3rd International Engineering Research Symposium 2025 (IERS 2025)
Colombo, Sri Lanka

Design of a Reusable Pen Assembling and Dispensing Unit

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Abstract. The paper discusses a reusable pen assembly and dispensing unit designed to meet the growing need for a sustainable and cost-effective alternative to single-use pens. This system automates key operations such as blind cap removal, ink tube replacement, and pen reassembly through a series of electromechanical actuators, sensors, and limit switches, thereby retaining proper alignment and operational precision. In addition to promoting sustainability, the design focuses on the reuse of pen components such as pen barrels and blind caps, reducing plastic waste. Also, it encourages environmentally responsible behavior, especially among younger users, by promoting the reuse of disposable pens. This initiative supports the global shift toward circular economy solutions in everyday consumer products. The machine features a compact footprint of 610 mm × 650 mm × 350 mm and completes a full pen reassembly cycle in just 48 seconds, making it suitable for educational institutions and small-scale applications. Performance evaluation will be carried out after fabrication to assess assembly accuracy, reliability, and cycle efficiency. Overall, the system contributes to green behavior on the consumer side and reinforces the concept of the circular economy in daily life.

Keywords: Reusable pen assembling unit, Automation, Plastic Waste Reduction

1 Introduction

Plastic disposable pens have turned out to be a major form of plastic pollution due to their wide use and short lifespan. Most consumers discard the entire pen when its ink runs out, even though only the refill is exhausted. Disposable pens are made of non-biodegradable plastic material and usually contain metallic components, which cannot be recycled easily. As a result, billions of used pens reach landfills and the environment annually, incurring long-term environmental damage, as shown in

Fig.. Waste minimization is needed to promote sustainable consumption and minimize environmental footprints [1].

Millions of disposable plastic pens are cast aside annually, causing plastic pollution and an environmental menace of sorts. Despite their small size, the cumulative impact of discarded pens is significant. These pens are typically made from non-biodegradable plastics such as polypropylene (PP), acrylonitrile butadiene styrene (ABS), and polyethylene (PE), which can persist in the environment for centuries [2].

Fig. 1. Environmental impact of plastic pens

A majority of pens are thrown away after the ink has dried out, rendering reusable parts like plastic barrels and metal tips useless. This creates unnecessary plastic waste and higher production costs [3]. Though replacing only the ink chamber is ecologically friendlier and cheaper, the lack of simple refilling mechanisms deters the use of reusing. A semi-automatic machine is proposed to simplify pen disassembly and assembly, rendering replacement of ink convenient and promoting sustainable writing in schools, offices, and stores.

A standard ballpoint pen consists of various necessary components that work together to draw ink smoothly on paper, as shown in Fig.. These are the pen barrel, which is the body, the ink chamber in which the ink is held, the metal tip through which the ink is expelled by a rolling ball, the blind cap which caps the rear of the pen, and the pen cap which covers the tip when not being used [4].

Among all of these, only the ink chamber can be consumed, while the rest of the parts still retain their structure even when the ink is exhausted. This indicates the potential for designing reusable systems to replace only the ink chamber and reuse other components of the disposable pen.

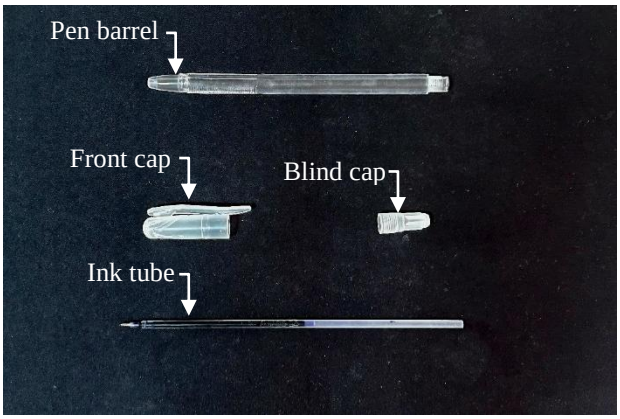

Fig. 2. Main parts of the pen

By enabling users to replace only the ink tube while reusing the pen's plastic body and caps, the proposed system directly reduces plastic waste at source. Based on measured part masses, each refill keeps approximately 5.30 g of plastic in circulation, which includes the pen barrel weighing 3.86 g, the front cap weighing 1.15 g, and the end cap weighing 0.29 g, instead of discarding the entire 5.90 g pen. This saving highlights the role of the machine in supporting sustainability by reducing plastic waste and improving resource efficiency.

2 Methodology

Developing an effective automated system in which pen reuse is easily accessible to small-scale businesses and educational institutions helps promote environmentally sustainable practices that counter a culture dominated by single-use pens.

Mainly, there are two types of ballpoint pens which are back-loading pens and front-loading pens. Back-loading pens are designed so that the ink tube is inserted from the rear end of the pen barrel, typically secured with a threaded blind cap while front-loading pens allow the ink tube to be inserted from the front. An initial survey was conducted among users to identify the most commonly used pen type and the machine was designed to accommodate this model mechanism as an initial step. The survey results indicate that Atlas Max is the most commonly used pen in Sri Lanka, featuring a back-loading mechanism (Fig. 3).

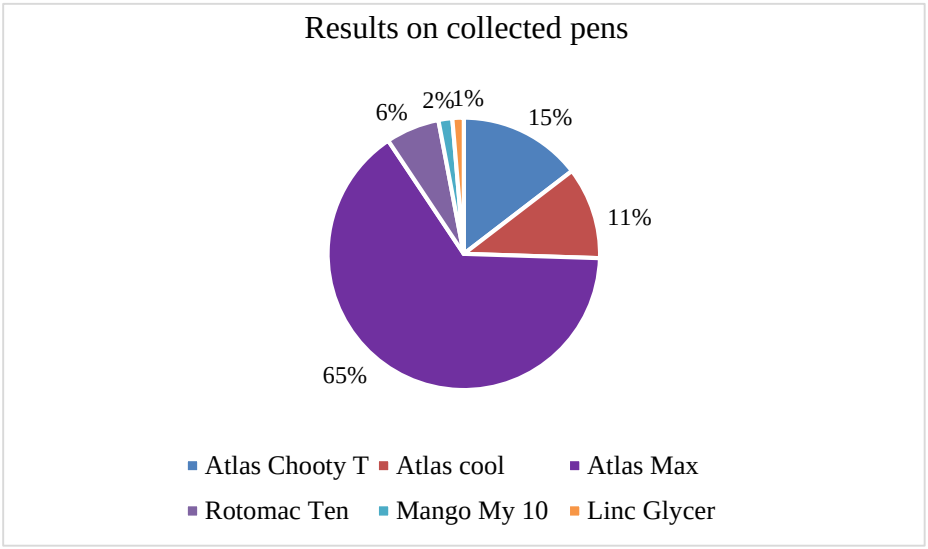

Fig. 3. Results of the initial user survey

In back-loading pens, the ink tube is inserted and secured from the rear end of the pen barrel. During testing with this type of pen, it was found that, in most cases, for back-loading pens, the ink tube tends to stay attached to the blind cap. As a result, when the blind cap is removed, the ink tube is often removed along with it, as shown in Fig. 4. Careful attention was given to this aspect during the design of the system.

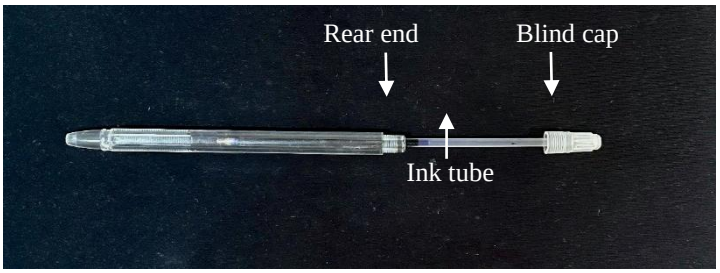

Fig. 4. Removing blind cap of the back-loading pen

The key processes are as follows. First, the user manually removes the pen clip and inserts the pen into the machine. The pen is clamped and transferred for blind cap removal,

where the blind cap is unscrewed and removed using a rotary mechanism. The blind cap removal mechanism then moves backward while holding the cap. The system separates the ink tube from the pen barrel. If the ink tube is not attached to the blind cap, it is removed directly from the pen barrel. The used ink tube is transferred to the disposal unit, where it is collected, and the pen is moved to the next station for a new ink tube insertion, which is supplied from the new ink tube storage unit. Once a new ink tube is inserted into the pen barrel, the blind cap is brought back to the front, and the pen is transferred again to the place where the blind cap removal removed. The blind cap is reattached to the pen, completing the assembly process. Finally, the pen returns to the initial position, the clamp is released, and the user retrieves the pen.

In addition to that, the machine should be compact and lightweight, making it suitable for portable use. Also, the mechanism should be simple to allow easy maintenance and user-friendly operation for all users.

3 System design and development

a. Design consideration

The following design criteria were taken in the designing process
Pen dimensions:

Table 1. Basic dimensions of Atlas max pen

Total pen length	135.95 mm
Ink barrel length	118.95 mm
Number of threads	6
Thread pitch	1.06 mm
Thread diameter	6.39 mm
Blind cap length	19.25 mm
Ink tube length	133.34 mm
Ink tube diameter	3.00 mm
Total pen length	135.95 mm
Ink barrel length	118.95 mm
Weight of the full pen	5.90 g
Weight of the end cap	0.29 g
Weight of the pen barrel	3.86 g
Weight of the front cap	1.15 g

- Nominal Cycle Time: 48 seconds per pen

Table 2. Nominal cycle time

1	Machine Start and Pen Clamp	2 S
2	Pen travelling to station 2	3 S
3	Main rack and pinion travelling forward (15 cm)	5 S
4	2 DOF clamp the end cap	1 S
5	Main rack and pinion travelling back (3 cm)	1 S
6	Clamp the pen tube	2 S
7	Main rack and pinion travelling back (12 cm)	4 S
8	Upper rack and pinion mechanism moves forward (2 cm)	2 S
9	Release the pen tube	1 S
10	Upper rack and pinion mechanism moves backward (2cm)	2 S
11	Pen travelling from station 2 to station 3	3 S
12	Scotch Yoke	3 S
13	Pen travelling from station 3 to station 2	3 S
14	Main rack and pinion travelling forward (15 cm)	5 S
15	Unclamp the end cap and refix it	1 S
16	Main rack and pinion travelling backward (15 cm)	5 S
17	Pen travelling station 2 to the initial position	3 S
18	Unclamp the pen	2 S
Total time		48 S

- Control System: Micro controllers with sensors and limit switches
- Size and Portability: Compact design (610 mm × 650 mm × 350 mm)
- Power Supply : Powered by 12 V DC

b. Key Mechanisms Used in the Machine

The described pen assembling and dispensing machine has several main mechanical systems to accomplish its tasks effectively. To maintain simplicity and quick performance, motor actuators are used for all main operations. The method of smooth, precise motion between stations is facilitated through a belt-driven linear actuator shown in Fig..

Limit switches are built into the system to detect part positions and assist in control throughout each step. Rotary to linear motion conversion for the insertion of the ink tube is facilitated through the reciprocating mechanism.

To keep the pen barrel in a fixed state for operations, a clamp system should be used. Also, another two-arm clamp is used to hold the used ink tube. In addition to that, a two-degree-of-freedom (DOF) robot arm is used to hold and rotate the blind cap, allowing it to be unscrewed or tightened as required. The linear movement of this robotic arm is achieved by a rack and pinion mechanism.

Fig. 5. Belt-driven linear actuator

c. CAD Design

A complete CAD model was developed to visualize the design arrangement. Refer to Fig.6 and Fig. 7 for the overall CAD model.

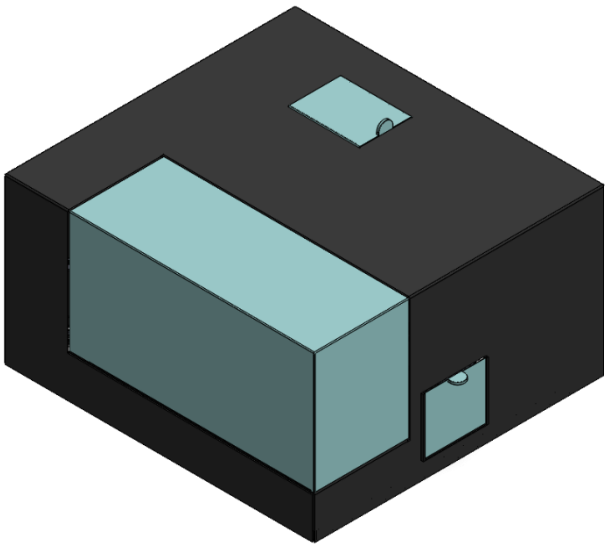

Fig. 6. CAD model

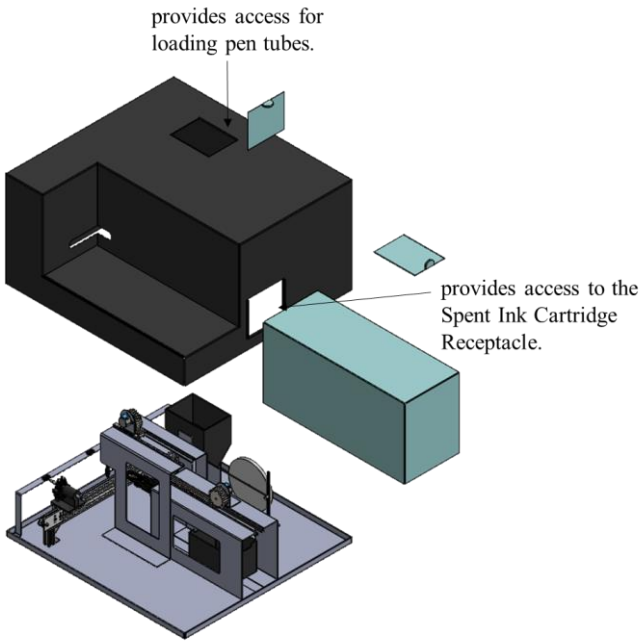

Fig. 7. With easy access to load and unload pen tubes

Fig. 8 illustrates the same design without the outer cover, with individual components labeled.

Then the belt conveyor moves the pen to station 3. Upon reaching station 3, the presence of the pen barrel is detected by a limit switch, and again, the conveyor is stopped. Here, using a reciprocating mechanism, a new ink tube is inserted into the pen barrel from the pen tube holder. A sensor placed in front of the pen can detect the presence of the tip of the new ink tube, and it confirms the end of the process.

The conveyor again becomes active, returning the pen to station 2. At the same time, the robot arm brings the old blind cap to the front using the rack and pinion mechanism. After the pen reaches the station, the system halts, and the robot arm reattaches the blind cap. Finally, the conveyor moves the pen back to the station 1 where it is released.

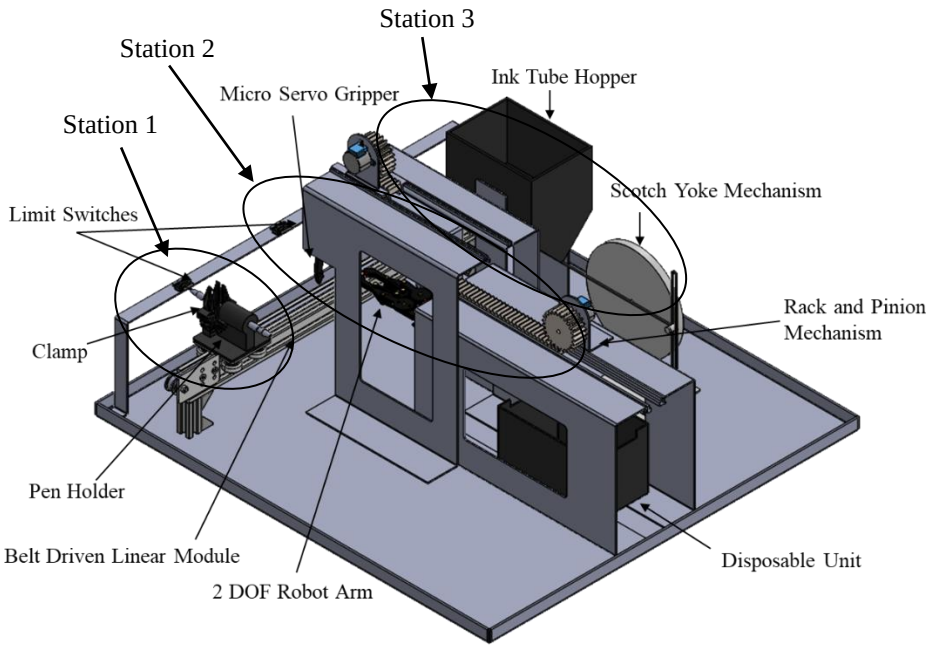

Fig. 8. Design without Outer Cover

4 Conclusions and Future work

a. Conclusions

The production of the reusable pen assembling and dispensing machine presents an alternative way of reducing plastic waste caused by disposable pens. Since the machine only replaces the ink chamber, it encourages an environmentally friendly use of pens without compromising on functionality and ease of use. Usage of mechanisms such as the belt-driven linear actuator, reciprocating mechanism, limit switches, clamp mechanism, and rack-and-pinion assembly ensures precise and automatic assembly of pen parts. The device is easy to use, occupies minimal space, and can be easily implemented in schools, bookstores, and shopping stores. Overall, this project offers a utilitarian and sustainable alternative to traditional pen usage, promoting environmental sustainability as well as longer-term economic returns.

b. Limitations and Future Work

The current design also has certain limitations. It is only compatible with back-loading pens, and manual removal of the pen clip is required, which limits the level of full automation.

Future work may include:

- Completing fabrication and conducting experimental testing to validate the system's reliability, success rate, and efficiency.
- Developing a coin-based operation system to enable automated payment and dispensing in public spaces.
- Incorporating a damaged component identification mechanism to detect worn-out or defective pen parts and replace them automatically.
- Extending compatibility to different pen types through adaptive clamping and modular gripper designs.
- Automating clip removal to achieve full automation.
- Optimizing mechanism design for higher speed, throughput, and energy efficiency.

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