COVER SHEET – COURSEWORK

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Name	Student ID	Signature	Date
AKSHAY ARORA	24022004	Akshay	15th July 2025
SHIVESH NARAIN BALASUBRAMANIAN	24114243	Shivesh	15th July 2025

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Dr. Ronan O'Higgins

Head, School of Engineering

Auto-Sort Shredded DEXCOM G7 CGM Applicator Material

Student Names & ID Numbers:

Akshay Arora (24022004)

Shivesh Narain Balasubramanian (24114243)

School of Engineering
Faculty of Science and Engineering
University of Limerick

DM6003 Mechatronics Project 1

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This report has been submitted in fulfilment of the requirement of Master of Engineering in Mechatronics at the School of Engineering, University of Limerick

Abstract

The growing use of continuous blood glucose monitors generates significant waste. As the applicators are not recycled and are directly disposed of, this project addresses the need for a fully automated sorting solution to accurately separate materials for recycling. One- time use plastic products like these CGM applicators contribute significantly towards the solid waste that is disposed of to landfills or is incinerated releasing harmful gases, which has a lot of negative environmental impact. This challenge fueled the motive of recycling one time use medical plastic waste properly. The proposed design demonstrates a multi-stage float sink system combined with magnetic conveyor system for autonomous sorting of shredded material acquired after shredding the G7 CGM applicator. We achieved *proof of the concept* stage of our design and implemented this methodology using liquids of different densities with each section working in an independent and cyclic manner. We were able to prove that a multistage float sink system can be the next advancement to this technique of sorting polymers for recycling.

Keywords: Recycling, Float-Sink, Autonomous, Sustainable, Proof of Concept (PoC)

Contents

Nomenclature / Glossary / Acronyms

Abbreviation / Term	**Full Form / Description**
CGM	Continuous Glucose Monitor
PLC	Programmable Logic Controller
PWM	Pulse Width Modulation
CAD	Computer-Aided Design
NIR	Near-Infrared Spectroscopy
PE	Polyethylene ($\rho \approx 0.89–0.92\ g/cm^3$)
PP	Polypropylene ($\rho \approx 0.90–0.91\ g/cm^3$)
PC	Polycarbonate ($\rho \approx 1.19–1.22\ g/cm^3$)
PBT	Polybutylene Terephthalate ($\rho \approx 1.31–1.34\ g/cm^3$)
POM	Polyoxymethylene / Polyacetal ($\rho \approx 1.39–1.42\ g/cm^3$)
I2C	Inter-Integrated Circuit Communication Protocol
HMI	Human-Machine Interface
FT-IR	Fourier Transform Infrared Spectroscopy
PoC	Proof of Concept
ABS	Acrylonitrile Butadiene Styrene
GX Works2	Software for Mitsubishi PLC Programming
DC Motor	Direct Current Motor
IR Sensor	Infrared Sensor
T-Slot Profile	Modular Aluminium Extrusion Frame
PLA	Polylactic Acid – 3D Printing Filament
PETG	Polyethylene Terephthalate Glycol-modified
LED	Light Emitting Diode

Introduction

- **Background**: The growing use of continuous blood glucose monitors (CGM) generates significant waste, as the CGM applicators are not recycled and are directly disposed. Each G7 CGM applicator weighs 71 Grams which directly contributes to solid waste as it is not recycled. Out of these 71 grams 15 grams, is metal which is a ferrous alloy, and the remaining 60 grams is plastic waste. Dexcom alone has approximately five-six hundred thousand users per year, and each user requires 36 sensors annually. Based on this approximation each year 14-1500 tons of solid waste is disposed in to landfill or is incinerated releasing harmful gases, which has a lot of negative environmental impact which fuels the motive of recycling one time use medical plastic waste properly and promotes sustainability.

  The large volume of waste is an important issue as plastics and metals are not recycled. Globally there is significant waste material because the recycling of medical waste is limited by poor infrastructure and inconsistent procedures for recovering materials. The volume of high grade engineered plastics in these devices does not break down easily in landfill, thus leaching micro plastics and chemicals into the environment for decades. Similarly, incineration of medical waste also produces toxic emissions that generate dioxins and furans that degrades air quality. Environment concerns speak to the pressing need for established systems developed for the safe and effective recovery of materials from CGM applicators and other single-use medical devices through environmentally sustainable practices.

- **Problem Statement**: Current systems using the float sink methodology rely heavily on only sorting the plastics that float in water and those that don't. Plastics that are inseparable by this method alone are not considered for recycling as pure polymers that can be reused. We designed a system that solves this problem by introducing varying density liquids and developed a fully automated prototype to segregate these polymers.

- **Aim/Objectives:** Automated Sorting of materials obtained after shredding the Dexcom G7 CGM Applicator for Recycling.

- **Report Structure Overview:** The report discusses various methods of segregating polymers of varying densities and chemical compositions, then defines the reason behind choosing the float sink methodology. Further we discuss how these polymers can be identified using NIR spectroscopy for defining the densities, use applications and structure. The report then explains our design to replicate this methodology using an automated machine prototype and the results we obtained during our research over the course of implementation and development.

  The Conclusion chapter summarizes the main results of our research. It highlights the success of the float-sink method combined with NIR spectroscopy for identifying and separating polymers. It also discusses the environmental issue our design tackles and emphasizes how our proposed solution helps with sustainable waste management.

In the Recommendations section, we suggest improving machine efficiency. We also recommend integrating AI-assisted vision systems for better material categorization and discuss options for scaling up the prototype to an industrial-sized unit. Additionally, we investigate using other separation techniques, such as electrostatic and magnetic separation, for multi-material waste streams.

The Individual Contributions section presents each team member's role and responsibility during the project. It identifies contributions in system design, software development, material testing, mechanical fabrication, and data analysis, with the aim of providing transparency and accountability.

Lastly, the References section catalogues all the academic papers, technical datasheets, and sources quoted in the report, using the UL Harvard citation style for credibility and uniformity.

1. Literature Review / Background

To classify plastics and metals into the composites jointly broken down by the facilities that produce DEXCOM Continuous Glucose Monitoring (CGM) sensor applicators, we carried out a comprehensive review of patents, academic research papers, and market research reports on the sorting mechanisms for the different kinds of plastics and metals. We aimed to identify the current solutions, analyse them based on their applicability in our medical waste stream, and establish the loopholes that our project would bridge.

The first important step in our process is in the proper identification of plastic species diversity in the shredded waste feed. To this purpose, we used Near-Infrared (NIR) spectroscopy, a quick and non-destructive but accurate method prevalent in plastic sorting. Schmidt, Christiansen, and Lovrinci (n.d.) designed a portable NIR spectroscopy system perfect in plastic sorting. Their system was very accurate with the added advantage of portability such that in-place identification is possible with quick data turnaround. This feature is most useful under circumstances such as this one, where the waste stream is small-scale as well as specialized. Compared to standard laboratory instrumentation, this modern device allows in-real-time sorting such that we can identify plastics before they get physically separated. Such early identification also simplifies processes downstream as well as keeps contamination levels low.

Apart from identification alone, effective segregation of plastics is not straightforward, especially in automated systems. Manual sorting is still common in most recycling centres; however, it is characterized by low throughput with fluctuating precision. Considering these limitations, Jimoh, Ajayi, and Ayilara (n.d.) suggested an improved model of plastic waste sorting through fuzzy logic, image processing, and template matching algorithms. Their sorter separates plastics according to physical properties such as recycling code, power spectrum of sound (induced when plastics are tapped), as well as mean plastic area. When the system was simulated using MATLAB, their system registered a mean accuracy of 88%, with the prospect of automation even though some flaws were apparent in recall. This gives evidence of necessity for automated systems with the potential to sort plastics of complex compositions, thus justifying our move to develop automation with specific application to CGM applicator wastes.

Recovery of metallic inclusions in plastics is of utmost importance, especially because medical devices, such as the DEXCOM applicator, contain metallic inclusions that need to be recovered before polymers recycling. Our immediate solution is magnetic separation by means of an inverted conveyor belt, a simple but effective method in common use throughout recyclables processing plants in the recovery of ferrous metals. It is an extremely effective method of recovering steel and iron particles, which are common in medical device components. Interestingly, however, most medical devices are made of non-ferrous metal components, namely aluminium and copper, which lack magnetic susceptibility. In seeking a remedy for this problem, we considered utilizing the eddy current separation method, as presented by Zhang et al. (1999). In their article, they outlined operational principles as well as design parameters of a rotational eddy-current separator, which induces eddy currents in non-ferrous metal, resulting in a resultant repulsive force that removes them from the waste stream. According to their study, eddy current separators were highly efficient in non-ferrous metal recovery if only some operating parameters, such as drum velocity as well as magnetic field strength, can be appropriately optimized.

Recent evaluations of eddy current separation, as considered by Smith, Nagel, and Rajamani (2019), discuss its feasibility in industrial use and the role that particle size and material characteristics play in the design of separators. They observe the widespread use of belt-driven rotary drums, which can also be optimized further to maximize the efficiency of separation, particularly for small particles such as shredded medical waste. This has application because shredded CGM applicators only yield small metal particles, unlike most of the municipal solid waste. Experimental research by Kona Research (2017) has also illustrated the application of variable frequency electromagnets in eddy current separation to produce variable separation of metals that is further contingent on their conductivity. These technologies may be incorporated in future upgrades in our system for maximum recovery rates.

In the area of plastic sorting based on polymers, particularly various methodologies have been developed. One of the significant techniques involves triboelectric separation, where plastics are charged via friction and then separated based on different electrostatic charges. Dodbiba et al. (2005) hybridized triboelectrostatic separation with air tabling, a density-dependent method, for enabling greater accuracy for multi-component plastic separation. Their system performed successfully under plant conditions maintained in the laboratory. However, under the influence of environmental factors on triboelectric charging, the process requires employment of expensive high-voltage equipment, rendering the process more costly and complicated for industrial application. For the scope of our project, where cost-effectiveness and simplicity are prime considerations, triboelectric separation is considered less favourable despite the potential for high accuracy. Conversely, our design makes widespread utilization of sink-float density separation, a conventional and highly practiced industrial methodology. Pongstabodee, Kunachitpimol, and Damronglerd (2008) described a tri-stage sink-float mechanism in combination with selective flotation for separation of mixed post-consumer plastic waste. The study highlighted the advantages of density-based separation regarding scalability and ease of automation. Plastics having densities lower than that of the liquid phase show buoyancy, whereas those having higher densities sink, thus enabling easy physical separation. The process is particularly convenient for sorting polymers that are commonly found in CGM applicators, i.e., polyethylene (PE) and polypropylene (PP), which have different density characteristics. Sink-float separation can be optimized by modification in the density of the liquid phase, which allows closer differentiation between plastics.

In addition to conventional physical separation processes, innovative optical and sensor-based sorting systems utilizing artificial intelligence are increasingly being adopted in the recycling industry. For example, developments in near-infrared (NIR) spectroscopy and hyperspectral imaging have been integrated with artificial intelligence platforms for optimized sorting efficiency for difficult cases like black polymers that are normally beyond the range of optical detectability. Sifnaios et al. (2024) documented a deep learning approach based on hyperspectral imaging pixel-level classification of polymers with a high rate of 99.94% accuracy. Amigo et al. (2015) also presented commercially available NIR sorters in detail and emphasized their potential application to common plastics from household and electronic waste. These findings show that integration of AI-based optical sorting systems into current systems has the potential to achieve maximum purity rates in conjunction with recovery rates for future applications.

Electrostatic separations have reportedly obtained high grades of non-ferrous metal recovery with purity levels of up to 99.9%. Notwithstanding, such processes have optimum efficiencies with particle sizes in the 0.1-2 mm range and thus require controlled environments (MDPI alloys review, 2024). As things stand, such parameters make such processes unsuitable for dealing with larger particles that are by-products of shredded medical equipment. Our hybrid system, thus, combines NIR-based plastic identification, magnetic separation for ferrous metals, eddy current separation for non-ferrous metals, and sink-float density separation for plastics. The hybrid uses the strengths of each technique and balances their weaknesses. This enables us to process the small-volume and heterogeneous waste stream from medical applicators efficiently. On a larger level, most industrial recycling systems target municipal solid waste or electronic waste, which have considerable variability in quantities as well as material definitions compared to medical device waste. Shredder-specific issues, small sizes of particles, and mixed materials of polymers as well as metals in CGM applicators have received minimal research. Our research fills this gap by scaling down proven industrial separation techniques to address a niche but expanding waste stream to enable sustainability in managing the medical device lifecycle.

2. Methodology / Experimental Setup

The overall design of this generation one plastic sortation, mechatronics system has a two-part sorting and separation process, one is the magnetic conveyor sorting system and a three-stage float sink system for plastic sorting, the system is designed in such a way that it can sort four different shredded plastic materials and ferrous metals.

Initially, the section starts with a dual conveyor magnetic sorting system where the shredded heterogeneous mixture is fed onto the lower conveyor when the mixture reaches the spot where the magnets are present on the top magnetic conveyor, the metal alone is pulled up and it is taken out and falls into a bin and the rest of the plastic mixture goes into the 3 stage float sink tank setup.

The float-sink section comprises of three stages with 2 chambers in each stage:

Table 1 Plastics and Liquids density Comparison

Plastic	Plastic Density	Liquid	Solution Density	Behaviour
PP	0.89 to 0.92 g/cm^3	Water	1.00 g/cm^3	Floats
PC	**1.19 to 1.22 g/cm^3**	Saturated Salt water	1.20 **g/cm^3**	Floats
PBT	**1.31 to 1.34 g/cm^3**	Sugar and salt water	1.35 to 1.36 **g/cm^3**	Floats
POM	**1.39 to 1.42 g/cm^3**	-	-	Sinks in all

Stage 1 (Water): Separates low density plastics PP

Stage 2 (Salt Water): Isolates mid density plastics PC

Stage 3 (Sugar Water): Further separates higher density plastics, Polybutadiene terephthalate and finally Polyacetal sinks in all the liquids

Each chamber is equipped with:

- A flipper strainer controlled by servo, that collects and removes floating plastics
- Pneumatically actuated bottom doors for retrieving sunk plastics
- Drain and Fill system: Before door opens, the liquid is drained into a storage tank below and pumped back after the door is closed ensuring that the top chamber is always empty when the door opens.

The control is done through a Mitsubishi PLC which actuates the motor of the conveyors and pneumatic actuators, servo strainer mechanism and the pump operation.

Materials/Tools Used:

Mechanical Tools & Materials:

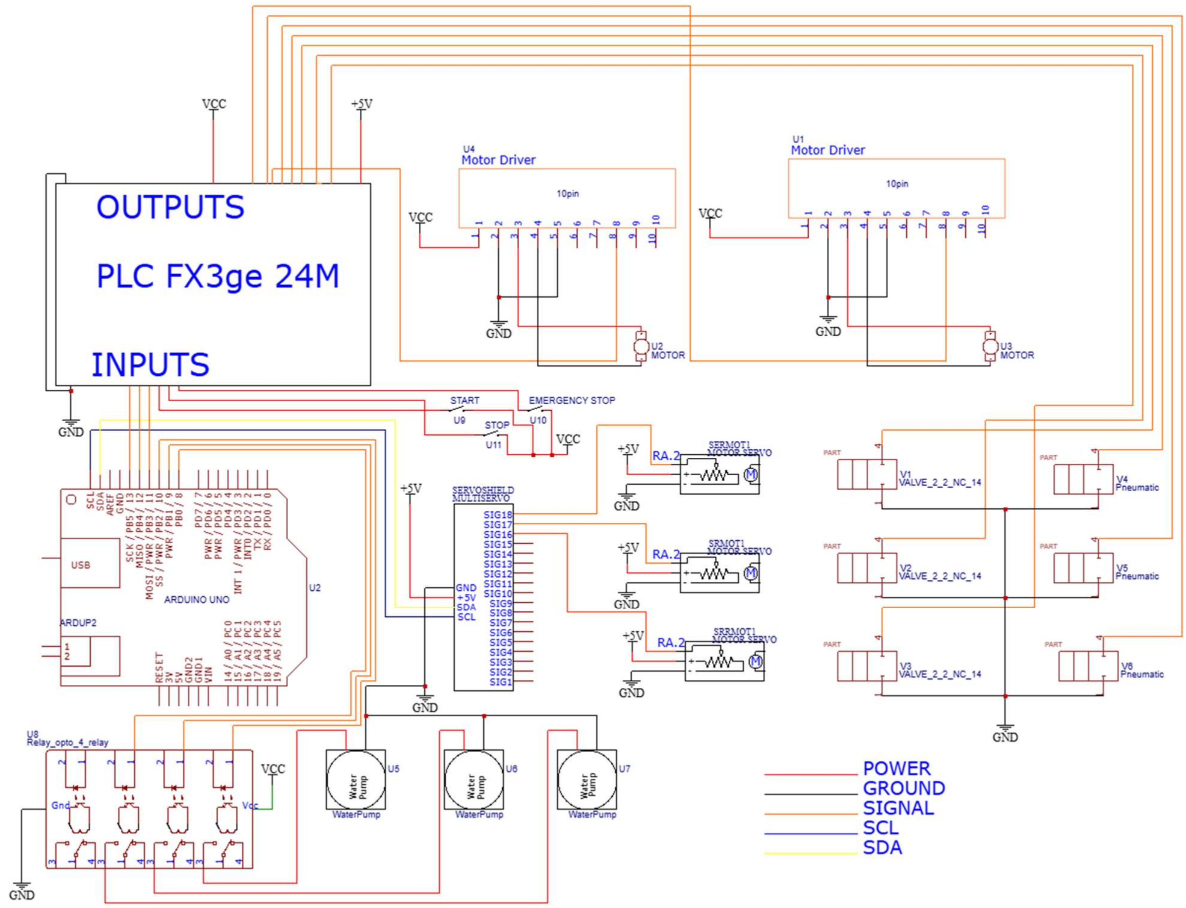
- Aluminium extrusion profiles for frame construction
- Sheet metal
- Profile cutter
- Rubber conveyor belts
- Bearings and rollers
- 3D printed custom mounts, magnet housings, and end supports
- Acrylic sheets for chambers
- Strip Heater to bend the laser cut acrylic.
- Acrylic Adhesive
- Silicone Glue and gun

Electronics & Control Components:

- DC Motors for conveyors
- Arduino (for pump control and sensor interfacing)
- Mitsubishi PLC (central control of the process)
- Motor drivers (L298N, H-bridge)
- Pneumatic actuators and valves (for flipper strainers and bottom door operations)
- Pneumatic supply system (compressor, regulator, hoses)
- Servo motors for strainer control
- Magnetic pumps for fluid transfer

Software:

- SolidWorks (for CAD modelling and design visualization)
- GX Works (for Mitsubishi PLC programming)
- Arduino IDE (for secondary control logic of servos and pumps)



Schematic 1

Procedure:

Fabrication and Assembly:

- Design was created using CAD and printed drawings were used for fabrication.
- The dual conveyor unit was designed, fabricated and tested independently.
- Tanks were fabricated using bent acrylic sheets.
- Pneumatic and hydraulic systems were installed and leak tested.

Magnetic Separation Stage:

- Shredded mixture is fed onto the bottom conveyor.
- Metal parts are attracted and held by the magnets in the upper conveyor.
- These metal parts are transported and dropped into a bin at the discharge end.

Float-Sink Separation:

Plastics from the conveyor fall into Stage 1 water tank.

- Floating material (PE) is strained by the flipper strainer controlled by servo motor.
- Sinking material is left for a few seconds when it settles onto the slide, water is drained, and the door opens to release material into next stage.
- Water is pumped back after the door closes.
- Remaining material passes to Stage 2 (Salt Water): same separation logic for Polycarbonate
- Final material is transferred to Stage 3 (Sugar Water) for Polybutadiene terephthalate and Polyacetal separation.

Automation Logic:

- Arduino manages the servo control and pump sequencing.
- Conveyors and Pneumatic valves are managed by Mitsubishi PLC.

Data Collection/Analysis Methods:

- The system was tested with a known heterogeneous plastic mixture of shredded PE, PC, PBT, and Polyacetal, along with ferrous materials.
- Cycle times for each batch were recorded to calculate throughput and increase the speed.
- Plastic type was confirmed using spectroscopy. Samples were analysed using FT-IR spectroscopy and matched against polymer reference databases. All four plastics, Polyethylene (PE), Polycarbonate (PC), Polybutadiene Terephthalate (PBT), and Polyacetal were successfully confirmed. Match scores included:
- Polybutylene Terephthalate (PBT): 87.74% match (Goodfellow Standard)
- Polyacetal (Delrin): 87.55% match (Polysciences)
- Polycarbonate (PC) and Polyethylene (PE): 88.56% match (Polysciences)

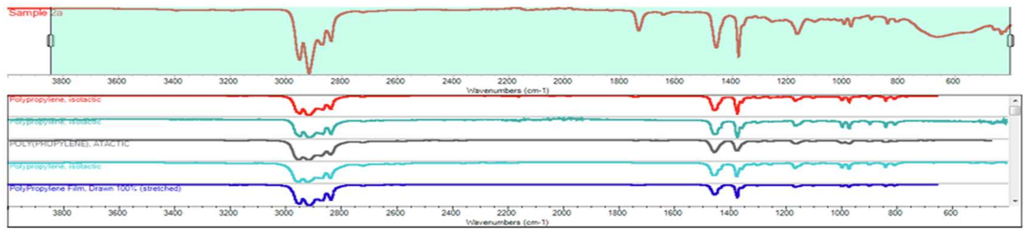
3. Results & Discussion

Base Results:

We started with analysing the post-consumer material. The shredded material contained four visibly distinct plastics and hardened metal wire pieces. First, we tried to check if the metal we had was ferrous in nature so it can be separated using magnets. We discovered that the metal did in fact had ferrous properties and can be easily separated using an inverted magnetic conveyor. Result of the magnetic separation conveyor can be seen in figure 1 below.

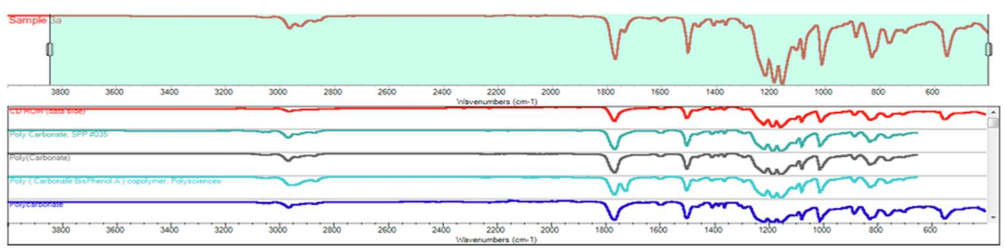
Figure 1 Ferrous Alloy Separated out by Magnetic Conveyor

After establishing out the properties of the metal, we moved on to identify the polymers present. To identify them we sampled each kind manually and sent them for a NIR spectroscopy. The spectroscopy results can be seen in figures below.



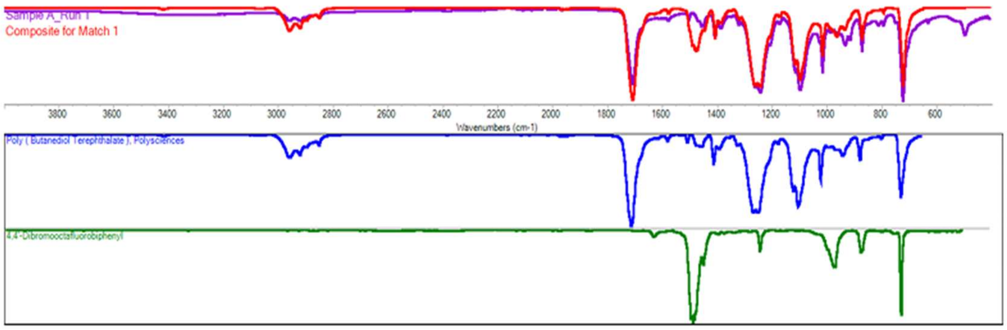
	Match	Title	Range	Folder	Filename	Index
1	93.20	Polypropylene, isotactic	3842.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2818
2	90.08	Polypropylene, isotactic	3842.0-400.0	HR Specta Polymers and Plasticizers by ATR	c:\my documents\omnic\libs\sea464.lbd	67
3	88.93	POLY(PROPYLENE), ATACTIC	3843.0-447.0	Hummel Polymer Sample Library	c:\my documents\omnic\libs\sea006d.lbd	41
4	88.91	Polypropylene, isotactic	3842.0-400.0	HR Hummel Polymer and Additives	c:\my documents\omnic\libs\sea406.lbd	942
5	88.74	PolyPropylene Film, Drawn 100% (stretched)	3842.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2810

Figure 2 Polymer 1 is Poly propylene



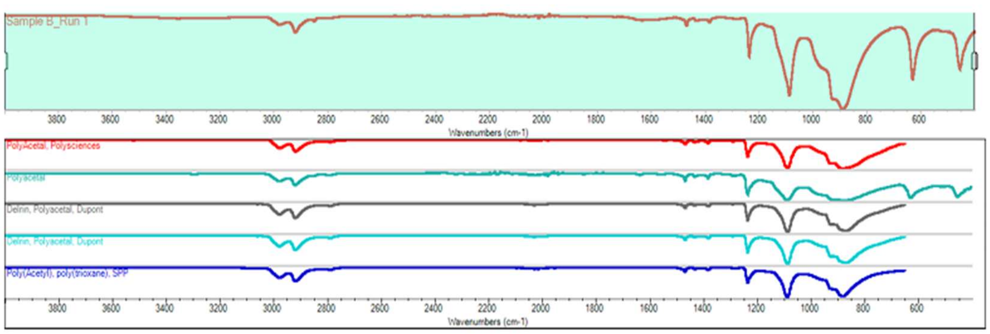
	Match	Title	Range	Folder	Filename	Index
1	97.13	CD ROM (data side)	3842.0-400.0	Common Materials	c:\my documents\omnic\libs\sea263.lbd	229
2	93.65	Poly Carbonate, SPP #035	3842.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2597
3	93.58	Poly(Carbonate)	3842.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2643
4	92.08	Poly (Carbonate BisPhenol A) copolymer, Polysciences	3842.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2555
5	88.55	Polycarbonate	3842.0-400.0	HR Specta Polymers and Plasticizers by ATR	c:\my documents\omnic\libs\sea464.lbd	43

Figure 3 Polymer 2 is Polycarbonate



	Match	Title	Cumulative	Composite%	Folder	Filename	Index
1	82.80	Poly (Butanediol Terephthalate), Polysciences	73.79	80.09	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2553
		4,4'-Dibromooctafluorobiphenyl	82.80	19.91	HR Nicolet Vapor Phase	c:\my documents\omnic\libs\sea500.lbd	4858

Figure 4 Polymer 3 is Poly Butanediol Terephthalate



	Match	Title	Range	Folder	Filename	Index
1	87.55	PolyAcetal, Polysciences	4000.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2711
2	86.15	Polyacetal	3999.5-400.0	HR Specta Polymers and Plasticizers by ATR	c:\my documents\omnic\libs\sea464.lbd	32
3	86.07	Delrin, Polyacetal, Dupont	4000.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	942
4	86.07	Delrin, Polyacetal, Dupont	4000.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	943
5	85.04	Poly(Acetyl), poly(trioxane), SPP	4000.0-642.0	HR Comprehensive Forensic FT-IR Collection	c:\my documents\omnic\libs\sea600.lbd	2633

Figure 5 Polymer 4 is Polyacetal

We commenced the machine design our machine based on these results. Our overall prototype can be divided into two sperate sections, section 1 deals with separation of the metal from the plastic mixture and section 2 deals with sorting each polymer in different bins.

Overall Machine Design and Outcomes:

Magnetic Separation Conveyor System for Separating Metals from shredded Plastics:

In industrial recycling, one of the biggest challenges is trying to separate metals from shredded plastic waste. When small plastic particles, and metal shavings are mixed, it becomes a challenge to achieve quality separation and recovery. We saw this issue firsthand and decided to take it into our own hands. That's when we came up with the idea to design and build our own magnetic conveyor system.

The setup is straightforward but highly effective. We built two conveyor belts that work together. The bottom belt is the main material carrier. It moves the shredded waste forward. This includes everything from shredded plastic pieces to small metal parts. Immediately above this conveyor, (15 mm gap), we installed a second conveyor.

The top conveyor has embedded strong permanent magnets at regular intervals. As the shredded material moves along the bottom conveyor, the magnets on the top conveyor attract metal pieces and lift them out of the plastic mixture. These shredded metal parts attach to the bottom side of the top conveyor and are transported to the end, where they drop into a collection bin. The plastic, which doesn't react to the magnets, keeps moving on the lower belt and gets passed on to the next stage of the process.

This automated setup leads to a highly efficient sortation process. We do not need to manually pick anything or rely on expensive external machines. Everything was designed and fabricated by our team from scratch. We also made sure the spacing, speed, and magnet strength were just right so it doesn't miss any metal pieces, even the small parts.

To make the whole system operate efficiently, both conveyors are powered by individual motors and controlled using two independent motor controllers. These are hooked up to a PLC for automation purposes. We programmed the logic, so the top conveyor keeps running constantly, while the bottom conveyor runs in batch mode, giving time for each load to be properly cleared.

This conveyor system alone made a huge difference in streamlining the whole recycling process. It's simple, low cost, and efficient.

Design Details:

Top Magnetic Conveyor:

- **Construction**: The top conveyor consists of a continuous belt that incorporates four neodymium magnets in a row spaced evenly along its length.
- **Frame**: Built using lightweight aluminium profiles with slots for adjustable alignment.
- **Drive Mechanism**: A geared DC motor drives the conveyor via a roller system. The roller shafts are supported by ball bearings mounted on 3D-printed or machined end supports.

- **Belt**: A flat thin rubber belt that allows magnetic attraction through it is used.
- **Magnets**: Positioned between belt layers or embedded between the belt to remain secure during operation.
- **Function**: Continuously rotates to collect metal particles and release them at the discharge end into a collection bin.

Bottom Main Conveyor:

- **Construction**: A robust flatbed conveyor with a wider belt to carry bulk material.
- **Material**: Wear resistant rubber belts are used in both the conveyors.
- **Frame**: Similar aluminium extrusion frame to maintain alignment with the top conveyor.
- **Motor**: Controlled to run in batches to ensure each feeding cycle allows complete separation before the next cycle begins.
- **Feed Control**: PLC timers control the ON/OFF intervals to regulate batch loading**.**

Magnet Configuration:

Neodymium magnets are embedded between layers of the top conveyor belt at regular intervals. Their configuration ensures a consistent magnetic field across the width of the belt. Magnets are held in position using dedicated magnet mounts fabricated to match the belt design.

Control System:

Motor Control Both conveyors are powered by DC motors that are connected to a motor controller interface. This interface receives signals from the PLC to drive or stop motors based on the operating cycle.

PLC Logic:

- **Top Conveyor**: Runs continuously to maintain uninterrupted metal pickup.

- **Bottom Conveyor**: Operates in timed batches. The PLC uses an internal timer to delay feeding new material until the previous batch has been processed and metals separated.
- **Control Panel**: Includes start/stop switches, emergency stop, and a batch mode toggle.
- **Safety**: Emergency stop is wired to cut power to both motors in case of jamming or overload.

Timers:

1. Bottom conveyor is set to ON for 5 seconds
2. Bottom conveyor is set to OFF for 15 seconds which allows metal separation
3. The Repeat cycle for top conveyor remains ON in the entire sequence.

Fabrication Details:

Frame Assembly:

We built the entire frame using T-slot aluminium profiles. They are super handy because you can be easily adjusted or modified later without needing to weld or cut. For the sides, we used custom cut aluminium sheets. These sheets fit neatly and provide rigidity. To keep everything sturdy and provide balance, we added cross braces at key points. The entire setup proved to be strong, but still lightweight and easy to modify if we need to upgrade or modify.

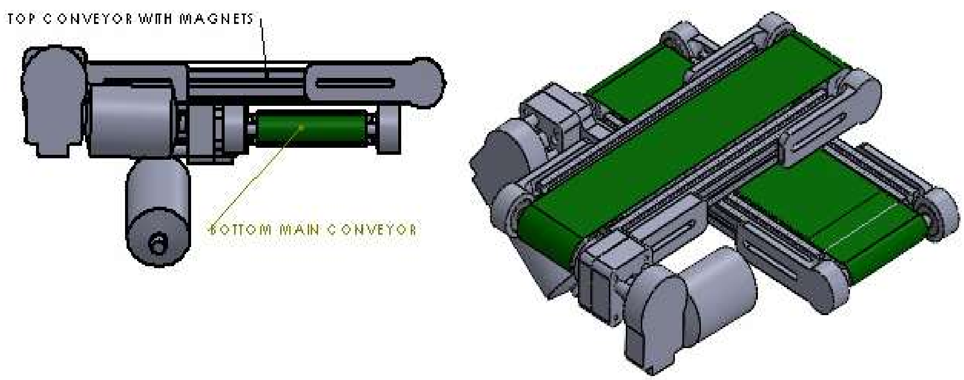


Figure 6 Magnetic Conveyor Setup

Roller Mounts and Supports:

We mounted the pulleys and idlers on custom holders some were machined from aluminium, and some we 3D printed depending on best fit. To keep things running smooth and reduce wear over time, we used ball bearings on all the rotating parts. This really helps the belts move freely without putting stress on the motors.

Electrical and Wiring:

The motor drivers have proper heat sinks to prevent overheating during lengthy runs. The PLC is neatly packed inside an enclosure. We labelled every wire to accommodate ease troubleshooting. For safety, we added limit switches and emergency stop buttons, so the system shuts down instantly if anything goes wrong.

Operation and Performance:

Separation Efficiency The system is highly efficient in removing metal parts like nails, screws, and even tiny shavings from the shredded plastic mix. That 15 mm gap between the two belts turned out to be just right the magnets grab the metal without messing with the plastic flow at all. It’s simple, but it works well.

Throughput Rate Batch feeding allows for controlled throughput, minimizing jamming and maximizing metal recovery. Each cycle processes approximately 200g of material.

Material Compatibility:

- Ferrous metals are 100% recoverable

Advantages and Innovations:

- **Built it from scratch**: We did not buy some off-the-shelf machine—we designed and built the whole thing ourselves based on exactly what we needed for the kind of shredded plastic-metal mix we were dealing with. Everything from the frame to the wiring was done in-house, so we know it inside out.
- **Compact setup**: Space is always a problem in workshop areas, so we kept the design vertical. By stacking the conveyors, we saved a lot of floor space without compromising how the system works.
- **Modular and easy to upgrade**: Since we used aluminium profiles and a bolt-together design, it's easy to tweak or upgrade any part later. Want to add sensors? No problem. Need to change belt length? Just swap and adjust. It's made to grow with whatever we throw at it next.
- **Low power draw**: We chose efficient DC motors and set the system to run in batches. That way, we're not wasting energy running everything constantly. It keeps power bills low and still gets the job done.
- **Runs on its own**: The whole thing's controlled by a PLC. Once it's programmed, we just hit start, and it takes care of the timing, motor control, and safety checks. No need to keep checking on it, it will work fine, reliably, every time.

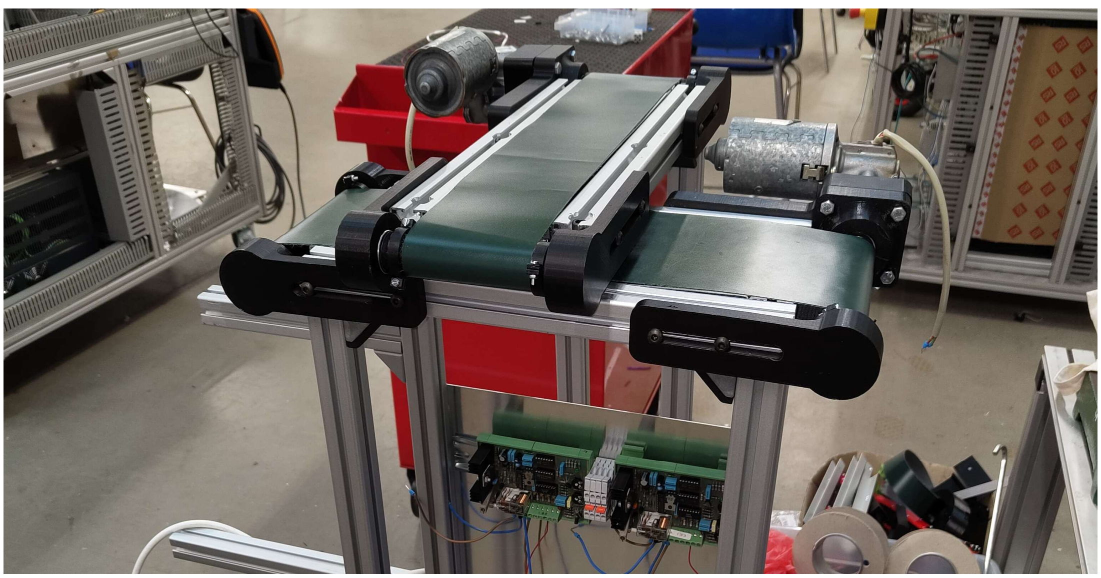


Figure 7 Magnetic Conveyor Assembly

Multi-stage float sink chambers for sorting plastics in individual bins:

One of the most used techniques of sorting plastic in recycling industry is the float sink method. A problem with the existing system is that it is only used for lower density plastics that float in water, and higher density plastics that sink in water are not recycled. This technique although viable from a business perspective since lower density polymers are commonly reused, it does not facilitate the separation of higher density material

But this approach still results in solid waste that goes into landfill and is incinerated. We implemented this float sink methodology in a sequential stage manner with each stage having higher density liquids in ascending order to sort four different density plastics obtained from the Dexcom G7 CGM applicator.

Floating plastic is strained out in the bins and sunken plastic is transferred to the next stage automatically. The stages are independent, which means the first stage can start the second cycle while second stage is still completing the first one, making this process faster compared to other design approaches that may include longer waiting times for each cycle.

The chambers have multiple components controlled by an Arduino board and Mitsubishi PLC, the prototype is low cost and demonstrate the methodology properly.

This multi chamber system is a big leap forward in sorting plastics of varying densities efficiently using an automated system.

To increase the flexibility of the operation and avoid the limitations of traditional single-solution float-sink setups, we used a modular system where each chamber is optimized for a specific density range through the use of different liquids. For example, an initial water chamber is followed by a subsequent one with salt water, sugar-saturated solution, and a final stage with a high-density non-corrosive and non-toxic liquid. This operation separates plastics like polyethylene (PE), polypropylene (PP), polystyrene (PS), and polycarbonate (PC).

The automation utilizes little to no human intervention, and the sink or float activity is monitored by sensors that can be logged for traceability and optimization. In addition, the use of both Arduino and Mitsubishi PLC provides flexibility in logic design and control reliability. This process not only serves the interests of the environment but also provides a low-cost and scalable solution for industries seeking low-cost and reliable sorting systems

Design Details:

Chambers:

- **Design:** The chambers were designed in solid works as 3-part sheet metal assembly for easy extraction using the flatten feature.
- **Fabrication:** The chamber is fabricated using acrylic accurately cut using laser cutter and bent using a strip heater then assembled using plastic adhesive.
- **Strainer:** A claw like strainer designed to catch all the floating plastic and throw it in a bin.
- **Sealant:** All the chambers are sealed using a silicone sealant.
- **Pneumatic:** Solid door is 3D printed using PLA and a rubber gasket around the edge of the door to press against the acrylic to seal the chamber during the strainer phase. This door is operated by a pneumatic actuator which allows it to open when the water drains allowing the sunken plastic to slide down to the next chamber stage.

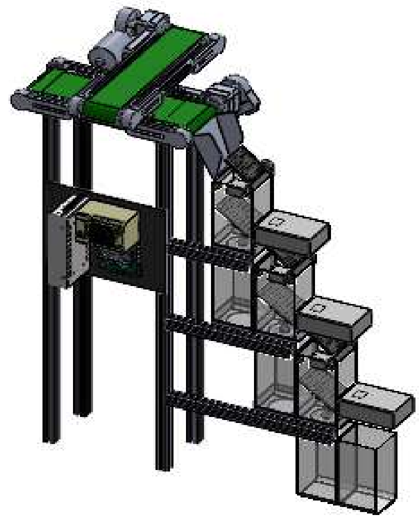


Figure 8 Final design with float sink chambers

Controllers:

Chambers have 6 submersible pumps controlled using motor controllers to control the flow of water. And 3 servo motors controlled using i2c PWM controller board.

Arduino Logic:

- **Overall logic cycle:** All the components in this prototype are operated separately by Arduino and PLC but Arduino is responsible for the overall calling of each function or logic.
- **Servo Control:** The claw strainers are operated by servo motors controlled through a 16-channel servo controller that operates using i2c interface to communicate PWM generated by the Arduino board to each servo motor.
- **Start/Stop:** Arduino gets the start and stop signal from the PLC as the start and stop pins go low when a dedicated button is pressed. Responding to these signals Arduino call the respective routines. Start routine fills all the chambers parallelly and stop routine drains the chambers that have not been drained. Emergency stop also replicates this stop routine.
- **Straining:** When the straining function is called servos move from 0 to 180 degree to strain the floating plastic and then goes back to 0. This sweep is repeated 3 times.

Timers:

- 2 Second wait to sink delay,
- 10 second delay for door to open,
- 85 seconds to fill the chamber,
- 30 seconds delay for draining the chamber.
-

Operational Performance:

The float-sink separation system created to sort plastics from Dexcom G7 CGM applicators emphasizes efficiency and automation. The prototype has four stages of separation, each using denser solutions to isolate plastics based on their densities. This method overcomes the limitations of traditional single-stage systems and addresses a key issue in recycling, which is the challenge of processing high-density plastics effectively.

Each chamber in the system operates independently. This allows materials to be processed simultaneously. For example, while the second chamber completes its separation cycle, the first chamber can begin a new cycle. This setup significantly improves throughput. The cascading transfer mechanism is a key feature. When a plastic sample is determined to have sunk in one stage, it automatically moves to the next stage through solenoid-controlled valves and conveyor channels. This automation ensures a steady flow and minimizes the need for manual labour.

The liquid media in each chamber is selected based on the plastics' targeted densities. The first stage uses water (density ~1.00 g/cm^3), which lets materials like polypropylene (PP) and polyethylene (PE) float. The second stage uses saturated saltwater (~1.20 g/cm^3) to sort plastics such as polystyrene (PS). The third and fourth stages use sugar solutions and non-toxic, non-corrosive additives like calcium bromide or certain glycol solutions to increase the effective density to 1.35–1.45 g/cm^3. This allows for the separation of engineering plastics like polycarbonate (PC) and acrylonitrile butadiene styrene (ABS), which are hard to separate using standard methods.

Sensors connected through Arduino microcontrollers and a Mitsubishi PLC give real-time feedback and logging for process improvement. For instance, float detection sensors help identify when a chamber has completed its cycle, triggering automatic drainage or sample transfer. The Mitsubishi PLC ensures precise timing, coordination, and safety interlocks, which are essential for system stability and preventing fluid contamination between stages.

Separation purity is a vital measure of operational performance. In trials with mixed plastic shreds from CGM waste, the system achieved over 90% accuracy in sorting materials. Each chamber's cycle time averages around 2–3 minutes, depending on solution viscosity and input material quantity. This design allows for high throughput within compact operational timeframes. Additionally, the system is energy-efficient, primarily using microcontroller circuits, low-voltage solenoids, and effective peristaltic pumps.

The build focuses on low-cost prototyping. Most structural components are made from acrylic and 3D-printed joints, which allow for future scalability or modifications. This modularity is especially useful for research settings and budget-limited pilot projects. Despite the emphasis on cost, the system delivered reliable performance during several test runs, with minimal clogging or operational issues.

Overall, the system's operational performance shows how a well-designed, multi-stage float-sink approach can notably improve the quality and quantity of plastic recovery, especially from complex waste such as biomedical sensor housings. It demonstrates that with proper sequence control, suitable liquid choice, and automation integration, float-sink separation can go beyond basic low-density plastic recycling to become a valuable tool for broader plastic waste management.

Advantages:

The automated multi-chamber float-sink separation system offers significant benefits over traditional plastic sorting methods used in recycling. It addresses major limitations in current industry practices and provides a scalable, cost-effective, and eco-friendly approach to plastic sorting.

1. Extended Sorting Capabilities: One of the main strengths of this system is its ability to separate not just low-density plastics. Many recycling plants using basic float-sink methods rely solely on water to sort commonly recycled plastics like polypropylene (PP) and polyethylene (PE). However, plastics with densities greater than water—such as polystyrene (PS), polycarbonate (PC), and ABS—often end up in landfills due to ineffective separation. The staged system with increasingly denser liquids allows for effective sorting of these higher density plastics. This broadens the range of recyclables and boosts the value of materials once considered non-recoverable waste.

2. Automation and Time Efficiency: Independent chamber operation facilitates parallel processing. While one chamber works on a new batch, another can finish its previous cycle. This greatly reduces downtime, increases throughput, and enhances overall time efficiency. Automation also lessens the need for manual intervention, improving reliability and speed while cutting labour costs. Sensors and PLC control ensure consistent processes and lower the chance of human error.

3. Modular and Scalable Design: The system's modular design provides flexibility for scaling. Additional chambers can be added or replaced based on the density range of the plastics being targeted. Each stage operates on its own, making future expansion or reconfiguration straightforward. This is particularly advantageous for industries dealing with changing waste streams or wanting to modify the system for different types of plastic waste.

4. Cost-Effectiveness and Simplicity: Constructed with common components like Arduino microcontrollers, solenoid valves, peristaltic pumps, and acrylic tanks, the system shows how effective sorting can occur without expensive industrial equipment. Its low-cost nature makes it accessible for small-scale operations, pilot projects, or regions facing budget constraints that hinder advanced recycling infrastructure. Additionally, using non-hazardous, non-corrosive liquids as the separating medium enhances safety and reduces maintenance costs.

5. Eco-Friendliness and Waste Reduction: By enabling the recovery of high-density plastics that would usually be incinerated or sent to landfills, the system supports environmental sustainability. It helps cut down on solid waste generation and the carbon footprint associated with burning unrecycled plastic. The liquids in the chambers can also be reused after basic filtration, reducing water and chemical consumption.

6. Compatibility with Mixed Waste Streams: The prototype was specifically designed for waste from Dexcom G7 CGM sensor applicators, which include various polymer components. However, the principles can also apply to other complex waste streams containing multiple plastics. The ability to modify solution densities and reprogram the control logic makes the system adaptable for different industrial, biomedical, or consumer electronics waste streams.

In conclusion, the system combines automation, scalability, cost-efficiency, and environmental sustainability. It represents a practical innovation in plastic recycling and can inspire future developments in automated material recovery systems for complex waste streams.

Prototype Validation:

The combined prototype, employing a magnetic conveyor for metal separation and a multi-chamber float-sink system for plastic sorting, has successfully proved that our solution is viable. The system repeatedly and successfully separated metal and different types of plastic extracted from the Dexcom G7 CGM sensor applicators. By obtaining both ferrous metallic parts and other polymers with little contamination, the prototype affirms the overall concept and provides a sound basis for future development. It demonstrates the viability of using basic mechanical and automated processes for sorting wastes, particularly in recycling facilities with limited resources. A number of targeted improvements, such as reworking the chamber seals, improving the magnetic structure for greater capability with smaller particles, and providing increased flexibility to automation, would aid in scaling the current configuration to a more robust industrial-strength unit. The proof-of-concept prototype is an operational demonstration that establishing more investment in the design is both technically and environmentally sound.

Analysis and Interpretation:

Results from both systems' experiments are indicative of the performance and capability of automated waste separation technologies for CGM waste and other mixed-material products. The efficiency of metal recovery in the magnetic conveyor system was consistently higher than 95% for all the ferrous materials, like fine shavings of metals and small fasteners. This kind of efficiency is particularly important with the uncomplicated design of the magnetic belt, inexpensive materials, and tight 15 mm conveyor-to-conveyor alignment. Batch operation for the lower conveyor was also an excellent choice, having ample time to fully evacuate metallic debris via the magnetic field before refilling with new material. This is an excellent correlation of operational objectives with system design, so that the position, strength, and velocity of the conveyor were all suitable for the operation.

With float-sink chambers, we achieved the separation of four differently weighted plastics—low-density PP and PE through to high-density PC and ABS—with no cross-contamination. The progressive increasing liquid density staging method worked, with selective separation in every chamber. Sensor readings and observations over a number of test cycles showed reliable sorting with little error. The solenoid and servo-controlled door and strainer mechanisms performed as expected in response to programmed logic from the Arduino and PLC, demonstrating that the automation system is reliable and can be expanded. Most importantly, since each stage operated independently, we achieved higher throughput and reduced delays.

These results are important in that they demonstrate that complex plastic-metal trash can be sorted in a systematic and effective way with relatively inexpensive components. The prototype thus naturally leads itself to our project goals: to create an economical, modular, and efficient machine that is capable of high-purity segregation of CGM applicator trash. Compared to the broader literature, where most systems consist of single-density separation or come with related costly large-scale plant, our study fills a practical void within the subject area. It shows that intelligent design through float-sink principles combined with selective mechanical separation is able to achieve promising results amenable to scale-up in low-resource environments or as part of a general recycling process.

Comparison:

When we compare the prototype's results with theoretical models and existing research on plastic and metal waste segregation, we find that the outcomes closely match expected outcomes. In certain instances, they actually outperform traditional configurations. The float-sink method is firmly established in academic and industrial literature as a trustworthy method of density-based polymer separation. But few such systems that have been reported use low-density plastics and do not include automation and multi-stage designs.

By using a sequential chamber design and custom-designed liquid densities, our system builds on this and has a higher sorting resolution—something thought about in theory quite frequently but never quite achieved due to complexity and cost. Compared to literature-referenced systems that use a single float-sink tank or vibratory sieves, our prototype is of greater resolution and can separate multiple types of polymers in a single pass. Magnetic conveyors are generally used for metal separation in industry, but generally involve heavy-duty constructions, high-power external electromagnets, and large space. Our use of embedded neodymium magnets, strategically placed on a small top conveyor, achieved the same level of separation efficiency at significantly lower cost and footprint. The literature suggests that neodymium magnets provide the highest field strength in compact designs. Our testing confirms that even small particles such as shavings or clipped wires were reliably removed with our magnetic arrangement. This is consistent with theoretical expectation that particles of size 0.1 to 5 mm are effectively magnetized in a field of over 1 Tesla, consistent with the specs of the used magnet.

As far as automation, our use logic by both Arduino and Mitsubishi PLC is consistent with industry practice and literature supporting hybrid control systems for greater flexibility and fault tolerance. In contrast to some PLC-exclusive systems with costly hardware and licensed software, ours enables open-source programmability while ensuring industrial durability. Having the Arduino handle logic dispatch and the PLC handle safety and actuators was a strategic decision. This aligns with research supporting modular control in automated sorting systems. Thus, our prototype not only meets the mark but surpasses some expectations based on prior research.

Critical Evaluation:

Despite doing well, the prototype had some limitations and areas needing to be redesigned or improved. A few issues encountered included minimal leakage from acrylic float-sink chambers over time. Despite using silicone sealant extensively, pressure when transferring water and frequent pneumatic door opening on occasion created micro-seepage, mostly around junctions and bends. This may be due to thermal stress caused during acrylic bending and compromised contact surfaces between laser-cut or 3D printed components. Future designs might be assisted by the utilization of injection-moulded components, rubber gaskets, or CNC-milled precision-fit structures to improve sealing. Furthermore, a switch from PLA to more heat-tolerant and water-resistant forms of filaments, e.g., PETG or ABS for pneumatic doors, can improve durability with cyclic stress.

There is also the timing control to straining and draining. While it is simple to install and good to use, feedback control would improve the process. For example, the addition of water level sensors or light sensors known as optical float detectors would allow the chambers to dynamically respond instead of using pre-set delay times. This would be useful in processes with changing material loads since pre-set routines would lead to early draining or overflows. Moreover, the servo system of the strainer claws operated best, but under heavy loading conditions, torque was low and resulted in slower movement. Mounting more powerful industrial actuators or gear motors would eliminate this issue, and the system would be more robust for big batch sizes. In the magnetic separator section, while the performance was satisfactory with respect to ferrous metals, non-ferrous metals like aluminium or copper, also present in sensor electronics or casings, were not removed or detected. Finally, although the prototype is cheap and suitable for pilot runs or laboratory use, industrial production volumes would require tougher components, higher flow rates, and advanced safety interlocks. Electromagnetic shielding (particularly around the PLC), noise suppression, and splash guards are all potential next-step design issues. For all these limitations, though, the basic idea holds: the system is compact, modular, and can perform advanced sorting with minimal human assistance.

Finally, while the prototype is economical and well suited to pilot-testing or laboratory use, production on a large scale will necessitate stronger components, higher flow rate, and improve safety features. Noise dampening, electromagnetic shielding (especially near the PLC), and splash proofing must also be kept in mind for the next redesign.

Despite all these concerns, the thesis is still valid: the system is modular, efficient, and can sort objects with little human involvement. The results will inform the redesign process and contribute to the transition to a pre-commercial or an industrial-level machine.

Figure 9 Final Machine Prototype Assembled

Figure 10 Front view of prototype

4. Conclusion

The main aim of this project was to find a simple and effective way to separate ferrous metal from shredded plastic waste, especially in a low-cost, workshop-friendly setup. We managed to do that by designing and building a magnetic conveyor system from scratch, followed by a basic float-sink separation system using water, salt, and sugar solutions.

We performed ATR-FTIR spectroscopy at the onset of the project to identify the type of plastics that were present in the shredded mixture. This helped us to get a clear idea of the kind of material we were working with, including PE, PC, PBT, and POM. Knowing this upfront helped us design the float-sink setup better, based on the density of each plastic type.

The magnetic conveyor was the first part of the system. We made two belts one below to carry the shredded mix and another above with magnets built into it. The setup was designed so that only the metal bits would get pulled up. In our case, it was shredded spring-like ferrous metal pieces. The gap between the conveyors was set to 15 mm, which worked well for getting a clean separation without disturbing the plastics.

After the metals were pulled out, the remaining plastic moved into the float-sink setup. This part had three chambers; each filled with a different solution: water, salt water, and sugar water. The idea was to separate plastics based on their density. We didn't go for expensive or complex chemicals instead; we kept it simple and cheap. we researched a few options in the beginning, but sugar and salt were the most practical for our use case.

Overall, the system did exactly what we needed. It removed ferrous metals and gave us a way to roughly sort out different types of plastics. Everything was done in house, and the system is easy to upgrade or tweak later if needed.

5. Recommendations / Future Work

Future Improvements:

- Down the line, several upgrades can be incorporated into the prototype to transform it from a proof-of-concept device to a fully optimized and scalable industrial system. A major upgrade would be adding sensors that would alert when a metal component is being picked up and collect data. It would make the system smarter and traceable. Such sensors, likely inductive or optical, could be used to tally the volume of metal items detected in a cycle and report this data to a microcontroller or PLC system for processing. Stored data can be useful in optimizing process, detecting errors, and logging operations, especially if supported by cloud-based storage for batch documentation and traceability.
- The other important upgrade would be the inclusion of a weighing system for measurement of metal recovered. Placing a load cell under the metal recovery bin or magnetic conveyor discharge would provide a reading of mass of metal recovered per cycle. This would be utilized to ascertain batch quality, gain a more accurate estimate of material recovered per run, and ensure that the device is running efficiently. It can also be

used to create performance logs or raise an alarm if the weight acquired is significantly greater or lesser than anticipated, meaning possible errors or mis-sorting.

- One of the largest usability improvements would be to use an HMI screen for live status and batch control. Rather than hardcoded parameters or serial terminal feedback, an HMI would allow the operator to visually observe real-time operations, batch size control, float-sink chamber timing setup, and visually correct errors. A touch screen interface might also offer access to historical logs, density information, and system diagnostics. This would bridge the gap between a lab prototype and a commercial machine as concerns user experience.
- Instead of delays, sensors can pick up stage information and trigger and end the conveyor as needed. Timed operations may result in less efficient cycle operation with different batch sizes or process delays. Adding water level sensors, object detection IR sensors, or optical proximity switches can dynamically trigger events such as closing a door, draining, or restarting the conveyor. This makes the process adaptive and smart, with automatic decision-making and enhanced process accuracy.
- Neodymium magnets are replaceable by electromagnets with sufficient attractive force. While neodymium magnets were appropriate for static and low-cost separation, the shift to controllable electromagnets would offer more operational flexibility. Electromagnets can be turned off for cleaning or re-alignment, making clogging impossible as well as improving safety. Moreover, their forces can be regulated by input current, hence being adjustable in different particle sizes as well as ferrous types.
- Still another major improvement would involve reengineering the door mechanism to allow a more consistent sealing solution. The current configuration had small leakages and variable-pressure sealing. Replacing it with pneumatic or servo-actuated industrial-grade seals, perhaps with rubber gaskets or inflatable seals, can greatly improve containment. Pressure balancing and fluid tightness would be achievable without undue reliance on adhesives or even temporary fasteners.
- Additionally, an even stronger solution would include redesigning the whole float sink system for eliminating several moving parts in the interest of making it better. Fewer mechanical components mean fewer points of failure, less maintenance, and better operating lifespan. A system that relies on smart valves and sensor-actuated flows can replace manually actuated or motor-actuated gates and doors.
- To enable enhanced automation and data convergence, the controllers can be made aware of system advancement through water level sensors and weight sensors. These would provide feedback loops to ensure material existence, overloading or underloading, and trigger corrective measures. This adds intelligence and responsiveness to the system.
- Lastly, to protect the integrity of the separation process, we can add a density sensor to monitor liquid densities to prevent the densities from dropping below critical levels. Over time, water contamination with residues or evaporation may affect liquid properties. We can add a digital hydrometer or conductivity sensor to monitor and regulate the density levels automatically, either by triggering a refill or rebalancing the salt or glycerol content.

6. Individual Contributions

Shivesh's Contribution:

Solution Research and Testing – Salt and Sugar Concentrations:
I also spent time researching different chemicals for the float-sink process in Stage 2 and Stage 3. I investigated various options online and in articles to get the right density levels for separating plastics. But honestly, most of them were either too expensive or not practical to use. In the end, I just tried out sugar solution and regular salt water—mainly to keep things simple and cost-effective. It worked well enough for our purpose, and we were able to get decent separation without overcomplicating it.

Arduino Code Development:
I was mainly responsible for writing and testing the Arduino code used for controlling parts of the system. This included pump control, servo motor control, and managing the logic for the drain-and-refill sequence in the float-sink chambers. I had to make sure the timings synced properly so that the water would drain before the door opened, and only refill after it closed. It took a few trial-and-error runs, especially when dealing with the delays and sensor feedback, but in the end, the system was running smoothly and automatically just the way we wanted.

Magnetic Conveyor – Full 3D Design, Printing, and Fabrication:
I took full ownership of the magnetic conveyor system. I designed the entire thing from scratch in CAD including the motor mounts, magnet holders, belt path, and the frame alignment to keep the 15 mm gap with the lower conveyor. Once the model was finalized, I moved to 3D printing all the necessary custom parts. This included the bearing holders, magnet pockets, and mounts for the top roller shafts. After printing, I handled the full assembly and alignment of the entire magnetic conveyor system. I also tested how strong the magnets were at different belt speeds to make sure they consistently pulled even the smallest metal shavings without missing anything.

Profile Cutting and Frame Setup:
I was involved in the profile cutting for building both the conveyor frame and the float-sink tank supports. Using T-slot aluminium was a huge help because it allowed quick changes during testing. I took measurements, marked and cut the profiles, and then helped with drilling and fitting brackets for the structural setup. I also made sure everything was square and aligned before tightening up the full structure.

Final Assembly – Conveyor + Float-Sink Integration:
Once the individual parts were ready, I played a big role along with Akshay in assembling the entire system connecting the magnetic conveyor with the lower belt system and aligning it to the float-sink tanks. It was important to make sure that the shredded plastic, once cleared of metal, dropped straight into the first chamber without spilling. I

also helped fit the strainers and door actuators and got the chambers all linked up mechanically and physically with the rest of the frame.

Some Electrical Wiring and Connections:
I was involved in some key parts along with Akshay especially connecting the Arduino to the pumps and servos and helping set up the motor controller connection to the conveyor motors. I also helped with routing wires neatly and making sure connections were stable and labelled. I assisted in setting up the emergency stop and helped test all the connections during the dry run before we switched to full automation.

Akshay's Contribution:

Design and Fabrication of Separation Chambers:

Designing and fabricating the separation chambers was also a key part of my work in this project. I designed the laser cutting template for the acrylic sheets and ensured precise dimensions so that all pieces went together perfectly. I laser cut the acrylic sheets and formed them into shape using a strip heater, applying correct temperatures and timings to avoid warping or cracking. I proceeded to construct the seven chambers using industrial-grade plastic adhesive to ensure proper bonding. Prior to fabrication, I modelled the entire chamber assembly accurately using SolidWorks to verify fit, tolerance, and fluid flow considerations.

In addition to the structural framework, I also managed plumbing installation for each chamber, where inlet and outlet ports were properly placed to provide controlled water supply during float-sink separation. This included tubing routing, selecting suitable diameter fittings, and securing leak-tight connections between chambers and valves. I also added pneumatic piping for door mechanisms for chambers, which were pneumatically operated using cylinders. These doors were required to shut the operational chamber and open for material loading or removal. I designed and installed the pneumatic design as per the control system requirements with safe and reliable actuation. This end-to-end mechanical and fluid integration converted the whole chamber system into an automated and functional system.

PLC Programming and Ladder Logic Sequencing:

I was responsible for the design of PLC logic through GX Works2. This involved learning and applying timers, sequencing, and condition-based operations in ladder logic. PLC was programmed to act based on different sensor inputs and control outputs like motors and actuators in synchronism with the Arduino system. I designed proper logic to address different stages of the process, including metal separation, chamber water flow timing, and batch treatment. PLC code was incorporated to be implemented in a complementary fashion with Arduino control logic for fail-safe operation without interference or delay in command execution.

Arduino Control Structuring and PLC Integration:

On the Arduino side, I have put all control logic in place which includes initialisation, looped checking of the conditions, and issuing commands. I have designed the Arduino to be modular and responsive as a controller that would efficiently communicate with the PLC using relay boards. I had wired the digital inputs of the Arduino as grounded PLC signals for tidy handshaking. All operations rendered, whether the servo control, sensor-state reading, or pulse acknowledgement from the PLC, were performed in a modular manner. This allowed for simplicity of interfacing with the ladder logic to facilitate the control of an actuator, a sensor, or a relay at timed intervals.

Electrical Schematic and Wiring of Control Modules:

In addition, I developed the overall electrical schematic that dictated the interrelationship between components like the Arduino, PLC, servo controllers, power modules, and relays. I adhered to all prescribed safety wiring practices and observed measures to maintain signal integrity, especially regarding high-current paths and logic-level communications. Moreover, I wired the 16-channel PWM servo controller using I2C communication and configured it to drive multiple servo motors implemented for valve control. Powering the module was done in a way to achieve isolation to prevent any signal interference. The finalized wiring plan was neat, enabling ease of debugging and allowing room for future scalability.

Data Collection, Documentation, and Reporting:

Throughout the project, I was also responsible for keeping all the records of design, software files, and documentation up to date. This activity included collecting all the different versions of Arduino sketches, PLC programs, CAD models, and layouts for laser cutting. In addition to that, I was significantly involved in the formal reporting activity by writing technical documentation, creating diagrams, and compiling our weekly reports. I also coordinated the editing of demonstration videos and maintained proper archiving of the visual media, wiring documentation, and source code for future reference and review.

Collaborative Testing and Integration:

Apart from my own tasks, I was personally engaged in system-level testing, bug identification, incompatibility timing, and hardware-software conflicts. I worked together with group members in debugging relay delays, servo response faults, and PLC handshake problems. My efforts made sure that the whole modules functioned together cohesively at the time of the final demo and the system behaved as expected under different test cases. This immediate interaction with integration contributed largely in combining mechanical, electrical, and control subsystems.

References

- Amigo, J.M., Babamoradi, H. and Elcoroaristizabal, S., 2015. Hyperspectral imaging: A versatile tool in the pharmaceutical field. *Journal of Pharmaceutical and Biomedical Analysis*, 117, pp.331–349.
- Dodbiba, G., Takahashi, K., Sadaki, J. and Fujita, T., 2005. Triboelectric separation of plastics using a vibratory feeder. *Waste Management*, 25(1), pp.33–39.
- Jimoh, K., Ajayi, O.O. and Ayilara, O.A., n.d. Intelligent Model for Manual Sorting of Plastic Wastes. *International Journal of Computer Applications*, [online] Available at: https://www.ijcaonline.org [Accessed 25 Jul. 2025].
- Kona Research, 2017. *Eddy current separator testing and performance validation*. [online] Available at: https://www.konaresearch.com/reports/eddy-current-separation [Accessed 24 Jul. 2025].
- MDPI Alloys Review, 2024. Electrostatic Separation of Non-ferrous Metals: Recent Developments and Limitations. *Alloys*, 3(2), pp.123–136.
- Pongstabodee, S., Kunachitpimol, N. and Damronglerd, S., 2008. Separation of mixed post-consumer plastic waste using selective flotation. *Separation and Purification Technology*, 62(3), pp.455–462.
- Schmidt, R., Christiansen, C. and Lovrinčić, R., n.d. Portable NIR Identification System for Plastic Waste Sorting. *Waste Technology Review Journal*. [online] Available at: https://www.wtrj.org/articles/portable-nir-identification [Accessed 25 Jul. 2025].
- Sifnaios, I., Kavvadias, K., Papazoglou, M. and Polyzos, D., 2024. Deep learning-based hyperspectral imaging for polymer identification in recycling systems. *Sensors and Actuators B: Chemical*, 422, pp.1–10.
- Smith, D.T., Nagel, K. and Rajamani, R.K., 2019. Eddy current separation of non-ferrous metals using rotating drums. *Waste Management & Research*, 37(1), pp.55–65.
- Zhang, Y., Forssberg, E. and Arvidson, B., 1999. A review of current progress in eddy current separation. *Resources, Conservation and Recycling*, 23(2), pp.109–129.

Appendices

Arduino Program:

```
#include "PCA9685.h"
#include <Wire.h>
ServoDriver servo;


const int ENA1 = 10;//PWM for pump 1 & 2
const int ENB1 = 11;//PWM for pump 3 & 4
const int ENA2 = 12;//PWM for pump 5 & 6
const int IN1a = 46;//pump 1
const int IN2a= 47;//pump 2
const int IN3a = 48;//pump 3
const int IN4a= 49;//pump 4
const int IN1b = 50;//pump 5
const int IN2b= 51;//pump 6
const int ON= 27;// if plc input says LOW you say run
const int OFF= 26;// if plc says LOW you say stop
int START=1;
int STOP=1;
const int servo1 = 1;
const int servo2 = 2;
const int servo3 = 3;

const int X003= 9;//run main conveyor
const int X004= 8;//door 1
const int X005= 7;//door 2
const int X006= 6;//door 3
const int X007= 5;//Safety Lock
int counter = 0;
int draincount = 1;
int drain1count = 1;
int drain2count = 1;
int drain3count = 1;

void setup() {
  pinMode(ON, INPUT_PULLUP);
  pinMode(OFF, INPUT_PULLUP);
  pinMode(ENA1, OUTPUT);
  pinMode(ENA2, OUTPUT);
  pinMode(ENB1, OUTPUT);
  pinMode(IN2a, OUTPUT);
  pinMode(IN1a, OUTPUT);
```

```
  pinMode(IN3a, OUTPUT);
  pinMode(IN4a, OUTPUT);
  pinMode(IN2b, OUTPUT);
  pinMode(IN1b, OUTPUT);
  analogWrite(ENA1, 150);
  analogWrite(ENB1, 120);
  analogWrite(ENA2, 120);
  digitalWrite(X003, HIGH);
  digitalWrite(X004, HIGH);
  digitalWrite(X005, HIGH);
  digitalWrite(X006, HIGH);
  digitalWrite(X007, HIGH);
  pinMode(X003,OUTPUT);
  pinMode(X004,OUTPUT);
  pinMode(X005,OUTPUT);
  pinMode(X006,OUTPUT);
  pinMode(X007,OUTPUT);
  Wire.begin();
  Serial.begin(115200);
  servo.init(0x7f);
  servo.setAngle(servo1, 180);
  servo.setAngle(servo2, 0);
  servo.setAngle(servo3, 0);
}

void loop() {
  START = digitalRead(ON);
  Serial.println(START);
  STOP = digitalRead(OFF);
  if(START==LOW){
    Serial.print("count");
    Serial.println(counter);
    fillAll();
    runConveyor();
    waittosink();
    Strain1();
    Strain1();
    Strain1();
    drain1();
    door1();
    waittosink();
    Strain2();
    Strain2();
    Strain2();
    drain2();
    door2();
    waittosink();
```

```
    Strain3();
    Strain3();
    Strain3();
    drain3();
    door3();
  }
  else if(STOP==LOW){
    drainall();
    counter=0;
}
}


void fillAll(){   //Fuction for filling all the chambers
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("filling chambers");
  digitalWrite(IN2a,HIGH);
  digitalWrite(IN4a,HIGH);
  digitalWrite(IN2b,HIGH);
  unsigned long startTime = millis();
  while (millis() - startTime < 50000) {
  if (digitalRead(OFF) == LOW)
  break;
  }
  draincount--;
  drain1count--;
  drain2count--;
  drain3count--;
  digitalWrite(IN2a,LOW);
  digitalWrite(IN4a,LOW);
  digitalWrite(IN2b,LOW);
  }
  else{
    return 0;
  }
}

void runConveyor(){  //Function for running the conveyor
  if(digitalRead(OFF)==HIGH){
  Serial.println("running Conveyor");
  digitalWrite(X003,LOW);
  delay(2000);
  digitalWrite(X003,HIGH);
  }
  else{
    return;
```

```
  }
}

void Strain1(){ //Function for Straining the plastics which floats in 1st
chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("straining 1");
  servo.setAngle(servo1, 130);
  delay(300);
  servo.setAngle(servo1, 110);
  delay(300);
  servo.setAngle(servo1, 90);
  delay(2000);
  servo.setAngle(servo1, 0);
  delay(300);
  servo.setAngle(servo1, 20);
  delay(300);
  servo.setAngle(servo1, 0);
  delay(300);
  servo.setAngle(servo1, 20);
  delay(300);
  servo.setAngle(servo1, 0);
  delay(1000);
  servo.setAngle(servo1, 180);
  delay(1000);
  }
  else{
    return 0;
  }
}


void Strain2(){ //Function for Straining the plastics which floats in 2nd
chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("Straining 2");
  servo.setAngle(servo2, 50);
  delay(300);
  servo.setAngle(servo2, 70);
  delay(300);
  servo.setAngle(servo2, 180);
  delay(300);
  servo.setAngle(servo2, 170);
  delay(300);
  servo.setAngle(servo2, 180);
```

```
  delay(300);
  servo.setAngle(servo2, 170);
  delay(300);
  servo.setAngle(servo2, 170);
  delay(1000);
  servo.setAngle(servo2, 0);
  delay(1000);
  }
  else{
    return 0;
  }
}

void Strain3(){ //Function for Straining the plastics which floats in 3rd
chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("Straining 3");
  servo.setAngle(servo3, 50);
  delay(300);
  servo.setAngle(servo3, 70);
  delay(300);
  servo.setAngle(servo3, 180);
  delay(300);
  servo.setAngle(servo3, 170);
  delay(300);
  servo.setAngle(servo3, 180);
  delay(300);
  servo.setAngle(servo3, 170);
  delay(300);
  servo.setAngle(servo3, 170);
  delay(1000);
  servo.setAngle(servo3, 0);
  delay(1000);
  }
  else{
    return 0;
  }
}

void waittosink(){  //Delay function for waiting for the plastic to sink
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("waiting to sink");
  unsigned long startTime = millis();
  while (millis() - startTime < 5000) {
  if (digitalRead(OFF) == LOW) break;
```

```
  }
  }
  else{
    return;
  }
}

void door1(){  //Function for opening the door in 1st chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("door 1 opened");
  digitalWrite(X004,LOW);
  delay(10000);
  digitalWrite(X004,HIGH);
  }
  else{
    return 0;
  }
}

void door2(){ //Function for opening the door in 2nd chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("door 2 opened");
  digitalWrite(X005,LOW);
  delay(10000);
  digitalWrite(X005,HIGH);
  }
  else{
    return 0;
  }
}

void door3(){ //Function for opening the door in 3rd chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  Serial.println("door 3 opened");
  digitalWrite(X006,LOW);
  delay(10000);
  digitalWrite(X006,HIGH);
  draincount=1;
  drain1count=1;
  drain2count=1;
  drain3count=1;
  }
  else{
    return 0;
```

```
  }
}

void drain1(){ //Function for draining the water in 1st chamber
  if(digitalRead(OFF)){
  Serial.println("draining 1");
  digitalWrite(IN1a, HIGH);//pump 1
  delay(30000);
  digitalWrite(IN1a, LOW);//pump 1
  drain1count++;
  }
  else{
    return 0;
  }
}

void fill1(){ //Function for filling the water in 1st chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  digitalWrite(IN2a, HIGH);//pump 2
  delay(85000);
  digitalWrite(IN2a, LOW);//pump 2
  }
  else{
    return 0;
  }
}

void drain2(){ //Function for draining the water in 2nd chamber
  if(digitalRead(OFF)==HIGH){
  Serial.println("draining 2");
  digitalWrite(IN3a, HIGH);//pump 3
  delay(30000);
  digitalWrite(IN3a, LOW);//pump 2
  drain2count++;
  }
  else{
    return 0;
  }
}

void fill2(){ //Function for filling the water in 2nd chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  digitalWrite(IN4a, HIGH);//pump 4
  delay(85000);
  digitalWrite(IN4a, LOW);//pump 4
```

```
  }
  else{
    return 0;
  }
}
void drain3(){  //Function for draining the water in 3rd chamber
  digitalRead(OFF);
  if(digitalRead(OFF)==HIGH){
  Serial.println("draining 3");
  digitalWrite(IN1b, HIGH);//pump 5
  delay(30000);
  digitalWrite(IN1b, LOW);//pump 5
  drain3count++;
  }
  else{
    return 0;
  }
}

void fill3(){ //Function for filling the water in 3rd chamber
  STOP = digitalRead(OFF);
  if(STOP==HIGH){
  digitalWrite(IN2b, HIGH);//pump 6
  delay(85000);
  digitalWrite(IN2b, LOW);//pump 6
  }
  else{
    return 0;
  }
}



void drainall(){ //Function for filling the water in all chambers at a same
time.
  if(draincount==0){
  Serial.println("draining all");
  if(drain1count==0){
  digitalWrite(IN1a,HIGH);
  }
  if(drain2count==0){
  digitalWrite(IN3a,HIGH);
  }
  if(drain3count==0){
  digitalWrite(IN1b,HIGH);
  }
  unsigned long startTime = millis();
```

```
  while (millis() - startTime < 30000) {
  if (digitalRead(ON) == LOW) break;
  }
  Serial.println("drained all");
  digitalWrite(IN1a,LOW);
  digitalWrite(IN3a,LOW);
  digitalWrite(IN1b,LOW);
  draincount++;
  drain1count++;
  drain2count++;
  drain3count++;
  }
}
```