Development of Filament Extruder using Recycled Plastic Material for 3D Printer

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ABSTRACT

Waste pollution has been a perennial problem faced by generations of Filipinos, especially wastes that pollute Philippine waters. Despite the apparent problems and issues that this poses, the production of numerous virgin plastics in the form of PET and ABS still continuously grows especially in the manufacturing industries soft drink and toy. The idea of fabricating an extruder machine that could be used to melt waste plastic bottles is perceived to help lessen the plastic waste. Hence, this study aimed to transform extruded plastic material into a filament with a constant diameter size output to be utilized as load to a 3D printer. The extruder machine makes use of cut-out plastics from plastic waste bottles, which would undergo a heating process of 220-260°. This is the requirement to melt down plastic wastes. It also uses an Arduino that will control the device's whole system and the nozzle that would help shape the extruded plastic to a constant diameter output of 1.00 mm to 1.75 mm in order to fit to a 3D printer. The 3D printer serves as the testing device for the extruded filament. It was found out that in producing a constant diameter, the speed of the motor had a very important role in giving the acceptable filament, as well as the fan that helped the melted plastic to cool down. On the other hand, in printing an object to the 3D printer using the extracted filament out of recycled plastic bottles meant that the design project was a success.

Keywords*:* filament, extruder, 3D printing, plastic extrusion

1. INTRODUCTION

Innovation has always been a strategic motivation to be able to ensure sustainable development in every organization, especially in manufacturing companies. Computer technology, in the mainstream of progress of various industries, plays a major role in the design and fabrication of new products while knowledge and expertise in computer engineering provide a wider perspective on how to automate manufacturing processes through research and development. All of these are geared at producing significant impact and contribution to the community without threatening the environment.

One innovative practice is the in-depth analysis of the construction of any design work in the engineering world. Specifically, in the field of plastic engineering, extruder manufacturing is at the core of design and implementation. Plastic allows a wide range of machines that can be used to process it. Viscosity, melt flow, and the size of the machine determine the predictability and manufacturability of the product. It is imperative to have proper knowledge on the design and implementation of the necessary design fractures, as well as of the machine parts to ensure optimization. A systematic process should be carried out to make it feasible, and in order to make it functional, different working principles of the machine should be properly studied. The portable machine can be optimized and may replace any bulky extrusion system. The unnecessary over-engineering may be corrected by making an extruder that can be used for specific purposes such as in making a filament. A number of related studies and research projects were delved into to substantiate the content of this design project. The main purpose of this project on making Portable home—made filament extruder is to produce homemade filament extruder. The filament should be suitable for use with FDM 3D printers. The dimension of the filament required is 1.75mm, and the quality expected is the normal filament which should be able to feed on 3D printers. The extrusion system only for the filament is not common and is only made by several makers and engineers around the world. The cheapest filament extruders on the market are still expensive compared to the 3D printer itself. The normal price of extruder is around twice the price of a 3D printer. The filament extruder used in Arcada UAS is too big and expensive for 3D printing purpose. This proposed homemade filament extruder would be cost effective for those who need only the filament for any purpose. Students, researchers and others willing to make their own filament can use this homemade extruder rather than buying a commercial filament. This homemade extruder is a portable machine so that can be very easy to work with in office or while travelling. The extruder itself is small, so the maintenance cost for this extruder will be less. [1]

The study of Bijaya Poudel, proved that the fabrication of this current design project is possible. As with Poudel's project, this project study also aimed to create filament by extruding recycled plastic bottles. This project made use of a heater band which is less expensive compared to the PTC heater. This project also has the safety capability of controlling the heater band on reaching a higher temperature than the desired temperature. This project also used a nozzle instead of die hole. Auxiliary was applied as the cooling element for the filament.

Extrusion is the process by which 3D printing filament is created. Melted plastic is pushed through an extrusion die and is shaped into a long thin strand of plastic. Extrusion machines are usually sized for industrial use, capable of creating hundreds of feet of filament a day. This filament is expensive to purchase and many end-users would prefer to extrude their own filament, from a virgin plastic input or plastic waste input. Presently, there are no home scale filament extruders in the market for Polyethylene Terephthalate (PET) plastic waste. AkaBot was designed to allow end users to produce their own filament from a PET plastic input. It was designed and manufactured to create filament that has the required ductility for spooling and use in a 3D printer. It functioned well with PET pellets as the plastic input, but it was not as successful when recycled water bottles were used. The final filament product was dependent on the tension put on the filament as it exits the machine. At present, the production of acceptable filament is done by a skilled human operator. An automated spooling system for the filament would greatly improve the consistency of the output and decrease the cost of using AkaBot. [2]

A study on the parameters affecting the extrusion process of wood plastic states that Wood Plastic Composites (WPCs) are the wood substitute materials which are made of scraps of wood, sawdust, natural fiber and plastic mixed together, processed by extrusion. They are new substitutes for wood and are beginning to be used broadly in Thailand.

However, most manufacturers in Thailand still do not have adequate knowledge and know how of the production, bringing about the lack of quality and efficiency in the process. The project and analysis were geared towards the relation of parameters between extrusion process, temperature, screw speed and melt pressure of the production process that affected the quality by using width (X axis) and thickness (Y axis). The result was compared to mean score and then summarized in order to find the optimal value for the production process and to forecast the change of the quality of WPCs.

The objective of that research was to project and analyze the relation between the parameters by using the standard specification of WPCs. Resuts of the project, showed that with increase of temperature, metering section, screw speed and melt pressure, the absolute value of variance also rose. The researcher used this proper scenario to explore, use of screw speed at 3 rpm which was the maximum capacity, and temperature during metering section at 175°C, because it did not significantly affect the capacity. However, it initiated the low pressure which directly impacted on the energy or resource in the production process. [3]

The project study aimed to fabricate an extruder machine which is a device that will be used to extract cut-out plastic waste bottles or toys to filaments by melting them down. The extracted filament will be used as a load to the 3D printer, to used in printing 3D objects through a computer—aided drafting design software.

The extruder requires the use of ABS plastics, typically used in manufacturing toys, and PETE plastics, used in manufacturing plastic bottle containers for fruits juices and soft drinks.

However, the extruder has its limitation. Foremost it would take time to make it reach a high temperature to be able to melt the plastic. Waiting for the melted plastic to have the enough length to be able to load it to the printer will also take some time.

Also, when the electricity shuts down, the motor will

Stop working, as well as the heating element or band which would result to interruption of the extrusion process. Upon the return of electricity, the process will start again until the heating element or band reached the needed temperature. Also, while other kinds of plastic can be accepted by the extruder, these could cause congestion to the nozzle since the composition of their properties changes upon reprocessing them, they also have their own limitations on reprocessing. These limitations are beyond the device's capabilities.

Objectives of the Study

This study aimed to design and develop an extruder machine that extracts filaments to be used as load material to a 3D printer.

Specifically, it aimed to attain the following objectives:

1. Develop an extruder using locally available components to process waste PETE plastic materials
2. Design a program to control the different components of the extruder using Arduino
3. Test the compatibility of the extracted plastic filament using a 3D printer

2. MATERIALS AND METHODS

The design and implementation are mainly partitioned into two core activities that include:

- hardware and system design implementation
- development and testing stage

Hardware and System Design and Implementation

The heart of the design project is the Arduino UNO that controls the heating band through relay. The LCD displays the current temperature of the heating band that gets its data from the temperature sensor. The Arduino data will use to monitor the status of the heating band.

The DC motor is the part that pushes the melted plastic out of the machine, while the nozzle is the part of the extruder wherein the melted plastic is extracted. The extracted plastic then falls on a conveyor belt for it to cool down. The cooling down process is helped by two auxiliary fans. The speed of the conveyor is controlled by a separate speed controller. The relay is used to handle the high voltage input that is required by the heater band. When the output filament has the desired length, it can be loaded already to the 3D printer for printing.

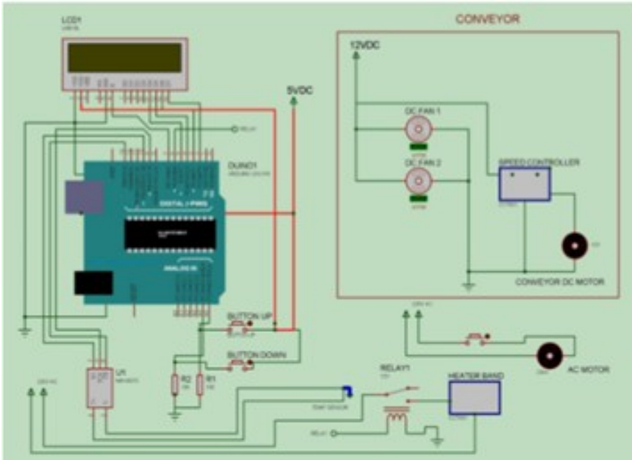

Figure 1. Schematic Diagram

The flow of the system begins by powering up the device to start the flow of the system. Automatically, when the device is powered up, the heating element/ band will also start heating. When the heating band temperature is greater than 210°C, the heater band will be turned off on its continuous heating and the auxiliary will be turned on to be ready for the flowing out of the melted plastic for cooling down. The DC motor would remain on to help push out the output. On the other hand, if the heater band temperature is below 210°C, the heater band will remain ON state until it reaches 210°C and above. The auxiliary will also be turned on and the DC motor will be turned off since it cannot melt down the plastic and may only cause congestion.

Development and Testing Stage

The design project employed experimental and descriptive research designs. The experimental approach was used to control or randomize the temperature of the extruder in melting the different kinds of plastics and to identify how they should be sorted. On the other hand, the descriptive research was used to define the kinds of plastics and their effects to the environment.

The extruder is a device that is composed of a funnel-like opening wherein the cut-out plastic materials will be loaded into. A switch button was implemented to switch the device on and off, while the LCD serves as the indicator to know if the device is already working. The LCD will also indicate the current temperature of the heating element or band to know if the machine is ready for melting. Inside the extruder is the DC motor that operates the drill bit, which serves as the tool to push the cut-out plastics to the center of the extruder where the heating band is located. The heating band is the component that will melt the plastic load.

The first stage was the planning stage which involved research on components and materials needed in developing the extruder. Research on plastics was also done for a clearer view on the kind of plastic should be used for recycling. This stage also included the canvassing and checking of the availability of the components in the market. Compatibility of the components was considered to avoid delays in testing. Budget cost management was also considered in this stage. The design of the circuitry was done after gathering all the necessary components.

The implementation of the circuit design in consideration of the components gathered was done after which fabrication was done. This included the programming of the Arduino UNO that would control all the components such as the motor, LCD and the heating band. Building the extruder as well as programming the Arduino UNO was done simultaneously. In this stage, framing and the physical appearance were also considered in building the project.

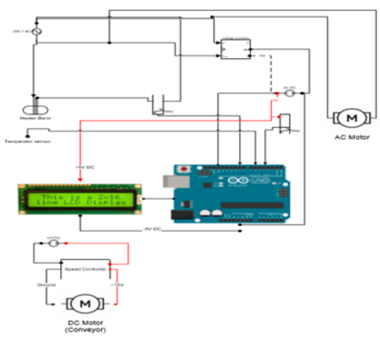

Figure 2. Circuit Diagram

The second stage was the assessment stage, which involved the assessment of the fabricated device along with the program loaded to its Arduino. After the fabrication and implementation of the circuit design, the final design of the extruder machine was finalized and readied for testing and improvements in terms of performance and physical appearance.

The researcher gathered at least 1 kg of cut-out plastic waste for extraction using the extruder machine for testing. Testing of the device was done in a room where a fire extinguisher was available as the device produced heat that could result to fire in case of failure. Also included in this stage was checking and verifying if the scope of the project was covered by the device.

Materials used in Development and Testing

Arduino UNO

Arduino UNO is a microcontroller board based on the ATmega328P. It has 14 digital input/output pins 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. This is considered as the brain of the system since it controls most of the main components of the project such as the heater band, DC motor and the LCD display.[4]

The Arduino UNO was used in this design project since it was cheaper compared to microcontrollers. Arduino UNO has a 13 pin output that would be enough to supply all the components connected such as the LCD display, relay and the temperature control.

120 Watts heater band

The 120 Watts heater band, in this design project, was used to melt the cut out recycled plastic materials that will transform it into a filament. The heater band was out sourced from the Arduino and was directed to the power supply.[5]

The 120 watts heater band was used since the PETE plastics' melting point starts at 98°C. This heater band was used since its design is rounded, hence, would fit the tubing where the cut-out plastics will flow and will be melted.

Liquid Crystal Display

The Liquid Crystal Display(LCD) in this project will display the status of the heating band element and its current temperature. It is directly connected to the Arduino UNO that would show the user the current status of the extruder.

The LCD was preferred rather than the use of LED displayas the LED was costly. The 2x16 LCD display was used since the information to be displayed fits the screen size.

Temperature sensor

The temperature sensor detects the current temperature of the heating element band. This is directly connected to the Arduino UNO and serves as communication between the heating element and the LCD.

The temperature sensor plays a big role in this design project since as signals the Arduino to cut the temperature or to re-open the temperature. This kind of temperature control was used since it is made of metal as similar to heating band which was also made from metal.

DC motor

The DC motor in this project serves as the motor to help push the cut-out plastic load through the drill bit to the heating band element, going to the auxiliary and then pushed out to the nozzle. The speed of the process is 10 revolutions per minute, which meets the right speed to push the melted plastic out to the nozzle.

3D printer

In this project, the 3D printer serves as the testing device for the output of the extruder machine, which is the plastic filament. The 3D printer can print three dimensional objects designed from drawing software such as Google SketchUP, which is a free software, and AutoCad by Autodesk, which is a paid application.

The drawings from the computer aided drafting software will be converted to the application bundled with the 3D printer for slicing and estimation of the design to be printed. On the other hand, there are also 3D drawings that can be downloaded from the internet.

3. RESULTS AND DISCUSSION

Development of an extruder using locally available components to process waste PET Plastic

This design project aimed to transform waste plastic materials, particularly the soft drinks bottles in the form of PETE plastic material into a more useful material. The PETE plastic material was used since such plastic is the only safe type to be reheated for recycling aside from ABS. Most of the 3D printers available in the market, also accept only the PLA, ABS and PETE plastics, just like the provided 3D printer used in this study.

The extruder machine starts its process when the device is turned on and waits until the heating band reaches the required heat of 200-260°C for the melting point of the PETE plastic. The cut-out plastic bottles will be partially loaded to the funnel to be able to extract the same length as the commercially available filament. The spiral drill bit inside the machine will help push the cut-out plastic so that it will be melted easily by the heating element.

The nozzle extracts the output filament until the plastic material is continuously loaded to the funnel. Upon testing the first run of the extruder, the first output produced a candle-like melted output, probably because of a very high temperature of 260°C that caused the liquidation of the PET plastic.

Upon research, it was found out that not all PET plastics have the same melting point in reheating them, since not all the containers contain the same content of liquid. Thus, on the second trial, the researcher set the temperature to 190°C. However, it also gave a failed output of deformed cut-out plastic. It was like a trial and error method of testing to get the right temperature that would fit the required temperature to melt the PET plastic.

On the third trial, the temperature was set to 230°C. It already produced a filament but after a few seconds, it hardened and became brittle. This was because the plastic was overcooked.

The fourth trial was a success using 210°C. Filament produced was not so brittle and string-like.

Design of a program to control different components of the extruder using Arduino

The program design includes the control of the different components of the extruder. It regulates the temperature of the heater band with the help of the temperature sensor and the relay coupled to the heater band. The program turns on and turns off the heater band as required maintaining the specified temperature. It also controls the motor and identifies when it will turn on or off by triggering the relay coupled to the motor during the process of the filament extraction. It also controls the auxiliary fan that cools the extracted filament so it will retain its desired size.

Compatibility of the extracted plastic filament to the 3D printer

The extracted plastic material with a consistent diameter was loaded to the 3D printer to test its compatibility to the 3D printer by producing an output. The process of printing a 3D object in the 3D printer was similar in extruding the plastic bottle. The printer showed have enough heat to melt the extracted filament and waiting should be done until the machine could start printing the output.

The length of needed filament depended on the object design to be printed. Also, there are two printing quality processes: the honeycomb printing, which requires a smaller amount of filament and the solid printing, which requires more amount of filament. The duration of solid printing was longer than the honeycomb printing. Both solid and honeycomb printing and solid printing were done to test the compatibility of the filament to the printing quality.

Upon the first use of the filament to the 3D printer, it was recognized immediately since the 3D printer is compatible with any plastic. However, on the first run, the 3D printer got congested with the plastic since the default setting of the printer was to 250°C which is the temperature for the commercially available filaments. With this, acetone was used to unclog the congested nozzle of the 3D printer.

On the second trial, the temperature was adjusted to 210°C, the same temperature that the extruder machine used. The printer successfully printed its first output from the extracted filament.

Upon testing of the device, the following findings were observed:

1. The process of transforming waste plastic materials into filament needed the proper temperature in melting them to form string-like filaments. As shown in Table 1, different temperatures were considered before producing the acceptable output.

Table 1. Output of the Testing of the Device

Temperature in degrees Celsius	Output
190	Deformed cut-out plastic
210	The right temperature that produces string-like output filament
220	Produces a string-like output but brittle
230	Produces a candle-like melted output

2. Proper programming of the Arduino was required to automatically perform its task during the operation of the extruder, including regulating the temperature and turning the motor and the motor and the auxiliary fan on.

2. The 3D printer accepted a filament with a diameter that was less than or equal to 1.75mm but not less than 1.00mm. The detection of the filament meant that it was compatible with the printer. But setting the right temperature for the 3D printer was a trial and error method as it could not print an output with the same temperature that the extruder used. The nozzle of the 3D printer was 0.4mm, which made it hard to extract the filament. The 250°C nozzle temperature and 60°C of bed temperature made the output successful. The success of the use of recycled plastic bottles as filament to 3D printer inferred that it could already be an alternative to the commercially available 3D printer filament.

4. CONCLUSIONS

The performed extrusion process generated the filaments with an acceptable diameter output. Proper heat and correct temperature setting during the process gave the high quality filaments. However, if the temperature was not suitable to the material being processed, the produced filament was rough and uneven. Too low temperature would not melt plastic pellets properly causing bubbles and roughness in the filaments. Thus, to control the consistency of the plastic melt inside and to have a good flow, the speed of the motor should be decreased vis-a-vis the required temperature.

After the development of the design project and based from the findings the following conclusion are drawn:

1. The use of the developed extruder may make it possible to transform plastic material into filaments.
2. The use of Arduino in the design simplifies the process of programming the task of the extruder. The controller can be coupled or connected to other components, and the programming is in a C-like syntax that most computer engineers are familiar with.
3. The use of extracted plastic filament as a load to the 3D printer proves its compatibility to the printer. The filament extracted from the recycled plastic bottles can be an alternative filament for a 3D printer.

5. RECOMMENDATIONS

For further development of this design project, and based on the findings and conclusions, the following recommendations are offered:

1. There should be a built-in shredder that would help cut the load into smaller pieces.
2. The application of color on the extracted filament can be considered for the enhancement of the output.
3. The funnel should have a sensor device that would detect the level of plastic on the machine.
4. Future researchers can combine the idea of 3D printer and extruder to directly modify the printer cartridge for the direct extrusion of the cut out recycled plastic material.

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