guide to help slider movement	1
Slider	8
Spring	8
Actuator	1
Stepper motor	1
Size converters	8
Funnel and base structure	1

5.2.1 Circular plate

The circular plate serves the purpose of holding all the cylindrical tubes on which the tablets can be loaded. As shown in Figures 5.2 and 5.3, the circular plate has eight slots on which the cylindrical tubes can be inserted. We decided to go with eight slots for the whole 360 degrees, each slot is carved out at 45 degrees as shown in Figure 5.4. The number of degrees between the slots can be varied according to the number of slots and working angle. If the number of slots is increased to twelve, the angle between the slots will be 30 degrees.

As mentioned earlier the circular plate serves as the base on which the whole system is built. There are two circular plates used in this system. The cylindrical tubes are held in between these circular plates. A cylindrical tube contains the loaded tablets to be dispensed. The circular plate of radius 150 mm is designed, as shown in Figure 5.4. The slots for the cylindrical tube are located at 105 mm distance from the center. The radius of a slot is 20 mm. We provide an opening for the actuator to rotate at the center is 58 mm. The reason for opening at the center is to allow the free movement of the actuator. In the preliminary design, we had a base plate without an opening for the actuator. A shaft connects the center of the circular plate to a stepper motor to rotate in Geneva mechanism model. As the plates are kept stationary in this model there is no need to connect these plates to the stepper motor. The initial design of the cylindrical plate is shown in Figure 5.2. Figure 5.3 shows three dimensional view of the circular plate done using Solidworks. Figure 5.4 shows the drawing of the circular plate.



(a) Circular plate (b) Bottom plate

Figure 5.2: Drawing of circular plate and base plate

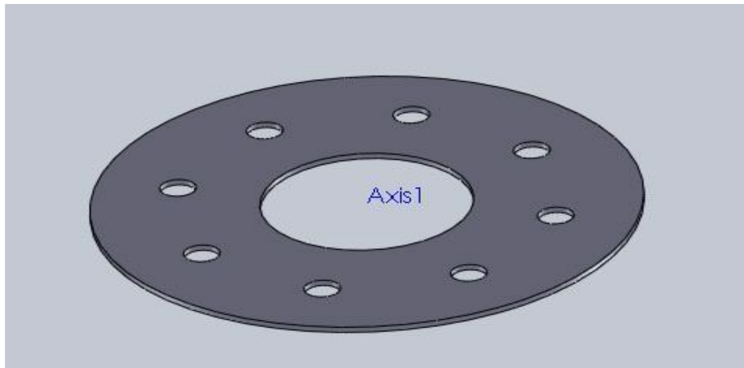


Figure 5.3: Circular Plate

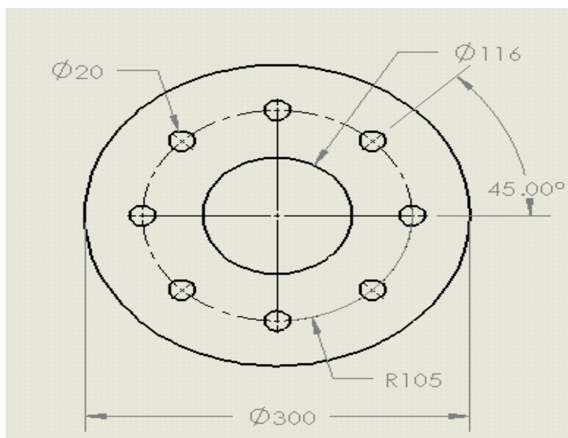


Figure 5.4: Circular plate –drawing

The reason for using a diameter of 20 mm for the cylindrical tubes is that is the maximum length of the medicine tablet according to the available data is 20 mm. The tablets sizes were listed in an Excel sheet for data validation. When the tablets were classified according to the height of the tablet, the minimum length of the tablet was around 3 mm and the maximum length was around 20 mm. The system should be designed in such a way to accommodate different tablet sizes. If the length of tablet is less than 20 mm then the size converters are used. The size converters are the washers which can be inserted in these slots and thus the size of these slots are changed. The length of the cylindrical tube inserted can be altered according to the requirements.

5.2.2 Cylindrical tube

The cylindrical tube holds the tablets to be dispensed and it is also used to connect circular plates. The cylindrical tube with a length of 90 mm is selected. The cylindrical tube is made of plastic and it is transparent. Figure 5.5 shows the cylindrical tube.

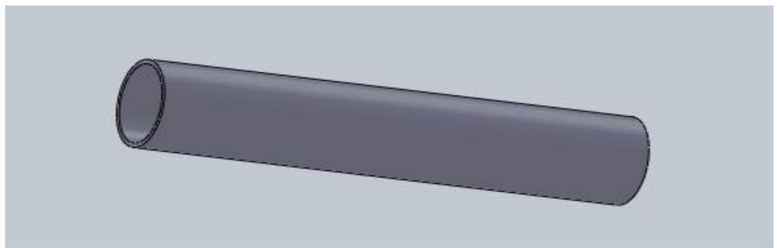


Figure 5.5: Cylindrical tube

The transparent tube is helpful to view the tablet's orientation. To avoid the misalignment of tablets, the space available in the cylindrical tube should be slightly larger than the size of the tablet. The tube is a primary component in aligning the tablets in proper orientation to the slider. The diameter of tube should be exactly equal or slightly greater than the length of the tablet. The reason behind the clearance space is that it allows the tablet fall freely by gravity. To keep the tablets in good orientation, the cylindrical tube should be slightly greater than the tablet size. In some cases the tablet shape is different from round, in such cases the cylinder is housed with some liner which gives the exact size of the tablet. For example, the capsule has an elongated shape and the cylindrical tube may not hold it in its orientation. A liner should be used to modify the cylinder to exactly enclose the capsule in the proper orientation.

5.2.3 Bottom plate

The main purpose of the bottom plate is to serve as a holder for the slider. Figure 5.6 shows the dimensions of the bottom plate. It guides the slider during the actuator stroke. The bottom plate is of 150 mm radius and the slots opening is from 125 mm to 145 mm from center. There is a border at the center of the plate which acts as a stopper to the slider. The angular guide for slider is 25 degrees and the angle of a stopper is 20 degrees, as shown in

Figure 5.7. The distance between these two slots should be exactly equal to the stroke length of the actuator. If the distance is less than the stroke length, it serves better for the purpose. If the distance is greater than the stroke length, the slider cannot reach the slot and dispense the tablet. The spring force pushes back the slider. The alignment should be in such a way that the opening in the slider should be in a straight line with the cylindrical tube. In order to align the slider back to its original position the stoppers and guide were designed. The guide is the space along which the slider can glide through.

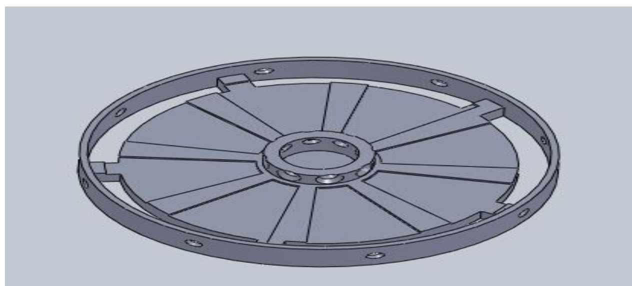


Figure 5.6: Bottom plate

The guide is designed in such a way that it aligns slider in its position at the end of each cycle. The main purpose of the guide is to guide the slider. A three dimensional representation is shown in Figure 5.6. The bottom plate drawing is shown in Figure 5.7.

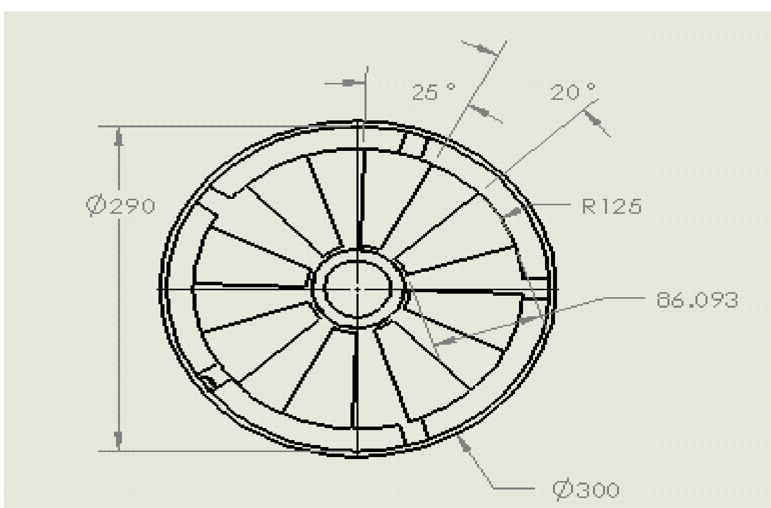
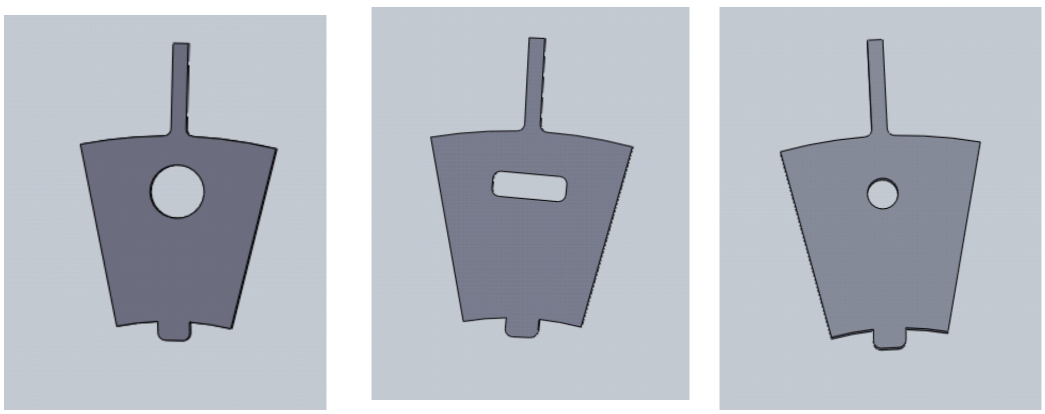


Figure 5.7: Bottom plate -drawing

5.2.4 Slider

The slider is an important component which holds the tablets from the cylindrical tube and drops them to the collecting cup. The slider is the key component in the tablet dispenser. As shown in Figure 5.8, the slider varies in the thickness depending on the height of the tablet and the slot in which it carries the tablet. It also depends on the different shapes of the tablets. Three different types of slider designs are shown in Figure 5.8.



(a)Slider for circular tablets. (b) Slider for capsule. (c) Slider for small circular tablets.

Figure 5.8: Different types of sliders

The slider was initially designed for 45 degrees without any guides. Thus eight sliders will constitute for 360 degree. While testing with these sliders, these sliders did not function properly due to friction. Then the design was modified with guides. The slider angle was reduced to 25 degrees and the side guides was modified to 10 degrees each on both sides. The guides were joined together to form 20 degrees. The design of the slider was modified to have some extensions on outer side and inner side. The long pin was, designed for the holding the spring, as shown in Figure 5.9. The purpose of the spring is to retrieve the slider back to its original position. The other end tail is to assist in making contact with the actuator.

When the slider is in its rest position, the center of the slider slot should be the same as the center of the cylindrical tube. This is to assist the tablets to drop into the slot of the slider directly. The total length of the slider should not be greater than the space available in the circular plate. The total length includes the extensions on both sides of the slider. The detailed dimensions of the slider are shown in Figure 5.9.

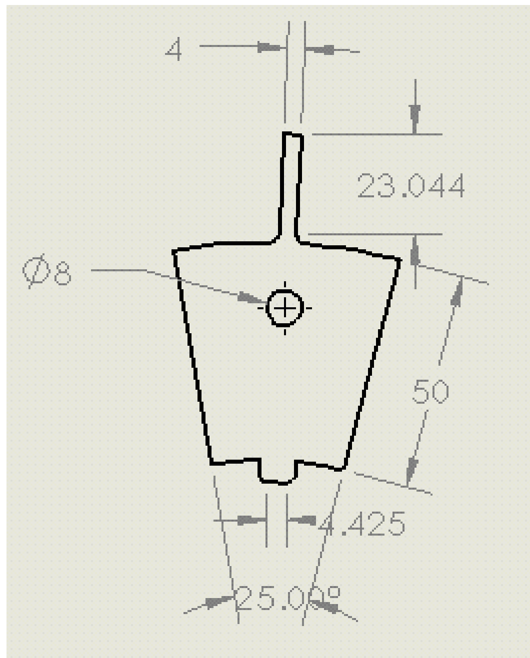


Figure 5.9: Drawing of slider

5.2.5 Spring

The main purpose of using spring is to push the slider back to its original position when the actuator reverts back its arm to the original position. Figure 5.10 shows the spring being installed on the extension pin of the slider. The spring is one of the important components for the system. Without spring action, the movement of the slider back to its original position is not possible. The only other way to bring the slider back to its original position is to use an actuator. To return to its original position, the slider can be pulled. Fixing the slider to the actuator is not feasible as there is only one actuator which serves all the eight sliders for the whole system. The spring is important in bringing the slider back to its position. The spring length should be slightly greater than the slider extension in order to exactly fix it within the position. Figure 5.10 shows the spring and slider.

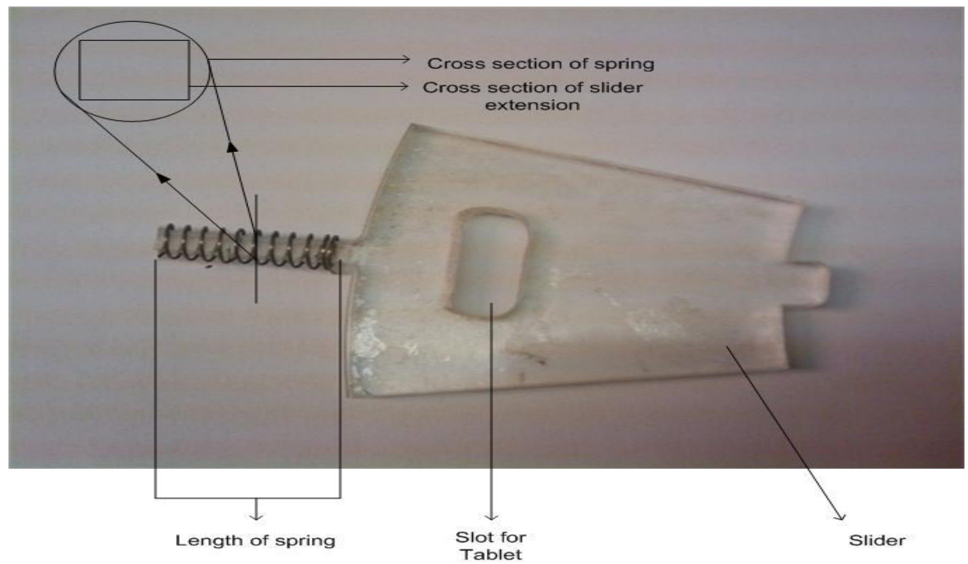


Figure 5.10: Slider spring interface

The length of the spring is an important parameter to be considered. If the spring length is less than the slider extension, it results in a gap space on which the slider can freely move without any obstruction. This may cause poor performance of the system. The slot at the center of the slider should be greater than the length of the tablet. The shape of the slot should also correct in matching the shape of tablet to function properly. For example if the tablet is round, the slider slot should also be a round one. The rectangular slot does not serve well in this case.

The design and selection of the spring are specified as follows (also see Figure 5.11):

Spring free length, L_{free} = 1.5 cm

Spring length when deformed, L_{def} = 0.4 cm

Force exerted by spring, F = 39.22 N

The spring constant, K

$$= \frac{F}{L_{free} - L_{def}} \quad (4)$$

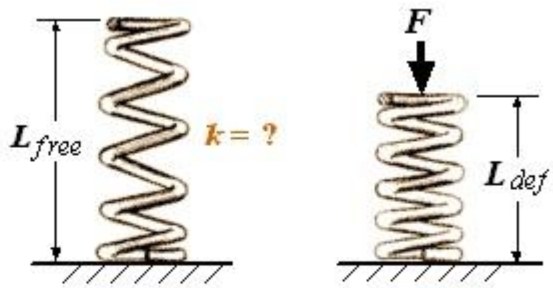


Figure 5.11: Spring specification details

Applying the values in Equation (4), the spring constant K can be calculated as follows:

$$K = \frac{39.22}{1.5 - 0.4}$$

$$= 20.2 \text{ lbf / in} = 3.55 \text{ x } 10^6 \text{dyne / cm}$$

5.2.6 Actuator

The actuator is one of the major components required to make the system work properly. The actuator consists of two beams. The actuator arm extends when the power is activated, as shown in Figure 5.12. When the actuator arms needs to be extended, the actuator is activated by connecting to power. For reversing the direction of the actuator the polarity is reversed. The force generated through this actuator should be large enough to push against the spring. The actuator is placed in such a way that it is equidistant from all the slots and sliders in the system. The actuator is connected with a stepper motor using a proper housing made up of sheet metal in such a way that the stepper motor can rotate the actuator to move the particular slider. Detailed specifications of the actuator are shown in Table 5.2. The weight of the actuator is 0.35 lbs which is very negligible. The time taken for the stroke is 0.2 seconds and the stroke length is 0.75". The operating voltage of the actuator is from 9 V to 15 V. The wires connected to the actuator can get entangled when the stepper motor keeps rotating in one direction. To stop this, the stepper motor is designed to rotate bidirectionally to reach to the initial position of the actuator. The actuator is shown in Figure 5.12.

Figure 5.12: Actuator used in the system.

Table 5.2: Actuator specifications

Specifications	
Actuator base diameter	1”
Full extension unit length	6-1/4”
No extension unit length	5-1/2”
Dimensions	4”L x 2-1/4”W x 1-5/8”D
Weight	0.35 lbs
Lifecycle	100,000 times
Temperature	-40c to +80 c
Push / pull load	4 Kg
Actuator lock/unlock time	0.2 seconds
Voltage	12+- 3

The car door actuator has a simple DC motor which runs a series of spur gears which serves as the gear reduction. The internal working gears are shown in Figure 5.13. The last gear drives a rack and pinion gear set that is connected to the rod. The rack converts the rotational motion of the motor into linear motion of the actuator. The gear system is shown in Figure 5.13.

Figure 5.13: Actuator - gear system

5.2.7 Stepper motor

The stepper motor generates the desired angular movement for the actuator. In this system one actuator is used to serve the whole system. The actuator needs to rotate the full 360 degrees for movement. This is achieved using a stepper motor. A stepper motor can be used to achieve precise rotational motion. The stepper motor we used has 7.5 degrees per step. It takes 48 steps to cover the full 360 degrees movement. The rotation of the stepper motor can be controlled using computer program. The stepper motor used in this paper is shown in Figure 5.14.

Table 5.3: Stepper motor specifications

Specifications	
AIRPAX Code	147878
Manufacturer Part Number	9904-112-31004
Angle per step	7.5DEG
SVHC	No SVHC
Current Rating	175mA
External Diameter	51mm
External Length / Height	25mm
Fixing Centers	60.2 mm
Fixing Hole Diameter	3.5 mm
Holding Torque	28 N-m
Indexing Angle	7
No. of Phases	4
Phase Resistance	65 ohm
Power Consumption	3.8 W
Shaft Diameter	3 mm
Shaft Length – Metric	8.2 mm
Torque	20 N-m

Figure 5.14: Stepper Motor

As shown earlier in Figures 5.2 and 5.4, we decided to go for a circular plate with a diameter of 30 cm with a slot for 7.5 cm radius at the center to allow the space for actuator. The cylindrical tube contains tablets at distance 10.5 cm from the center. The eight cylindrical tubes are fixed in a circular pattern so that they are equidistant from the center of the circular plate and are accessible by actuator. The cylindrical tube slots are drilled with 1 cm radius which makes it serve for all types of tablets even allowing the maximum sized tablet. The size of the tube can be reduced using size converters to fit the slots.

The position of the actuator is very important in the system. The precise motion of the stepper motor is important in the placement of the actuator. To achieve the precise position of the stepper motor, an encoder can be used. The encoder generates a pulse signal and these pulses can be counted to determine the exact position of the motor. This provides a closed loop control for the stepper motor. The processing of the pulses generated by the encoder needs a special program and it adds more complexity to the system. To attain full functionality of the precision of the stepper motor, it is better to use with an encoder. Details of the stepper motor are shown in Table 5.3. The stepper motor used in this system has 7.5 degrees per pulse. It needs forty eight pulses to make 360 degrees rotation. The timing sequence of the pulses and programmable control will be discussed in detail in next chapter.

5.2.8 Size converters

The size converters are the small circular shaped converters used to fix the cylindrical tubes of varying sizes to the circular plate. The size of the converter varies depending on the tablet sizes. The outer dimension is 20 mm, the same as the base diameter. The size converters are shown in Figure 5.15. The converters are made of acrylic sheet material of thickness of 3 mm. The size converters exactly fixes with the circular plate as it has the same dimension as the slot.

The size converters act like a washer to accommodate different tube sizes. Without the size converter, the cylindrical tubes of different shapes cannot be inserted into the hole at the circular plate. An example of cylindrical tube with the size converters is shown in Figure 5.16.

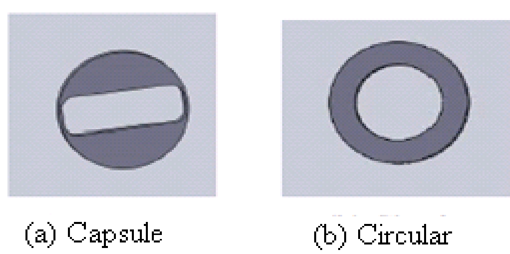


Figure 5.15: Different size converters

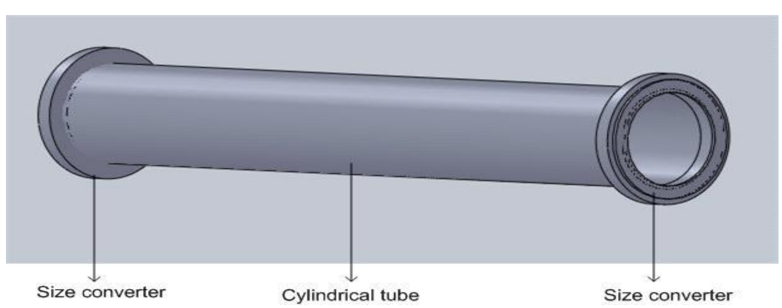


Figure 5.16: Cylindrical tube with size converters

5.2.9 Funnel and base section

To collect the falling tablets from different tubes, a funnel is used. A funnel is placed below the bottom plate so that the falling tablets are collected and deposited in a collecting cup. A sheet metal is bent into a sliding surface and fixed to the base. The height of the system needs to be increased in order to make the sliding angle better for the funnel. The stepper is fixed with the wooden base to prevent its movement. The sheet metal funnel is fixed with the base. This directs all the tablets moving towards a single point collection where the collecting cup is placed. More detailed illustrations will be presented in Chapter 7.

5.3 Circuit and wiring for control

The circuit diagram of the electronic connection is shown in Figure 5.17. The connector is used to connect the PC gadget with the computer using its serial port used for connecting printer.

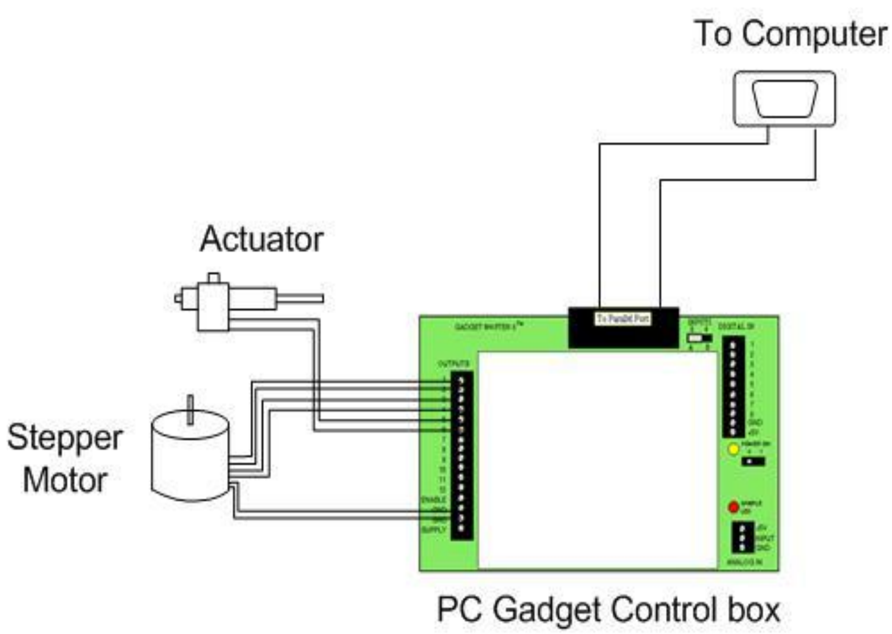


Figure 5.17: Circuit diagram with connection details

The PC gadget is also connected with the stepper motor and the actuator. The stepper motor is four phase and it has four connecting wires connected to pins 1 to 4 of PC gadget. The actuator has two wires. The actuator is connected to the pin 5 and 6. The stepper motor ground wires are connected to the ground pin available in the PC gadget.

The resistor is connected between the actuator and the PC gadget to adjust the voltage power supplied and to reduce the motor speed if needed. The normal response step time for the actuator is 0.2 seconds. The step time is very short. To increase the working time for the actuator, a resistor can be added. A resistor can control the time of actuator motion.

5.4 Summary

In this chapter we have presented the hardware components required to build the system and the detailed description of the components. In the next chapter, we will present the programmable control system and the software development which are to be interfaced with these hardware components.

Chapter 6

Development of Programmable Control for Automated Object Dispenser

In this chapter, the development of programmable control and software systems are discussed. Programmable logic controllers (PLCs) are the digital computers which control the automation and working of electromechanical components based on the inputs and sensor data. PLCs are most commonly used in industries for the purpose of automation. Computers can be used as the logic interpreter and decision maker based on the control algorithms. Details of the development of the programmable control for object dispensing are presented in the following section.

6.1 Hardware and software interface

In this system, programmable control and computer software program are used with the PC gadget hardware. PC gadget is an automation kit with input and output port. This can be connected to the serial port of a computer. It has 12 output ports which can be used to drive LEDS, stepper motors, etc. A maximum of three stepper motors of four phase can be connected. There are eight digital input pins and one analog input of 5V. It comes with a Visual Basic software application for testing the kit with input and output ports.

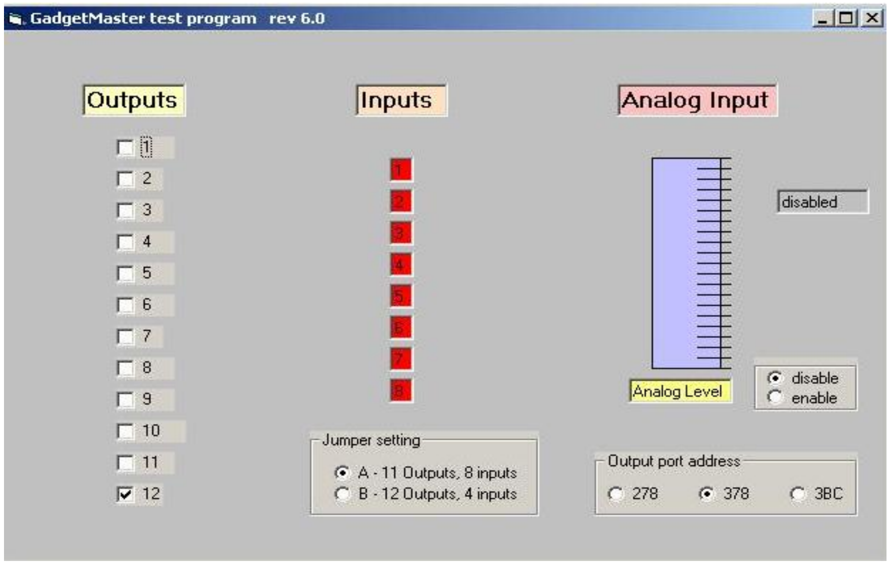


Figure 6.1: Input and output pins testing control

Figure 6.1 shows the different input and output ports of the PC Gadget software application. The software interface of this system is shown in Figure 6.2. Figure 6.3 shows the structural outline of PC gadget. The hardware deals with the mechanism with stepper motor, actuator and the signal from the sensors. The software part is the Visual Basic code which takes the inputs from the user and generates the outputs. The system interface diagram is shown in Figure 6.4.

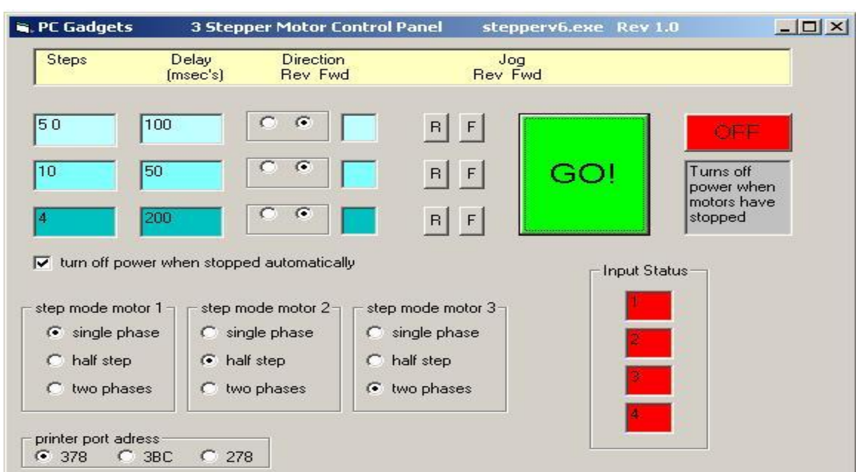


Figure 6.2: Stepper motor testing control

Figure 6.3: Structural outline

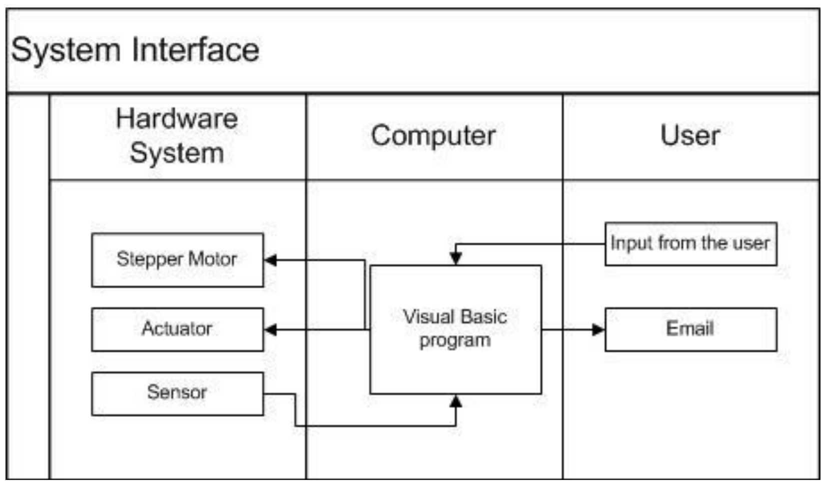


Figure 6.4: Hardware and software interface

The software program for this system was built using Visual Basic (VB) platform. The PC gadget is provided with a basic VB module for running a stepper motor and controlling input and output ports that have been configured to work with the printer port. In this case, there is a need to develop a software interface which can control the mechanisms. The basic module for testing the inputs ports, outputs ports and controlling stepper motor is given with the PC gadget. The Visual Basic application program needs to be developed for controlling stepper motor and actuator.

6.2 Design of the programmable control system

The basic purpose of the software is to get the input from the user. Given a prescription as input, the software actuates the dispensing system at a preconfigured time. The initial screen displays all the available tablets to be dispensed. The user can select the tablets which he/she wants to be dispensed. The time at which the tablet needs to be dispensed can also be configured. The user initially needs to load the tablets in the cylindrical tube and set the drug combination and dispensing timing via the user interface. For example, if a user is loading the tablet A in the cylindrical tube at position one, the user also specifies the timing when the tablet needs to be dispensed. When the position one is selected the system prompts asking for when the tablets should be dispensed. There are two kinds of cycles:

1. Regular schedule of morning, afternoon and night.
2. Interval schedule dispensing tablets at regular time intervals.

The user can select one of the two schedules. If the regular schedule is selected, then the interval schedule will be disabled. If the interval schedule is selected, the regular schedule will be disabled.

Once the routine schedule is selected it prompts the user to select the time period at which the system should dispense tablets. The patient can select at most three and at least any one of three. If the patient prefers interval routine i.e. the tablet needs to be dispensed at a regular interval, the user can select the interval period using the drop down box which list all possible intervals available.

Once the selection is done, the user can test the system using the test option. This will dispense the tablets scheduled for morning, afternoon and night routine once with proper message box and interval. This helps the patient to double check with the correctness of the input given to the system.

The program can also send E-mail reminder to the user, when the tablets need to be reloaded. This is done with the help of a sensor checking the presence of the tablets. If the tablets does not exist it triggers the program to send an E-mail. This system is built with a touch sensor to detect the tablets dispensed. The settings button can be found in the initial screen. Clicking on this button leads to another screen where the morning, afternoon and night schedule time can be changed according to the user's convenience. Once the time is set and saved the window will close automatically and the details are saved.

6.2.1 User interface development

User friendly interface was developed for the dispensing system. It is developed by using Visual Basic based software application development platform. The Windows environment and the command buttons of Visual Basic makes it very easy for the user. The user gives inputs to the computer and the computer to follow the same. The check box, drop down and the command button are the three controls used in the system interface. The control flow and the logic sequences are programmed in the system to use the inputs given by the user and to generate the output based on these inputs. The input values entered are shown to the user as a message box where the user can check the corrections, the values was given.

6.2.2 Timer and interval algorithm

In this system, the program works in real-time. Once the system dispensing schedule is set, the timer in the Visual Basic starts running the code for every second (1,000 milliseconds). The counter increment includes, the hours, minutes and seconds based on the timer. When the set time is met, with the output is given to the stepper motor and the actuator are activated to dispense the medicine. There are interval schedules on which the tablets need to be dispensed for every one hour, two hours, etc. When the count reaches the exact time specified in the program, the stepper motor and the actuator are activated.

6.3 Control algorithm

The timer control is implemented using a Visual Basic program. Detailed control algorithm is shown in Figure 6.5. Once the timer has reached a preset value, the module is called to activate the stepper motor and actuator control. The stepper motor has the accuracy of 7.57 degrees per step. The target position is calculated by the program and the stepper motor is used to turn the actuator to the target position.

Whenever the stepper motor is activated it moves and comes back to the home position number. The stepper motor can be moved in single step, double step and half step. In order to obtain a better resolution, the stepper motor uses a unit rotation step of 3.78 degrees. The values for the stepper motor positioning for different cylindrical tube numbers are shown in Table 6.1.

Table 6.1: Stepper motor position values in pulses

	Positions							
Direction	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Number of pulses for Clockwise	11.875	23.75	33.635	47.5	59.375	71.25	83.125	95
Number of pulses for counter-clockwise	95	83.125	71.25	59.375	47.5	35.635	23.75	11.875

The pulses actuate the stepper motor and thus actuator reaches a cylindrical tube. Then the actuator pulse is given to push the slider and to dispense the tablet. When the actuator pulse is given as 0, actuator arm retracts and the slider moves back to its original position. The stepper motor rotation is a bidirectional one. The actuator wires connected to the PC gadget may get entangled when rotating in a single direction. The stepper motor rotates in the clockwise direction to reach a position. It then dispenses the tablet by actuator. Then it returns back to home position in counter-clockwise direction. A Boolean variable helps the program identify the direction of rotation.

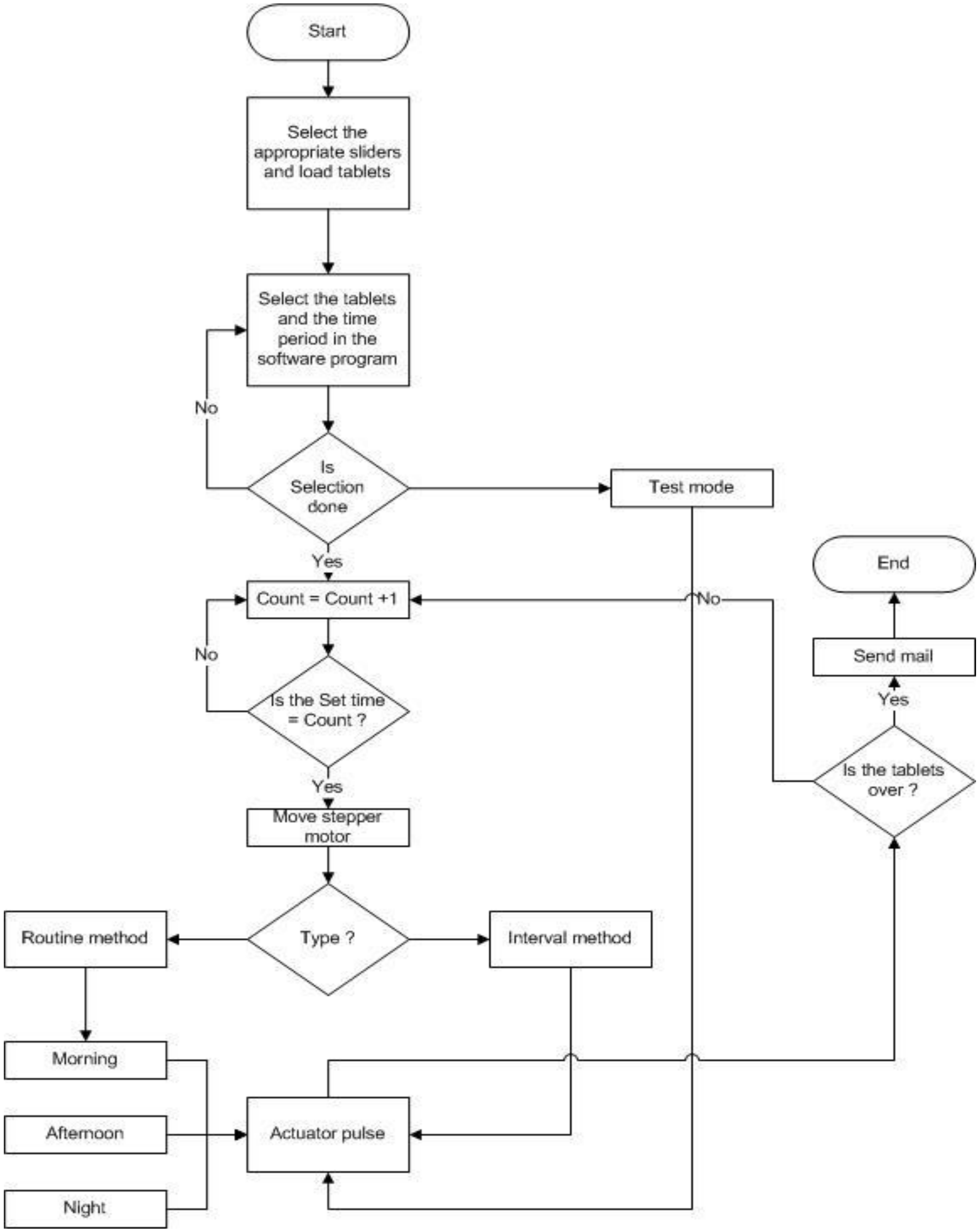


Figure 6.5: Control algorithm flowchart

The actuator for dispensing tablets should work once when the stepper motor reaches the desired position. Figure 6.5 shows the control algorithm flowchart for the implemented program.

6.4 Communicating information to users

Once the system starts working, the machine needs to be scanned periodically for system updates on resources like tablets and maintenance of the machine. An automated system was developed to send information to the user regarding the system status. This information can help the user to check the system and make appropriate actions to ensure the system works properly. There are a few methods to be used:

1. E-mail;
2. Text message;
3. A phone call with automated recorded message; and
4. Display warning lights –LEDs.

The most simple among the listed above is the display of the warning lights using the LED. Different color LED lights can be used for different purposes, for example green for good working, red for emergency, blue indicating the need for reloading the tablets, and amber for machine failure. The other methods include sending an E-mail, making a call to the user with an automated recorded message or sending a text message. The E-mail function in Visual Basic is done using the MAPI control which uses the outlook application with an E-mail account preset in the system.

MAPI (Messaging Application Programming Interface) is the E-mail control object for sending mails from a Visual Basic program. The MAPI object and session are created in Visual Basic form to send the E-mail from the VB application. An object of Outlook application is created and from the outlook account the mail is sent regarding the system status message. The mail function is triggered with the signal from a sensor. The function is event driven and we need an external event to trigger the function. The other events like system failure, stepper motor problem and actuator problem can also be addressed using the E-mail. The E-mail connectivity is shown in the Figure 6.6. The machine is connected to the computer that is connected to the internet and E-mail can be addressed to an independent user or a health care provider.

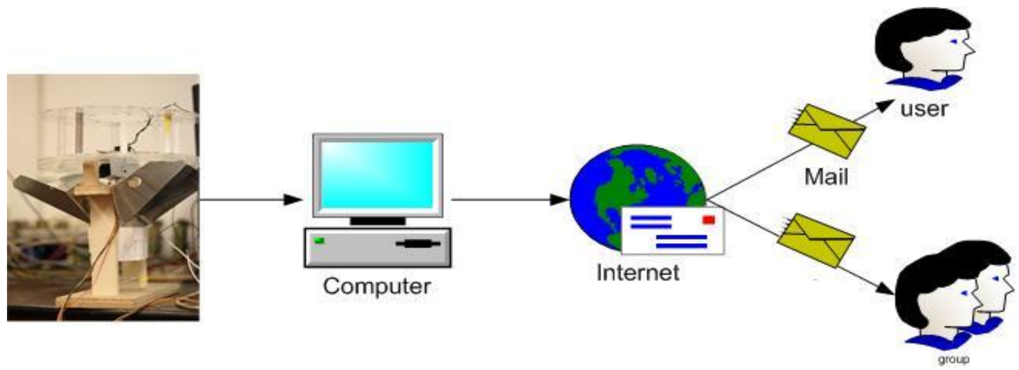


Figure 6.6: Communication to user

The other methods which can be deployed to send the notification can be done using a skype or other messenger application. Sending a text message can be achieved either through internet connection or through a dedicated cell phone connected with the system.

6.5 Sensors

Sensors are important component for providing feedback to the control system. The first sensor is the optical encoder which is a position detector sensor for the stepper motor. The stepper motor rotation needs to be very precise in this system. The stepper motor position can be detected using the encoder which produces the pulses based on the rotational direction and rotational speed. The encoder is a small plate with stripes which rotate against a photo detector. The detector detects the lines and generate the pulse based the speed and rotational direction of the stepper motor.

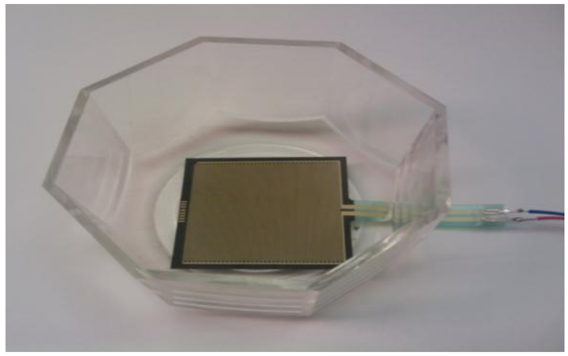


Figure 6.7: Touch sensor placed in the collecting cup

The actuator needs a sensor like limit switch which can detect the position of the actuator. The actuator position is important in dispensing tablets by moving the slider. When the actuator arm is powered, it extends till it strikes the limit switch. The limit switch generates a signal to stop the actuator arm. A proximity sensor is used to detect the availability of tablets in the cylinder. The sensor sends a signal if there is no tablet in the cylindrical tube. These signals can be used to send the information to the user to reload the tablets in the corresponding cylinder.

Tablets fall into a collecting cup. This can be detected using a touch sensor, as shown in Figure 6.7. If any sensor detects any problem, the system sends out a warning message and requires a corrective action.

6.6 Summary

In this chapter, we discussed the methods used in the development of the programmable control and logic flow sequences. These include user interface, timer calculation, interval between sequences, control sequence, mail interface using the MAPI protocol. In the next chapter we will present the experimental tests of the implemented system.

Chapter 7

Experiments and Results

In this chapter we will present the implemented hardware and software system and the experimental results.

7.1 Working procedure

In Figure 7.1 shows the implemented hardware system. The system was built using a stepper motor and an actuator controlled by the PC gadget interface with Visual Basic application program. The completely built hardware system is shown in Figure 7.1. The user needs to give inputs using the initial screen of the application as shown in Figure 7.2. This contains buttons, check box and drop down boxes which allows the user to give input to the system. This initial screen has four command buttons – "Test" for testing, "Go" for real-time working of the machine, "Settings" to set the timing schedule for routine working and "E-mail" to send email for the user about the system status.

The user can select any one of the two methods to dispense the tablets. If the user prefers tablets to be dispensed at a particular time in the day then the user can set the timing by clicking the settings button on the initial screen. When the user selects the routine method, the interval drop down will be disabled to prevent confusion to the user. When the user unchecks the routine checkbox, the interval dropdown will be enabled again. The initial screen is shown in Figure 7.2. The enabling and disabling of options is shown in Figure 7.3.

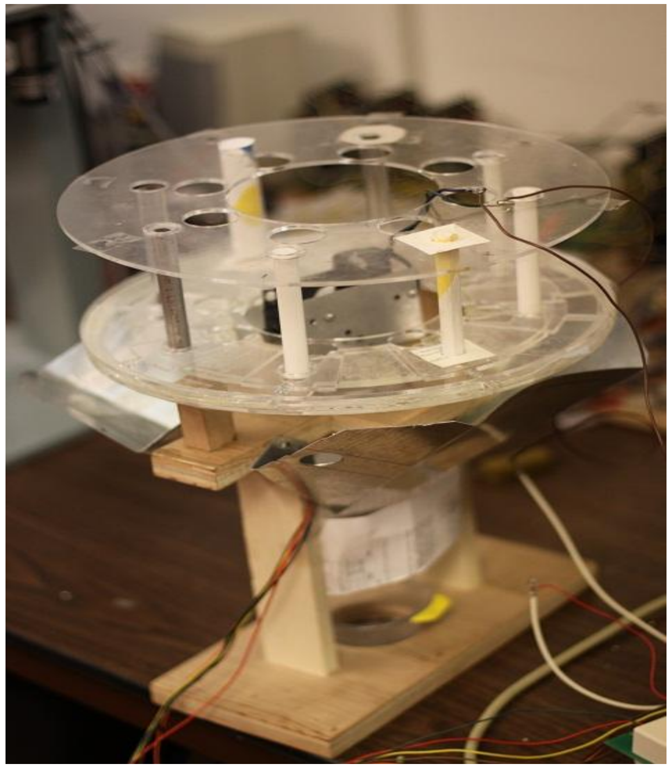


Figure 7.1: The assembly of the system

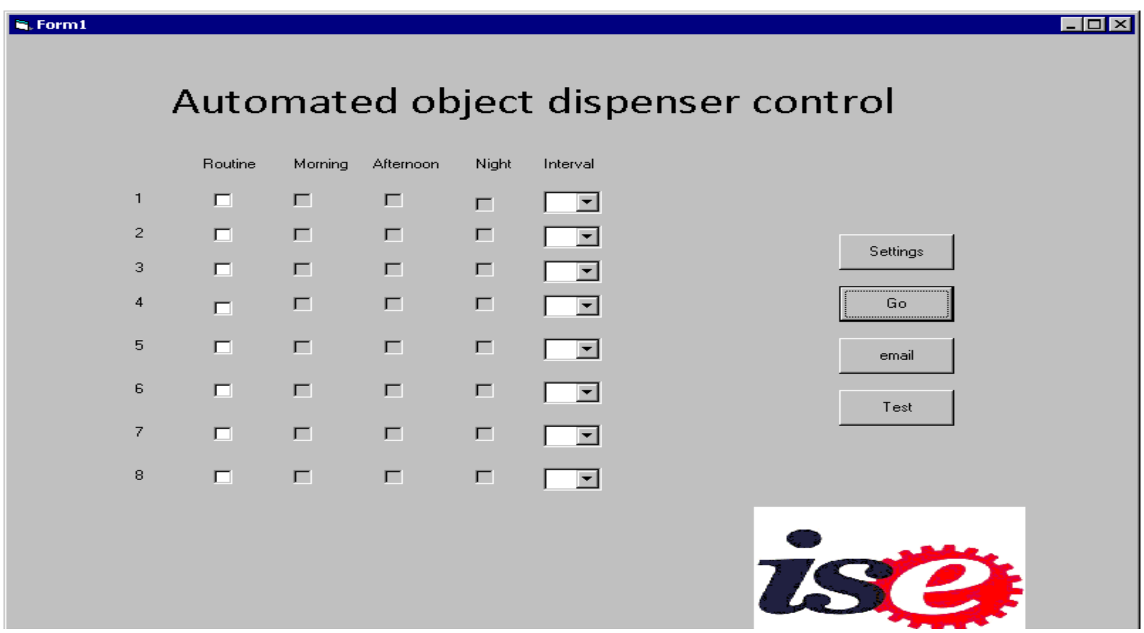


Figure 7.2: User interface window of Visual Basic application

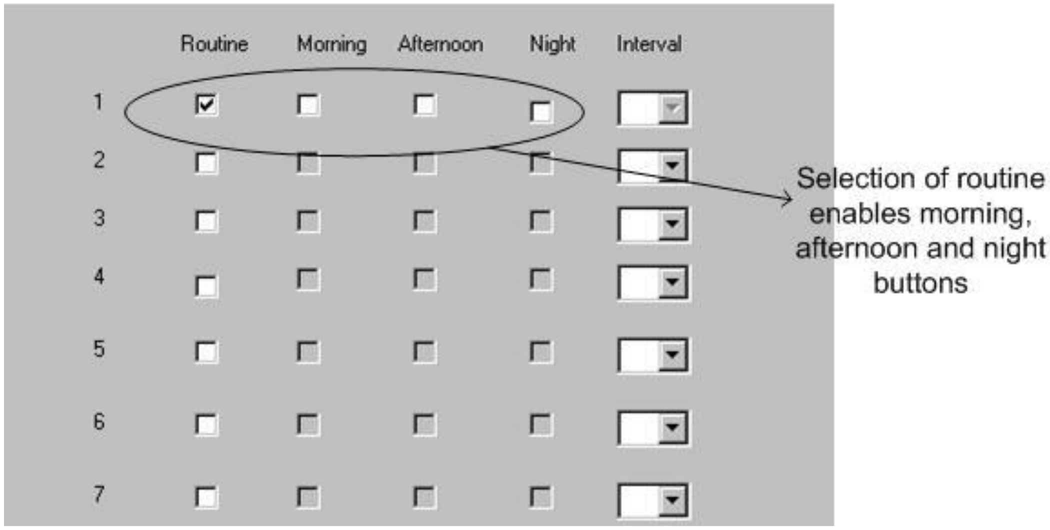


Figure 7.3: Selection of routine method

7.2 Selection of tablets

A demo on selecting the tablets as input is shown in Figure 7.4. As shown in Figure 7.4, the tablets 1, 2 and 3 are in the morning routine. Tablets 4 and 5 are in the afternoon routine. Tablets 6 and 8 are in the night routine. Tablet 7 is not selected.

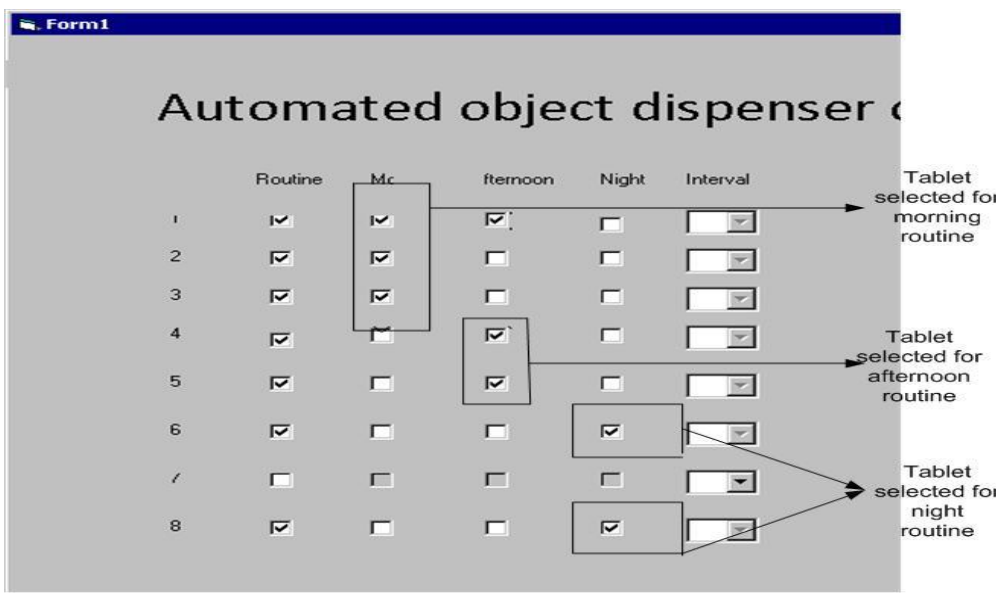


Figure 7.4: Selection of tablets by the routine method

The tablets can also be scheduled to be delivered at a particular time interval period. The interval is usually in a specific hours, for example every one hour, two hours. The selection can be done with the help of the dropdown box values. Figure 7.5 shows an example of setting a particular time interval. The selection of tablets using the interval method is shown in Figure 7.6

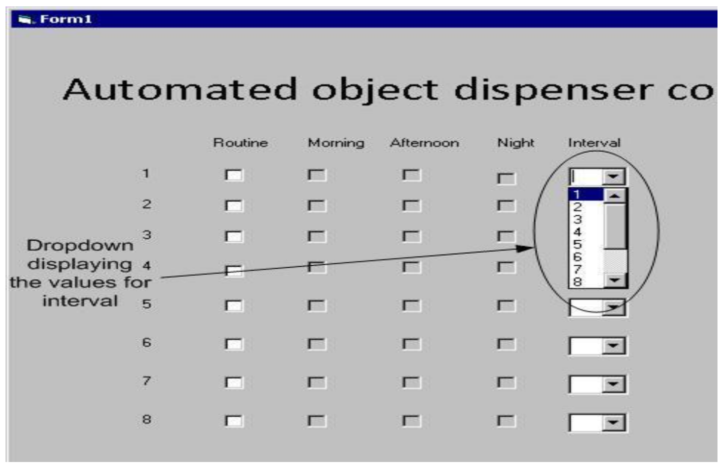


Figure 7.5: Selection of a tablet by the interval method

Once the selection is done, the user can click on the ’Go’ button to start the working procedure. Once the ‘Go’ button is pressed, the screen displays the tablets to be dispensed in the morning, evening and night. This is shown in the Figure 7.7 and Figure 7.8.

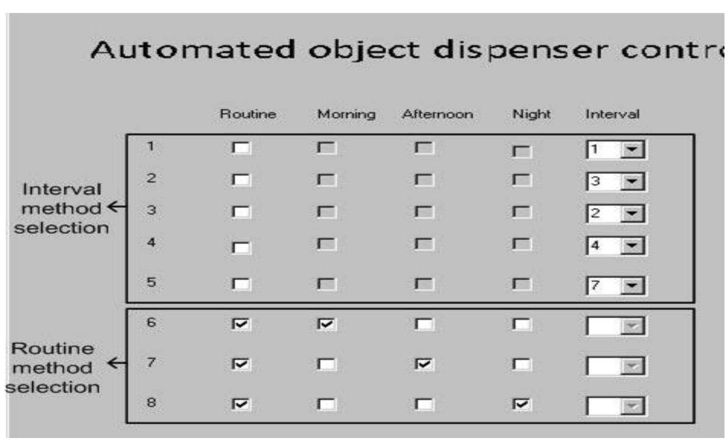


Figure 7.6: Selection of all tablets by the interval method

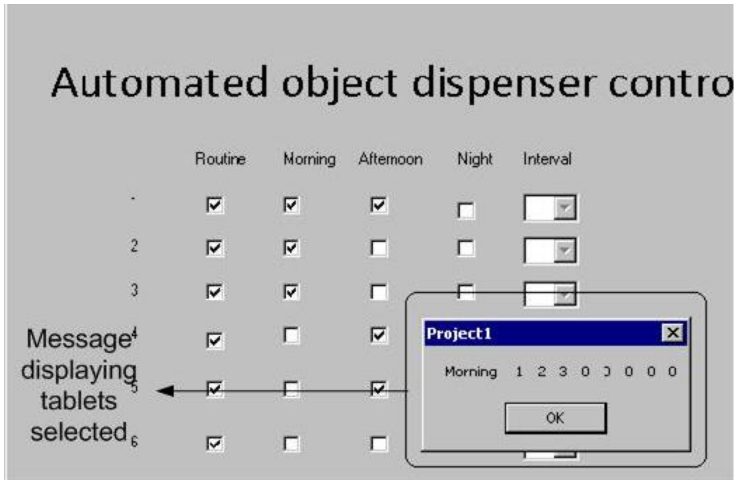


Figure 7.7: Tablets selected for morning cycle.

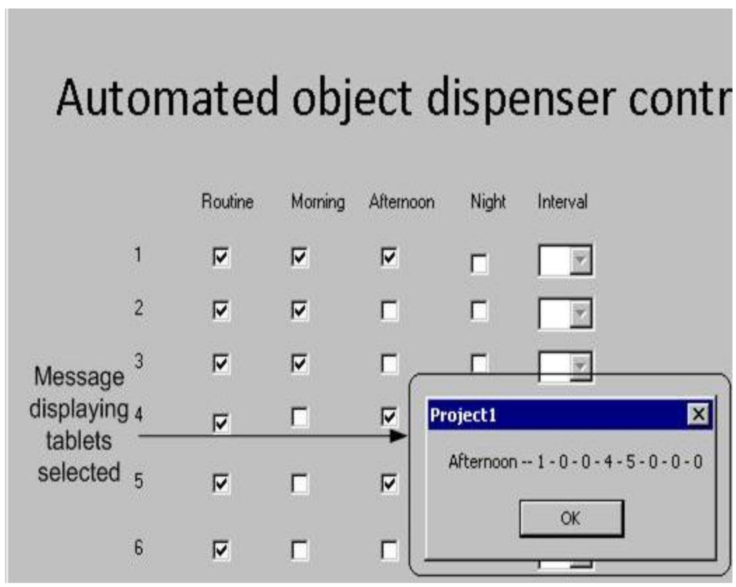


Figure 7.8: Tablets selected for afternoon cycle.

7.3 Settings

Once the user accepts all these selections, the system will start dispensing the tablets according the schedule. The user can also adjust or re-select a new timing. This is done by clicking the 'Settings' button on the initial screen and a new settings screen appears. This allows the user to select a new schedule. The Figure 7.9 shows the settings screen.

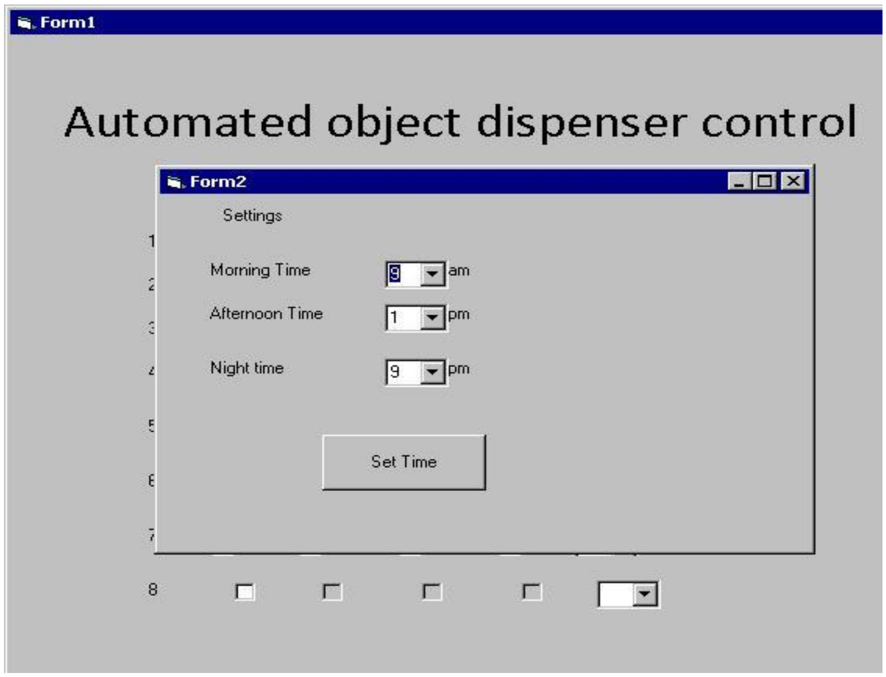


Figure 7.9: Settings screen of a new schedule.

7.4 Electronic notification interface

The sensors placed in the system detect the tablet's availability. Once a trigger event occurs, for example a cylindrical tube is running out of tablets, an E-mail message is sent to the user for corrective action. This is programmed and set in the Visual Basic program. When the E-mail is sent, it shows a warning message to the user, as shown in the Figure 7.10. An example of sent E-mail is shown in Figure 7.11.

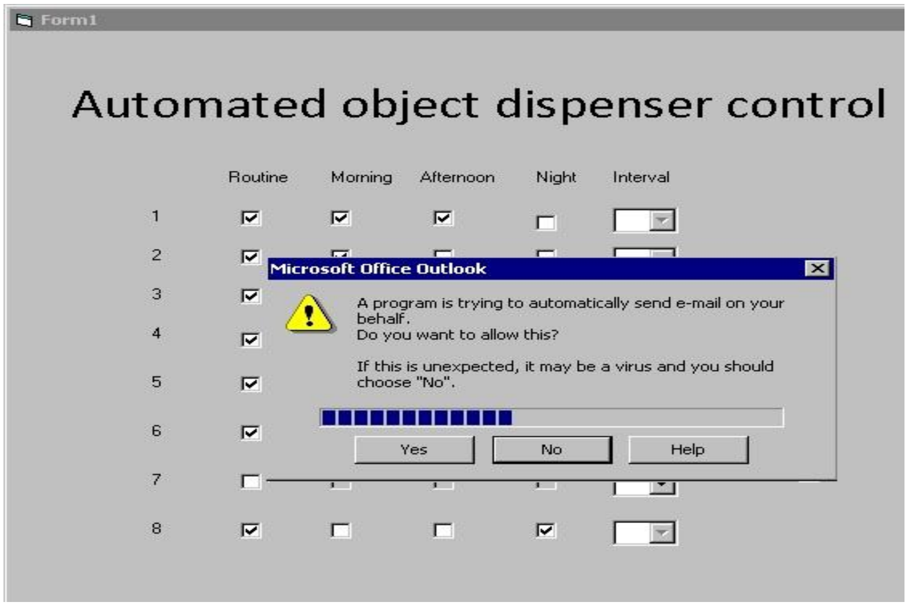


Figure 7.10: Warning message while sending a E-mail

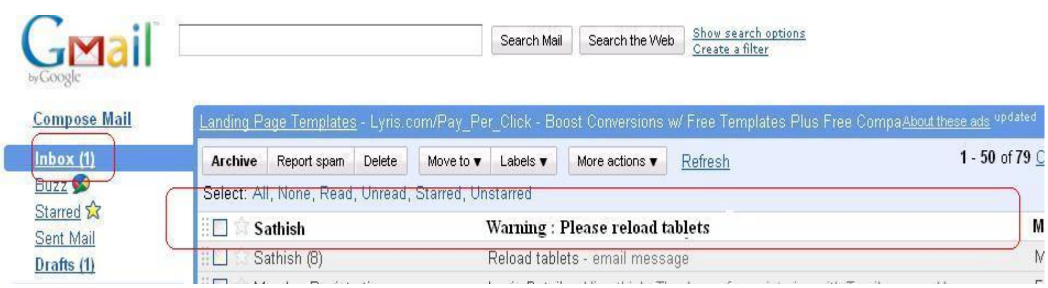


Figure 7.11: E-mail notification to the user

7.5 Testing

The initial screen also has a ‘Test’ button to test the tablets dispensed for the given inputs. Instead of waiting for real-time to see the outputs, the test option can be used to see whether the tablets will be dispensed according to the schedule. Figure 7.12 shows the message box for a morning routine dispensing of tablets. The message box for an afternoon is shown in Figure 7.13.

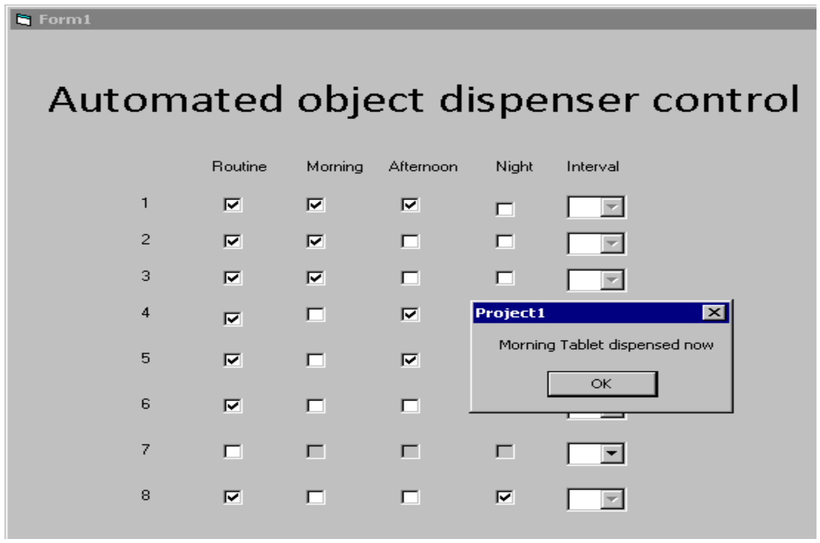


Figure 7.12: Test message for morning tablets

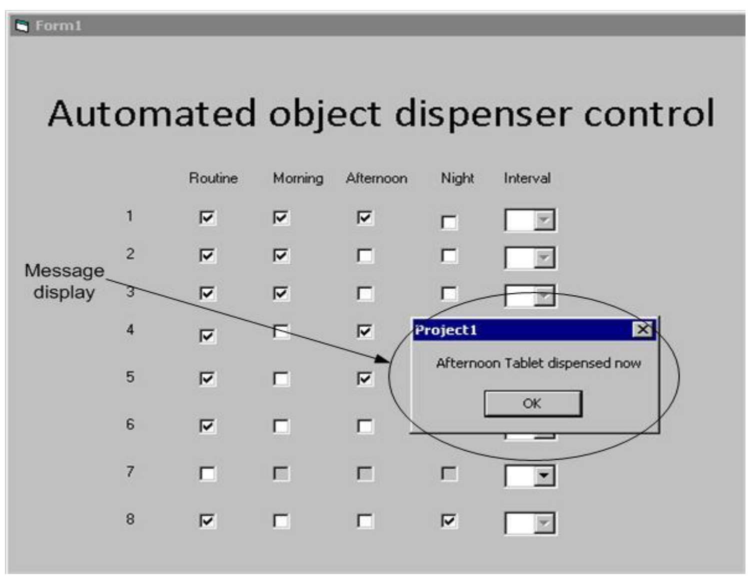


Figure 7.13: Test message for afternoon tablets

A sequence of testing was conducted to validate the hardware and software implementation. The Figure 7.14 shows the tablets being loaded into a cylindrical tube for testing purposes. Figure 7.15 shows the different positions of the actuator with respect to the slider. The actuator pushes the tablet into position once the actuator is activated, as shown in Figure 7.15.

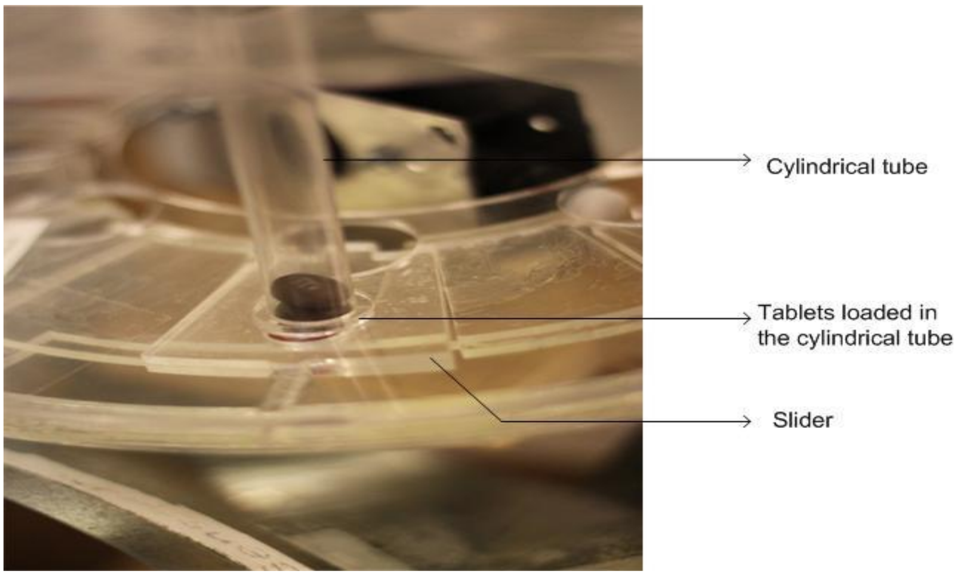


Figure 7.14: Tablets loaded in the cylinder

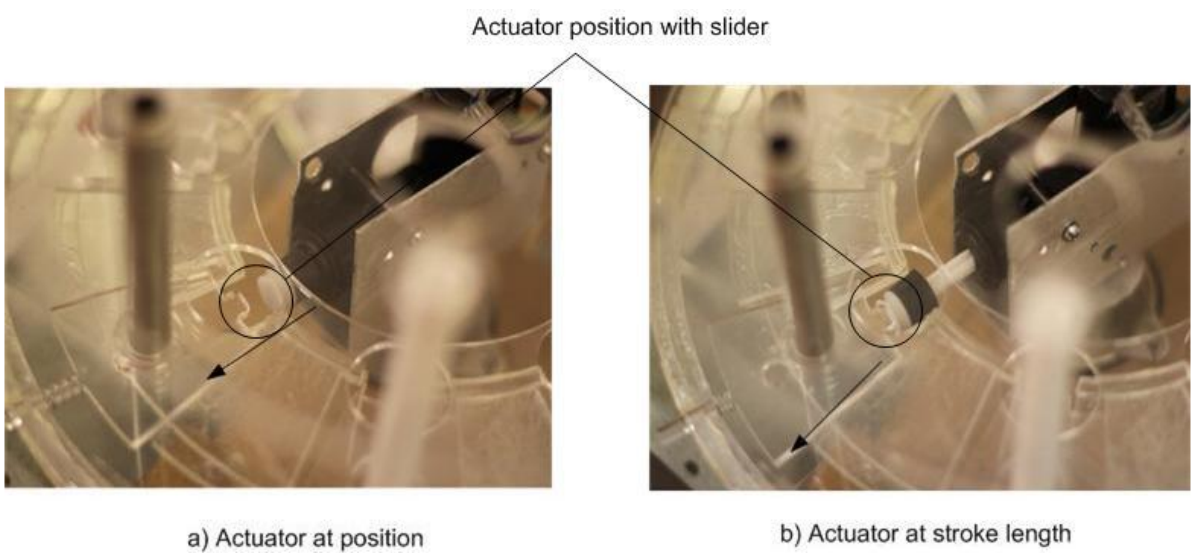


Figure 7.15: Actuator positions

Figure 7.16 shows the slider pushing against the spring. The spring compression is shown well. This is due to force generated by the actuator.

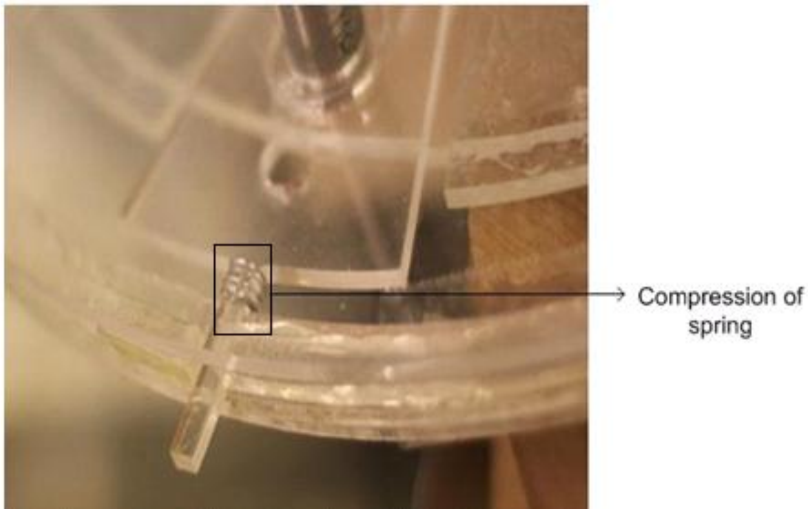


Figure 7.16: Slider and spring compressed

The slider with a tablet loaded in its slot is shown in Figure 7.17. The slider carries the tablet from the circular tube towards the opening of the bottom plate to be dropped to the collection cup.

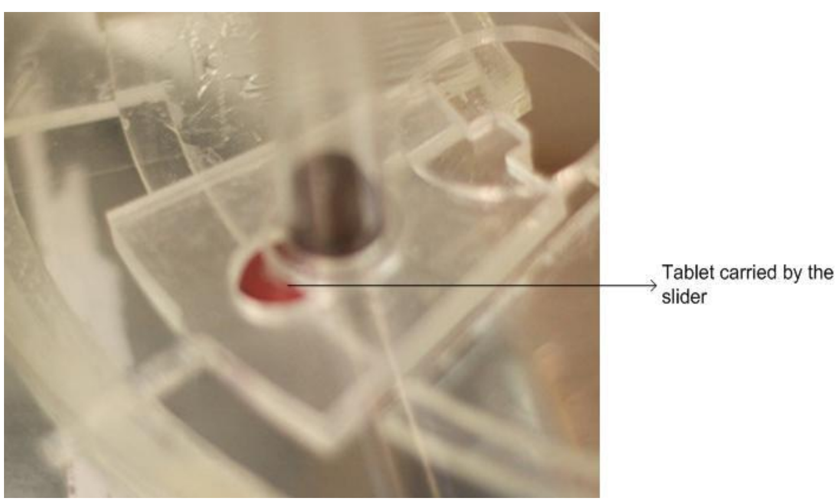


Figure 7.17: Slider with tablet loaded to dispense

Once slider is pushed into the dispensing position, the tablets fall on the sheet metal funnel and drop into the collecting cup at the center of the base, as shown in Figure 7.18. The user can collect the tablets deposited in the collecting cup and return the cup to the same position for next cycle. The collecting cup with tablets dispensed is shown in Figure 7.18.

Figure 7.18: Tablets collected at the collecting cup.

For testing the system, some test scenarios were tested. In the first scenario the inputs are given though the initial screen, as shown in the Figure 7.19. In this test case, six tablets are selected for the morning schedule. The tablets dispensed and collected in the collecting cup as shown in Figure 7.20.

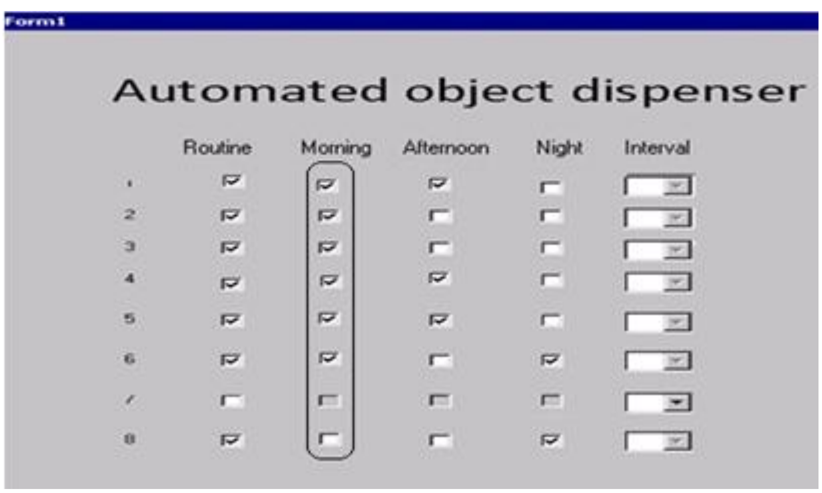


Figure 7.19: Tablets selected for test scenario 1

Figure 7.20: Tablets dispensed for the given test scenario 1

A second scenario is used to test the system. The input given is encircled and shown in Figure 7.21. The tablets dispensed are recorded and shown in Figure 7.22.

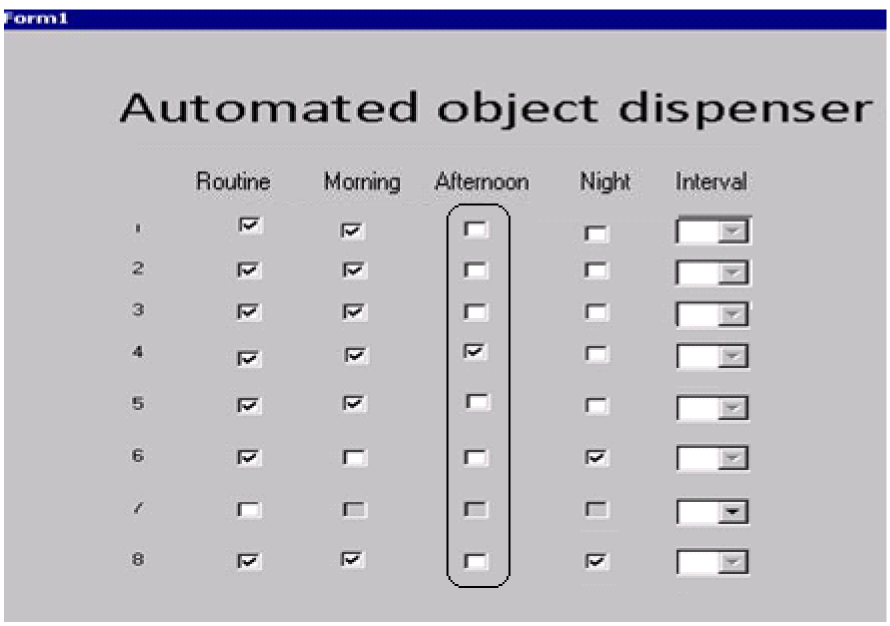


Figure 7.21: Tablets selected for test scenario 2

Figure 7.22: Tablets dispensed for the test scenario 2

The detailed assembly of the whole hardware system is shown in Figure 7.23. The hardware system consists of 38 components assembled to work with the programmable control and the software interface implemented by Visual Basic programming language.

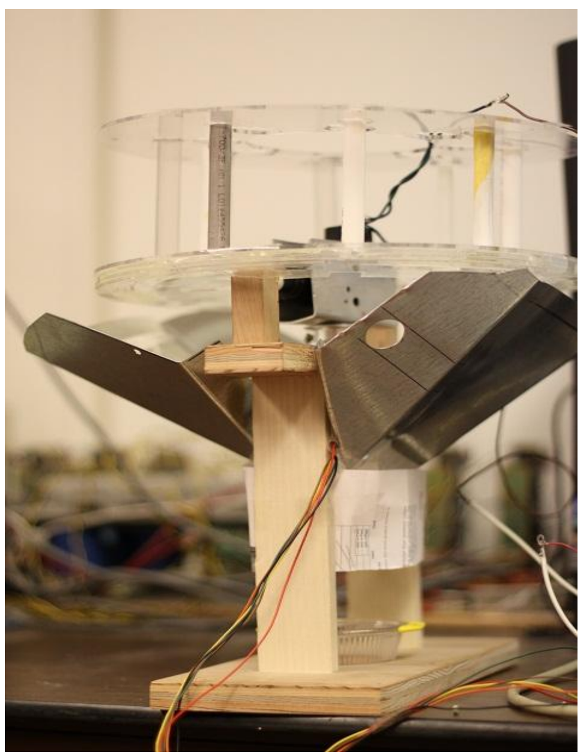


Figure 7.23: Side view of the system

7.6 Summary

In this chapter, we have built the prototype system, discussed the working procedure of the system and tested the working procedure. The output of the test scenario is compared with the given input. In the next chapter we present conclusion and future research topics.

Chapter 8

Conclusions and Future research

8.1 Conclusions

In this paper, techniques of developing an object sorting and dispensing system were presented. Based on the variant sizes and shapes of objects, new mechanisms were designed and analyzed to accommodate these variations in objects sorting and dispensing. Three different designs were proposed. Using the criteria of functional effectiveness and user friendliness, the best design was selected. A timer-based programmable control system was proposed to control the object dispensing system. The programmable control system was developed using the Visual Basic programming language. Engineering analysis and specification of the mechanical components were presented for the development of the hardware system. To prevent human errors and system errors, a set of sensors and logical checking interface were used in the programmable control system. Communication interface was developed to notify the users, once any error is triggered or a system malfunction is detected by a sensor. The presented hardware design and the programmable control system were implemented and tested at our lab. The presented technique has wide applications in the manufacturing industry and the health care systems.

8.2 Future research

Some possible future research includes:

- An embedded system can be developed, making the system more independent of the computer program.

- The implementation of more accurate sensors can be improved to make the system more reliable.

- The performance of the system needs to be tested in more extreme conditions to ensure the system is foolproof.

References

[Boy97] James P Boyer, Joseph H Boyer. Method for counting and dispensing tablets, capsules, and pills. US Patent 5,671,262, 23 September 1997.

[Booth05] Boothroyd, G., and NetLibrary, I. (2005). Assembly automation and product design (2nd ed.). Boca Raton, FL: Taylor & Francis.

[CKY06] Chun-Hsien Chen, Li Pheng Khoo, and Wei Yan. An investigation into affective design using sorting technique and kohonen self-organising map. Advances in Engineering Software, 37(5):334 – 349, 2006.

[Carl04] Carl F. Zorowski. Mechanical Design for Assembly – MAE 742, 2004

[EJ03] Tristan M Christianson, Richard J Thalheimer, Jesse J Patterson, Edward C Mckinney Jr. Pill dispenser with reminder. US Patent US 2003/0006242 A1, 9 January 2003.

[Gel04] Gershman Vladmir, Gomez Michael R. Geltser Aleksandr. Method and system for high-speed tablet counting and dispensing. US Patent 7,124,791 B2, 24 October 2006.

[Gir08] Jean-pierre Giraud. Dispenser having a dual lever mechanism. US Patent 2008/0230551 A1, 25 September 2008.

[Har76] Ronald J Billett., Bruce M. Harper. Tablet dispensing mechanism. US Patent 3,994,420, 30 November 1976.

[HI95] Masami Horizuti Chiyoji Ishikura Shoji Awazub Hideo Ishizuka, Yasuo Waki. Development and evaluation of a new automated dispensing system. International Journal of Bio-Medical Computing, 38:167–176, 1995.

[JRHS00] C. Jones, G. Ross, J. R. Hewit, and A. P. Slade. Robotic sorting of paper items from a random pile. Mechatronics, 10(8):869 – 880, 2000.

[Kim03] KR Kim, Jun H. Taegu. Tablet dispensing and packaging system. US Patent 2003/0066264 A1, 10 April 2003.

[KJ08] Richard D Michelli, Jennifer Ann Mauger, Edward Joseph Karwacki Jr. Methods and apparatus for dispensing solid pharmaceutical articles. US Patent 2008/0245810, 9 October 2008.

[Koo95] Alfred H Van Elk, Kees Kooijmans. Tablet dispenser. US Patent 5,409,132, 25 April 1995.

[KWWL08] Yuejun Kang, Xudong Wu, Yao-Nan Wang, and Dongqing Li. On-chip fluorescence-activated particle counting and sorting system. Analytica Chimica Acta, 626(1):97 – 103, 2008.

[Lew86] Roberts Jr., Arthur S, Kermit E Lewis. Automatic pill dispenser and method of administering medical pills. US Patent 4,573,606, 4 March 1986.

[LWG02] Qingzhong Li, Maohua Wang, and Weikang Gu. Computer vision based system for apple surface defect detection. Computers and Electronics in Agriculture, 36(2-3):215 – 223, 2002.

[MCG00] R. Mattone, G. Campagiorni, and F. Galati. Sorting of items on a moving conveyor belt. part 1: a technique for detecting and classifying objects. Robotics and Computer-Integrated Manufacturing, 16(2-3):73 – 80, 2000.

[Mol06] Vae E Sun, Jens H. Molbak. Coin counter/sorter and coupon/voucher dispensing machine and method. US Patent 2006/0219519 / A1, 5 October 2006.

[OMO09] Mahmoud Omid, Asghar Mahmoudi, and Mohammad H. Omid. An intelligent system for sorting pistachio nut varieties. Expert Syst. Appl., 36(9):11528–11535, 2009.

[Pea06] Dennis J Murdock, Todd R Funderburk, Walter G. Pearson. Vacuum drum pill counter. US Patent 6,997,341 B2, 14 February 2006.

[SC01] Neil Sclater and Nicholas P. Chironis. Mechanisms and mechanical devices sourcebook. McGraw-Hill, New York, 2001. 495 pp. Neil Sclater, Nicholas P. Chironis.; Rev. ed of: Mechanisms mechanical devices sourcebook [edited by] Nicholas P. Chironis, Neil Sclater. 2nd ed. 1996.

[Spa94] Pamela M. Spaulding, Kenneth M. Bueche, Gregory L Spaulding. Automatic dispensing system for prescriptions and the like. US Patent 5,337,919, 16 August 1994.

[Tak00] Manabu Haraguchi, Hideyuki Takahashi. Drug dispensing apparatus. US Patent 6,145,700, 14 November 2000.

[Var08] Joshua Samuelson, Nicholas M. Varvarelis. Electronic pill dispenser. US patent 7,359,765 B2, 15 April 2008.

[Wei91] Jack Weinstein. Non-reversing tablet dispenser with counter, US patent 4,984,709, 15 January 1991.

[YZ08] Fu-Cheng You and Yong-Bin Zhang. A mechanical part sorting system based on computer vision. In CSSE '08: Proceedings of the 2008 International Conference on Computer Science and Software Engineering, pages 860–863, Washington, DC, USA, 2008. IEEE Computer Society. ISBN 978-0-7695-3336-0.