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Three dimensional adjustable cavity for Flexible Singulation of Multiple Medications in an Automated Medication Dispenser*

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Abstract— **In the development of an effective medication management system to improve medication adherence, the challenge of flexibly dispensing of medications of multiple sizes and shapes was encountered. It is found that most of the medication dispensers in the market, as well as the feeding and orienting mechanisms in manufacturing sector, are customized to be operated with objects of specific size. In view of the inflexibility of those mechanisms, we proposed a novel method to handle and singulate medications of different sizes and shapes. A three dimensional adjustable cavity is designed as a carrier to separate and dispense one pill at a time. Rotational reciprocating vibration is then designed to provide centrifugal effect to the objects in hopper, in order to assist the singulation. An angle inclination test has been performed on the prototype built to investigate the optimum inclination of the feeding hopper. Preliminary testing has shown propitious results for dispensing round shape tablets of various sizes. The prototype built validated the concept of three dimensional adjustable cavity as a novel singulation technique. The mechanism is not only restricted to the dispensing of various sizes of pills, but has the potential to be implemented in dispensing or feeding of other objects in applications like vending machine, manufacturing system and etc.**

I. Introduction

Lack of medication adherence plays a major role in obstructing the effective delivery of treatment and healthcare, thus increases the number of hospital admission and deaths. The low medication adherence of about 50% for chronic ill patients in WHO 2003 report resulted from the complexity of medication regimens, poor communication between patient and caregiver, and lack of awareness of the treatment benefit [1]. There are various medication management system and solutions provided in the market but mostly in the software and services domains. Most dispenser hardware sold in the market requires the patients or caregivers to manually separate and pack the medication into individual dosage [2]-[4], and to manually set the alarm as reminder for patients to take medication on time. There are also services to pre-packed medication into special blister packs to be used with proprietary machines [5]. However, the machine cannot be used with common blister packs issued by pharmacies.

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In order to improve the user experience of a home-based medication management system, we designed a medication dispenser which is able to automate the process of storing, sorting, and dispensing of medication, with the aim of removing the hassle of manual sorting of pills into individual dosage. One of the challenges to achieve this is to be able to singulate pills of different shape and size in accurate quantity. Furthermore, as this is aimed for home-used, it has to be compact and designed for table-top application.

II. State of the Art

A. Medication Dispenser

Most of the medication counters and dispensers being used in pharmacy use rotating platform at the center to transport pills to the outlet by means of centrifugal force. The basic designs shown in Fig. 1 demonstrate the idea where the pills are actuated by the rotating base, moving towards a narrow passage that lines up the pills. Pills that fail to enter the passage will be circulated back into the chamber at the center and go through the process again.

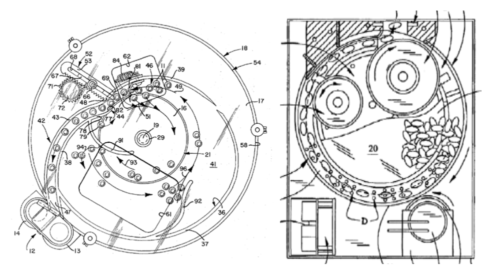


Figure 1. Rotating platform mechanism to align and dispense medication [6]-[7].

However, this mechanism allows only one type of pills to be used at a time. The device has to be reconfigured either manually or by electric actuators to fit medication of different size. For the solution of dispensing multiple types of pills, the automated system described in [6] is designed in the form of a cabinet consisted of multiple storage bins.

As for the medication dispenser shown in patents [8]-[9], they utilize cassettes that are tailor made for different types of medications. During dispensing, the cassette will be mounted onto the dispensing slot to be actuated. The cassettes can be interchanged to dispense different medications.

Having a separate singulation and dispensing system for each type of pills not only occupies extra floor space and causes the final product to be bulky; it also raises the cost of production as more actuators are needed. Besides that, the inflexibility of the system introduces extra labor of changing and tuning the adjustable member in the mechanism to suit different size and shape of pills. Thus, it is not an ideal design for a home based device.

B. Flexible Feeder

In view of the limitation of current dispensers in the market, we looked into the design of feeding and singulating mechanism in manufacturing setting for inspiration. Although there has been decades of research works done and advocacy for agile manufacturing, limited progress is observed in the design of a flexible hardware system that can be rapidly configured for different parts.

There are two approaches in the flexible part feeding and orienting, which are sensorless manipulation and vision guided manipulation. For sensorless manipulation, the research focuses on geometric algorithm which involves sequences of actions to manipulate the objects to the desired orientation across the conveyor belts.

In the research of sensorless manipulation, Akella *et. al* proposed a robust manipulation algorithm, using sequence of sensorless pushing actions by a fence to move any polygon from a known initial configuration to any desired final configuration [10]. He then further generalizes his algorithm to bypass the reliance on the information of initial orientation of polygonal objects [11]. Blind *et. al* designed a machine called Pachinko which uses gravitational force and array of pins to manipulate the configuration of an object [12]. Zhang *et. al* proposed an algorithm for the design of a parallel jaw gripper that is able to align an object from a known initial orientation to the desired final orientation [13]. Vibratory mechanism was employed in the research by Bohringer, Bhatt and Goldberg to transfer and orient objects, without involving any mechanical filters or traps [14]. Goemans *et. al* proposed the design of horizontal blade on vibratory bowl feeder that combines the functionality of reorientation and rejection [15].

For the vision guided manipulation, Carlisle *et. al* introduced a vision-based pivoting gripper system to reorient objects [16]. The planning algorithm for the system to reorient objects is further explained in [17]. A flexible part feeding system which can arrange objects accurately onto a tray utilizing robotic arm has also been designed by researchers from Case Western Reserve University [18].

Unlike the prior research which formulates various methods to orientate polygonal parts, our problem focus on singulation of objects without any demand of specific final configuration. Furthermore, the prior arts presented above designed with workshop environment in mind, requires fair amount of floor space to accommodate conveyor systems or robotic arms. The option of lining up pills in certain orientation is helpful for flexible singulation if the issue of size limitation can be addressed.

III. CLASSIFICATION OF INDUSTRIAL METHODS

The requirement of sorting, singulating and dispensing mechanism is similar to the technology being used in automated manufacturing environment. In an automated production line, materials are processed in sequential operation before being refined into end product. In the process of transferring the materials/products from one operation station to another, they are required to be lined up in series and in certain orientation, so that treatments can be applied to individual products in sequential manner.

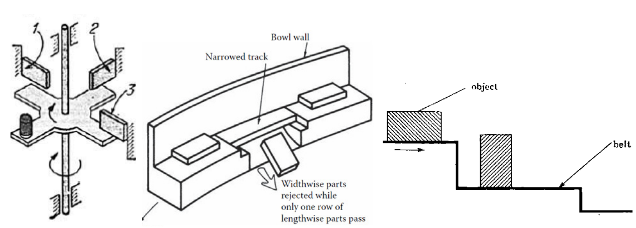
Since there is lack of prior research in the similar problem, we studied the fundamental mechanisms of feeding, conveying and singulating. Generally, orienting and aligning will be done during feeding stage or conveying stage, and parts singulation occurred at the end of the conveyor or feeder. The following section shows some of the conventional mechanisms being practiced in industry:

A. Orienting and Aligning at Conveying Stage

The principle of orienting during conveying stage works on part selection and recirculation. The parts with desired orientation will be able to pass through layers of obstacles to be transported to the end point while those with wrong orientation will be channeled back to the origin and go through the process of selection again. The idea is best illustrated in Fig. 3a, where the filters are installed as fences above a rotating platform in cross shape. The object will be filtered according to the height during rotation. If the object entered in the wrong orientation with a taller height, it will be knocked off from the platform for recirculation.

Besides the mechanical filters or fences, another mechanism widely used in vibratory bowl is the trap. The trap is a narrow portion of the track in vibratory bowl. As the parts are being vibrated up the spiral track of vibratory bowl towards its outlet, they will pass by traps of various shapes. Parts with incorrect orientation will have their center of gravity lying outside of the trap, and fall back to the bottom of vibratory bowl when they are trying to pass through.

Another class of orienting mechanism on conveyor system is step. The conveyor system transporting parts may consist of a few steps to create "jumps" on parts for re-orienation. There is algorithm designed by Natarajan [21] to determine the effective height of the step to produce a successful jump.



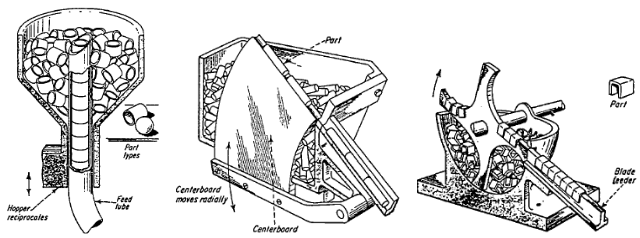
(a) (b) (c)

Figure 2. Three types of mechanical filters. (a) Fence [19]. (b) Trap [20]. (c) Step [21].

B. Orienting and Aligning at Feeding Stage

The mechanism of orienting parts during feeding stage works on the principle of random selection of chance-orientated parts, where the orientation of the parts is uncertain and not controlled. Through the movement of the hopper or feeder, the parts will have the chance to reorientate themselves into the correct configuration and be discharged through the feeder.

The reciprocating feeding shown in Fig. 4a demonstrates feeders or part selectors that move up and down repeatedly to pick up the objects with correct orientation. They are suitable to be used with cylindrical shape parts. The mechanism in Fig. 4c utilizes a rotating center blade to scoop up parts and transfer it to a slide. In the application, it is used to lift U-shaped parts that are strong enough to withstand the compression force when the blades cut through.



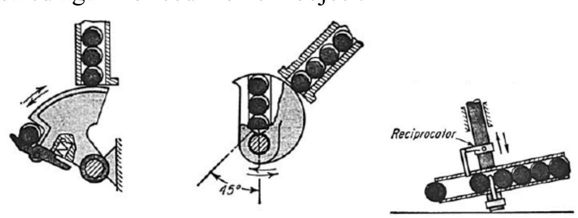
(a) (b) (c)

Figure 3. Three types of feeders to orientate parts [16]. (a) Vertical reciprocate movement. (b) Radial reciprocate movement. (c) Continuous sweeping with centerblade.

C. Singulation/Escapement

Singulatation often occurred at the end of conveyor belt or feeder to separate the parts for further operation. Fig. 5a & 5b show the fixed size carrier mechanism where the parts are fed down the chute by gravity, where the desired number of parts will then be picked up by an oscillating sector positioned at the bottom. During each cycle, sufficient time has to be allocated for parts to fall in and out of the sector.

For the separator mechanism in Fig. 5c , it separates the first object from others in three steps. Firstly, the rear reciprocating rod will be pushed in between first and second objects to separate them. Next, the front rod will be lifted up to release the first object while the rear rod is blocking the second object. After that, front and rear rod will slide down to move second object forward and the process will be repeated again to feed the next object.



(a) (b) (c)

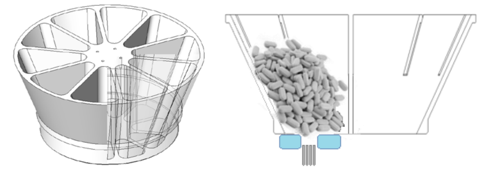
Figure 4. Singulation mechanism to feed accurate amount of parts [19]. (a) & (b) Fixed size carrier. (c) Reciprocating separator.

Another singulation method employs the geometry of the track to pull away the distance between successive aligned parts. As discussed in patent [6], the system comprises of a track defined by two side walls, while the movement of the objects are propelled by a rotating disk at the bottom. The curvature of the track is intentionally designed off centric as compared to the spinning base to create an effect of increasing angular velocity across the track.

All of the above mentioned mechanism requires custom designed track or fixture to fit a particular shape or part. The conventional automated manufacturing system is usually customized for a specific product with minor adjustment allowed. If these mechanisms were applied in the medication dispenser, it will not be convenient for the user, since different fixture or template has to be switched to match the correct size and shape of pills to be dispensed.

IV. Proposed Mechanism

Due to the limited space allowed as a home based device, we abandoned the design of conveyor system but directly coupled singulation to the feeder. The proposed design is based on the principle of random selection of chance-orientated mechanism. In order to simplify the problem, the sorting of different types of medications is avoided by storing different medications in separate compartments. This is done during loading stage, where the device will assign different compartments for patients or caregivers to pour in different medications. As shown in Fig. 6a, the hopper is divided into 10 compartments to store 10 different types of medications. These 10 compartments then share the same singulation unit which is connected directly at the bottom. The medications will be stored at random oriention in bulk. Detailed explanation of the singulation unit will be presented in the following sections.



(a) (b)

Figure 5. (a) Hopper with 10 compartments to contain 10 different types of pills. (b) Singulation unit below hopper to catch pills.

A. Generalization of Pills Sizes

In order to solve the problem with a one size fit all solution, a novel mechanism is proposed. The concept is similar to the "fixed size carrier" mechanism above with a flexible adjustable cavity on the carrier.

As all the medications (or any objects) can be treated as three dimensional polygons, they can be contained by three dimensional boxes which are defined by their furthest width respectively in the Cartesian space. Hence, each medication with the same shape and size can be defined by its own specific size of box. With this concept in mind, a carrier with an adjustable cuboid shape cavity is able to singulate all types of medications and dispenses them one at a time.

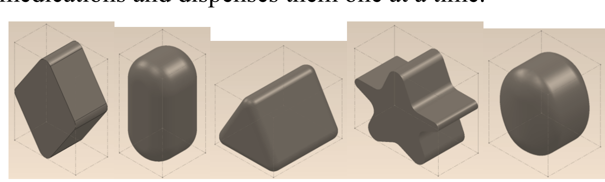
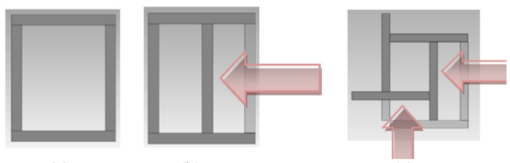


Figure 6. Objects of various shape can be contained by specific size of cuboid envelope.

B. *Three Dimensional Adjustable Cavity (3DAC)*

The realization of a three dimensional adjustable cavity (3DAC) is not easy as there is fundamental challenge mechanically. Consider a planar area as a space with one adjustable dimension; one moveable wall is sufficient to complete the design. This is shown in Fig. 8 with a right moving wall. However for the same area to vary in two dimensions, we will require three moving walls to complete the motion.



(a) (b) (c)

Figure 7. One dimensional adjustable cavity. (a) Opened cavity. (b) Right wall moves to change cavity size. (c) Two dimensional adjustable cavity with two active moving walls alter the size of cavity.

The actual design of the two dimensional adjustable space is proposed in Fig. 10. It is formed by one stationary wall and three moveable walls (two active blocks and one passive block). Two active blocks are driven by actuators to define the size of tunnel, while the passive block is connected to compression springs.

When the first moveable block is actuated, second moveable block will follow; similarly passive block adheres to the movement of second moveable block moves. Compression springs are used to return the blocks back when first and second moveable blocks retract.

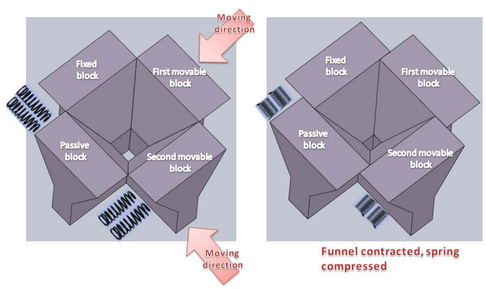
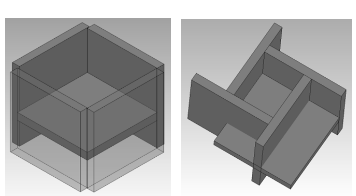


Figure 8. Realization of a two dimensional adjustable cavity.

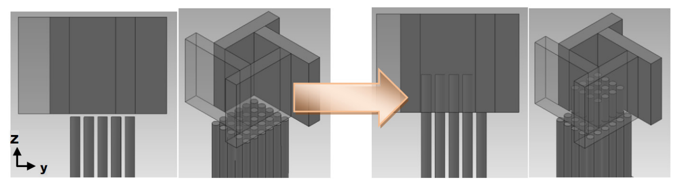
Similarly, consider an 3DAC with three orthogonal moving walls. It requires an additional moving wall at the bottom, on top of the three moving walls in the two dimensional case above. However, the bottom wall cannot have a fixed area since the other two walls are moveable and the cross sectional area is changing constantly.



(a) (b)

Figure 9. Challenge of 3DAC realization. (a) The vertical moving wall with maximum cross sectional area opened. (b) When the cross sectional area is shrunk, a rigid vertical moving wall cannot pass through.

Hence, the bottom wall has to be adaptable according to the movement of other walls. An original mechanism is designed to demonstrate the concept. The bottom wall is made of an array of compressible rods where they can adapt to the size of cavity. As shown in Fig. 12b, during adjustment of the position of bottom wall, rods that are outside the cavity will be blocked and compressed by the upper walls, while those rods inside the caivty area will continue to travel upwards and define the bottom position of the walls.



(a) (b)

Figure 10. Compressible rods defining the depth of the 3DAC. (a) Origin position. (b) When they move up to the middle of cavity, rods that are outside the cross sectional area will be compressed.

C. *Singulation for Dispensing*

For the fixed carrier mechanism shown in Fig. 5, the parts are lined up prior to singulating and dispensing. However for a flexible dispenser, lining up parts of different size and shape will require the feeder tube to be adjustable in cross sectional area and introduce more complexity into the mechanical design.

The singulation mechanism is connected directly to hopper, moving horizontally between two end positions: the collection point beneath the hopper and the dispensing point away from the hopper. The dispensing cycle starts with the singulation unit positioned at the dispensing point, adjusting the dimension of flexible cavity to fit the target pill size. Next, the hopper will rotate and bring the compartment containing the desired pills above the collection point. The whole singulation unit will then be carried to the collection point, without altering the size of the 3DAC. Afterthat, a reciprocating rotational movement is induced to vibrate the hopper to drop a single pill into the cavity. The singulation unit will carry the captured pill back to the dispensing point, separating it from others medications before ejecting it out through the exit. An infrared sensor is installed at the outlet to detect a successful dispensing event. If nothing is dispensed in a cycle, the process will be repeated for another attempt.

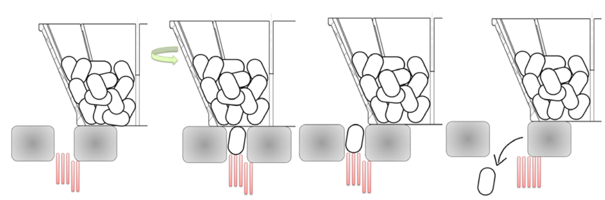


Figure 11. The singulation process, in sequence from left to right.

The singulation and dispensing cycle is summarized in the flowchart below:

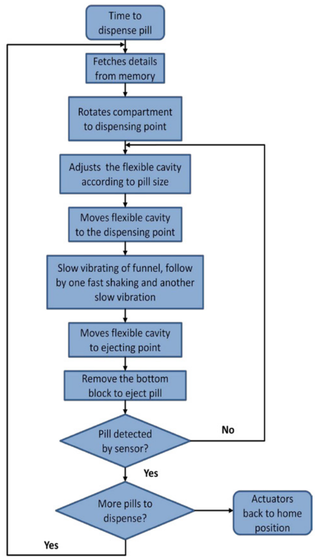


Figure 12. Flowchart of the dispensing cycle.

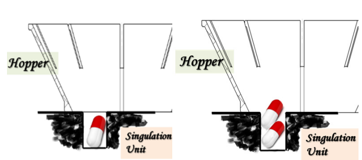
V. Testing and Discussions

A medication dispenser prototype has been designed and assembled, based on the principle of the mechanism proposed above. The prototype was tested with 10 different types of pills vary in shape and size, to evaluate the performance of the mechanism. Extensive testing like system throughput test, endurance test, and angle dependence test [22]-[23] are not carried out in this prototyping stage as the mechanical design and actuators selected are not optimized for the best performance. It serves as a proof of concept to explore further issues in the mechanism.

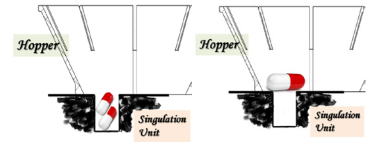
(a) (b)

Figure 13. (a) Actual prototype of medication dispenser. (b) 10 types of pills tested on the dispenser.

The first preliminary test explores the effect of inclination angle of hopper towards the success rate of dispensing. A successful dispensing is pictured in Fig. 16a, while unsuccessful events comprises of three possible failing modes as observed (Fig. 16b – 16d).



(a) (b)



(c) (d)

Figure 14. (a) A successful dispensing event. (b) A failed event where second pill ride on top of the pill at the bottom, and jam the system when the singulation unit tries to move out to dispensing point. (c) A failed event where two pills fit into the 3DAC. (d) A failed attempt where the pill at the bottom is in incorrect orientation.

The inclination test is motivated by the observation of low throughput when the hopper is positioned upright. The inclination angle tested is defined by the angle between side wall of hopper and vertical axis. Inclination angle of 30°, 45°, 60°, 75° and 85° were tested by performing 2 sets of 10 consecutive dispensing of the same medication (labeled 1 in Fig. 15b) for each angle. The results of the test are shown in table I.

TABLE I. Inclination Angle Test

Angle (°)	*Successful rate (%)*		*Average performance (%)*
	Set 1	*Set 2*	
30	20	30	25
45	50	40	45
60	70	100	85
75	100	90	95
85	100	90	95

It was found that the throughput of the dispenser improves with increasing angle until 85°. This is due to the relief of the weight of medications acting onto the pill at the bottom of hopper, giving it a higher chance of re-orientating to be dispensed. However, for angle bigger than 85°, the performances of the throughput drop significantly since the medications are not directed towards the 3D cavity but channeled outwards of the funnel.

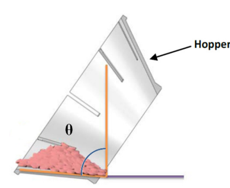


Figure 15. The inclination angle investigated for good throughput.

In the next test, we intended to explore the effect of variation in size and shape of the objects towards the successful rate of dispensing. The test was not completed due to the limitation in prototype designed. The successful rate of dispensing for pills 1 to 7 in Fig. 15b corresponds to the results in angle test. However, for long pills 8 to 10 with higher length to width ratio, the successful rate is much lower.

It was found from the observation that the area of opening for 3DAC in horizontal plane plays a part in affecting an event of successful dispensing. As shown in Fig. 18a, the maximum opening area of the 3DAC is shown by the hatch marked rectangular region. For long pills which have a circular profile from top view and a cylindrical profile from side view, the intended singulation profile designed is to let the pill drops in vertically in circular profile (Fig. 18b). However, due to the centrifugal effects from rotational vibration, the long pill tends to stabilize dynamically in the configuration shown in Fig. 18c, and not falling into the cavity.

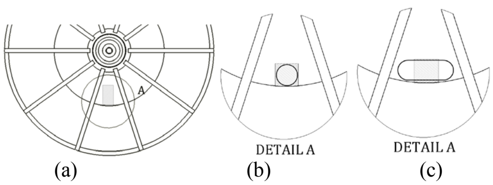


Figure 16. Top view of the hopper. (a) The maximum cross sectional area for 3DAC designed in the prototype. (b) The intended singulation profile where long pill will drop into 3DAC vertically. (c) Frequently, long pills rest horizontally after vibrating and would not drop into the cavity.

From the observation in dispensing other type of medications using the prototype, we postulate that the centrifugal force will influence the orientation of the objects being vibrated by:

- maximize the surface area of contact with side wall of hopper in the rotation plane.
- minimize the distance between center of gravity (COG) of objects with the side wall.

This results in a configuration of the object that minimizes its moment of inertia during the vibration.

VI. Conclusion and Future Works

The concept of 3DAC directly coupled to the bottom of hopper has been proven to be feasible. The prototype built has shown promising preliminary results with dispensing of round shape tablets of various sizes. However, there are more factors including the shape of hopper, vibration design, feeding orientation and shape of 3DAC to be investigated to determine the optimum design for medication of other shapes and sizes. For the limitation in the current dispenser prototype, the sharing of the 3DAC poses the risk of cross contamination of different medications. Cleaning mechanism for the 3DAC after each dispensing cycle will be considered in the future.

The second prototype is being built to provide a bigger 3DAC envelope. With this size of adjustable space available, we will further investigate the interdependent factors of object shape and feeding orientation, to prove our postulations presented in previous section. The testing result presented for this first prototype is preliminary and done with small number of runs. A more extensive experiment will be designed and tested on the second prototype to check performance in dispensing of pills with variation in sizes and shapes. After determining the optimum feeding orientation and vibration mode, an endurance test will be carried out to conclude the effectiveness of the proposed flexible part singulation mechanism.

Acknowledgment

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