The University of British Columbia
Department of Materials Engineering
MTRL 466: Engineering Project I

Detecting Defects in FDM 3D Printing

Midterm Report

(Group 2)

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Executive Summary

Fused deposition modelling or FDM is a type of additive manufacturing (AM). FDM is the most common 3D printing method used today which is becoming increasingly popular in the manufacturing industry [1]. Objects are created using digital models like a CAD (computer aided design) file which must be converted to an STL (stereolithography) file for the machine to understand. The machine works by heating up a thermoplastic filament, like PLA (Polylactic Acid), to its melting point. The constituent material is then extruded out of the machine where it is deposited in a layer-by-layer manner following the design [2].

This method of AM has the potential to be a main mode of commercial manufacturing as "rapid prototyping" is eliminated [1]. Instead, objects can be made immediately and more efficiently. This method also allows for custom, complex and light-weight parts to be made. Currently, this technology isn't quite ready to take the market. A major setback is printing failures that occur in the form of obvious defects. As it is, there are no commercially available solutions that can detect defects such that failures can be stopped or mitigated. This creates inherent material waste as the printed model cannot be used, as well as inefficient use of the FDM printer [2].

Research was conducted on different types of sensory methods able to detect defects in unsuccessful prints. The requirements of the chosen solution is that it must be a non-contact method, cannot exceed the cost of the FDM printer ($300-400 CAD), be compatible with different FDM printers, and lastly be able to detect the common defects that lead to a "spaghetti monster", often formed when the object detaches from the print bed [3].

Thermal detection, infrared cameras, sonar and acoustic, optical lenses, laser speckle and laser line projection were all methods explored in depth. As budget, data processing and feasibility constraints were deciding factors on choosing which methods to continue with, optical, laser speckle and laser line projection were examined more closely. Through analyzing the advantages and disadvantages of the top three solutions, the laser line projection method was chosen as the most viable option. Using basic geometric optical principles, laser line scanning can accurately detect for surface flaws and defects, including the "spaghetti monster" type defect. This non-contact method requires 3 components that are affordable and readily available, including a camera, a laser line and a filter. The chosen solution meets the project objectives and constraints defined.

Problem Definition

There are different processes that can be used to 3D print an object, such as material extrusion, vat polymerization, and powder bed fusion. This project will work only with the material extrusion process, or fused deposition modelling (FDM), using PLA (Polylactic Acid) filaments. Before defining the problem tackled by this project, it is important to understand the basics of how an FDM printer works.

The user has to create a 3D version of the object they want to print using a CAD program. The printer cannot interpret CAD files, so the file has to go through a slicer before being sent to the printer. Slicer is a program that divides the CAD model in horizontal "slices" that the printer can interpret and print. Each "slice" corresponds to a layer in the printed object. Now that the printer can interpret the file, it can start extruding material. The user has to make sure there is a spool of filament loaded into the printer before starting the process. When the print starts, the nozzle is heated up, melting the filament. The nozzle and then print bed then move along specified coordinates and the nozzle deposits a layer of filament. After being deposited, the filament cools down and solidifies again in the shape determined by the CAD file [4]. The following figure shows the layer by layer construction.

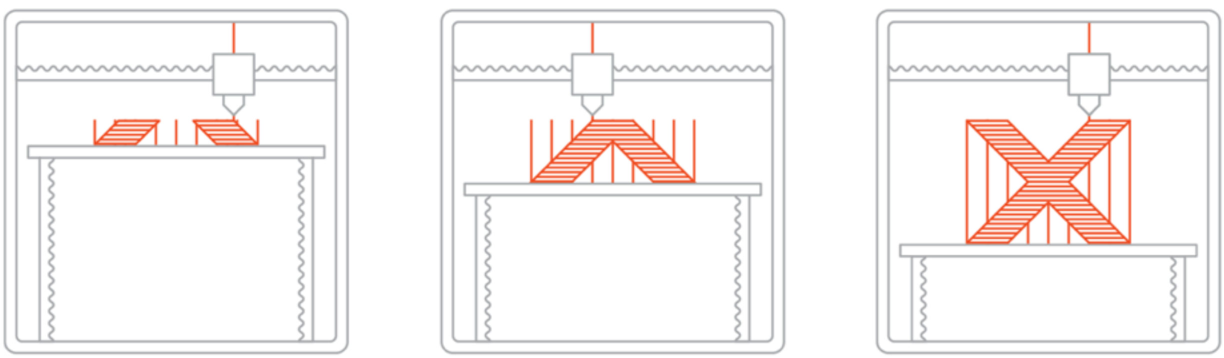

Figure 1: FDM layering of filaments [4]

Additive manufacturing processes, such as FDM printing, require less raw material than subtractive manufacturing processes, because it only uses the amount of material required for the final product [5]. The problem with FDM printers is that most printers accessible to the general public doesn't have a system to detect when a defect has happened, so if a defect occurs, it will keep printing and wasting material until someone stops the machine.

A study conducted by the Georgia Institute of Technology showed that around 35% of the plastic used in an open 3D printing studio was wasted. The open studio had 25 printers operating at all times and was mainly used by engineering students at a large university. For the study, two collecting bins were labeled and placed in the studio for users to sort the kind of material they were disposing of: failed 3D prints or support material. In order to calculate the fraction of material wasted, the inventory of the filament was recorded periodically. The duration of the study was ten weeks, and the material used to print was ABS (Acrylonitrile Butadiene Styrene) filaments. The conclusion of the study was that 35% of the total amount of ABS used during the study was wasted, either because the print failed or because the material was just used as a support for the print and had to be removed upon completion of print. The study also revealed that 55% of the 35% of material wasted was due to failed prints. To put in perspective, 106 kg of ABS filament were used during the study, which means that more than 20 kg of plastic were wasted because of defective prints [6].

Even though the study was conducted during only ten weeks and in one location, it illustrates the need for reduction of material waste in 3D printing. Depending on the dimensions of the object, the process might take 10 hours or more to finish printing. For that reason, most people observe the beginning of the print to make sure the object is attached to the print bed and the material is extruding and then leave the printer running by itself, coming back every few hours to check everything is still running smoothly. If a defect occurs while the printer is unattended, it will propagate and all the material used will go to waste.

There is a clear need to reduce the amount of material waste during FDM printing. The objective of this project is to create a proof of concept that will minimize material waste and maximize efficiency by sensing defects and stopping the print when a defect is detected. The requirements for the solution are that it has to be non-contact, so it won't interfere with print quality, has to cost less than the printer itself (less than $400) since it is an add-on to the printer, and has to be able to sense defects and stop a print that may potentially lead to a "spaghetti monster" type of defect, this is shown in Figure 2. The solution is intended to be sold to manufacturers of FDM printers, so that the cost for the final consumer can be lowered. This implies that the solution must be compatible with multiple FDM printers and printing materials. For this project the group will be limited to using a Prusa i3 printer with PLA filaments.

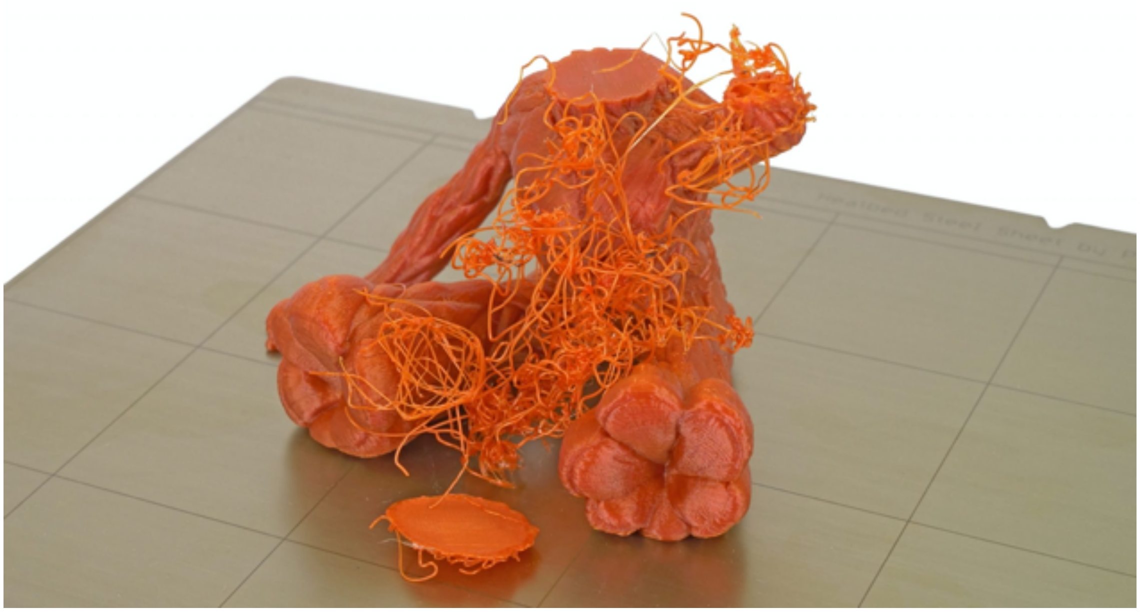

Figure 2: "Spaghetti Monster" Defect [3].

Technical Review

Defects

Many issues can arise during FDM printing. The possible types of defects have been sorted into five main groups: detachment, deformed object, missing material flows, surface errors and deviation from the model [10]. The approximate size range, the negative effects and the frequency of various defects within each defect group will be discussed.

Detachment describes the object detaching from the print bed [10]. This defect could cause a slight bending in the object, or, if the object falls over and/or moves, the nozzle could start printing onto nothing. The latter causes a catastrophic failure. Detachment can occur from uneven cooling during the print, an uncalibrated distance between the nozzle and the print bed and vibrations from external sources shaking the object off the print bed [10]. Warping due to uneven cooling is the most common of these defects, and will bend the object to a minimum of 0.08 mm, but will most likely be much larger [10]. See appendix for calculation [12]. Both an uncalibrated distance from the print bed and external vibrations are less common, but may cause a catastrophic failure [10].

A deformed object results from a collapse in structure [10]. This may be a result of a bridge in the object collapsing or the nozzle missing the print bed [11]. These defects may be as small as the nozzle diameter, ~0.4 mm or extremely large [10]. The collapse of a bridge is common, especially with complex designs, whereas the nozzle missing the print bed is uncommon and usually due to human error [11].

Missing material flows describes any defect that is caused by issues with the filament feeding through the nozzle [10],[11]. This can occur if the filament spool runs out, the nozzle starts too close to the print bed, the nozzle is blocked, the filament snaps, or the filament tangles [11],[12]. All of these defects have the same effect - the print stops. Examples of these issues are the roll being empty, tangled filament and snapped filament.

Surface errors include any small defects on the surface of the print. These are some of the hardest to detect as they can be infinitely small and only as large as the nozzle diameter [11]. Surface errors can occur from a messy first layer, gaps between the infill and the wall, cracks between layers and stringy sides [11]. Cracks between layers are the most common and serious defect of all the surface errors.

Deviation from the model includes a print with a bowed bottom (elephant's foot), a leaning object, waves in the print, bumps from over extrusion and holes in the top layer [11]. The most common of these defects are elephant's foot, leaning objects and holes in the top layer [11]. Elephants foot is especially common with large objects and a print base that is too hot. Elephant's foot and holes in the top layer can be infinitely small and as large as the nozzle. Learning objects can be any size.

Thermal

To detect the errors outlined above, several different sensors were considered as possible solutions - their methods of operation will be outlined below. Thermal sensors came up as a possible solution due to the fact that the PRUSA i3 model extrudes heated PLA filament at roughly 220°C [13], and the final part is built on a heated bed held at 60°C [13]. However, most thermal sensors such as Pyrometers via "monitoring the temperature of the melt pool [14]", and thermocouples "conduct contact measurement of temperature [14]" thus rendering them not useful for the purposes of this project.

Infrared

Infrared cameras, such as the Microsoft Azure Kinect [12] "offer a high-speed, non-contact form of temperature measurement, and provide the data accuracy necessary to correlate process parameters and in-process temperature data with measures of finished part quality [16]". However, this technology does not provide a direct correlation to part quality. Certain inferences must be made to relate temperature at certain points during the print to finished print quality. Due to the indirect nature of this technology it will not be further considered for this purposes of this project.

Sonar

Sonar stands for "Sound Navigation Ranging [17]". "For sonar equipment to function, three key elements are necessary: [a] source, [a] medium, and a receiver [18]". This system works when the sound source travels through the medium to the receiver which then "transform[s] the mechanical energy (sound waves) into electrical energy (electrical signal) in order to process the sound into signals for information processing [18]". However, this technology can be unpredictable as depending on the shape of the object sound waves may be deflected causing the sensor to not pick up crucial data. For the purposes of this project, this setup will be too costly and therefore will not be further considered.

Acoustic

Acoustic emission is a technology that was tested by Wu et al to detect errors in the first layer of the FDM printing of ABS. AE has the "advantages of information richness, non-intrusive installation, and high throughput for real-time monitoring [19]". There are three main parts required for an AE system: "[an] AE senor, [a] preamplifier, and [a] DAQ [data acquisition] system [19]". For this particular experiment, acoustic measurements were recorded in two printer situations: "normal printing and printing failure with material peeling, buckling, and scratching [19]". In both scenarios, the sampling rate was set at 5 Million and samples were recorded as "a series of AE hits [1]" to speed up the processing time. These hits can then be interpreted as a measure of print success or failure. "Only 5 AE hits were detected during the normal printing process. This is because after tuning the threshold, most of the background noises were ignored by [the] AE system. These recorded AE hits also imply that the normal printing process has some imperfections or process fluctuations. In contrast, 120 AE hits were detected during the failed process. The reason is that the detected AE hits are largely associated with AE events generated from the abnormal failure modes [19]." An increased number of AE hits is an indirect method of detecting an error in FDM printing. For the purposes of this project, this setup will be too costly and therefore will not be further considered.

Optical

Opticalsensors have a setup that is generally composed of one of more cameras. The rest of the setup has varied greatly in previous work. Outlined in the paper entitled *Vision Based Error Detection for 3D Printing Process* the setup consisted of multiple cameras working alongside an "auxiliary thresholding algorithm [20]". This algorithm has the capacity to receive the footage from the optical cameras and "segment the digital image into binary images with a clear distinction between the object and the background [20]." To identify whether the print was successful or not, the differential images (in this case the difference between three images) were generated. For this method during "an error free print the object does not change its horizontal location but will only grow vertically [20]." Another method outlined by Nuchitprasitchai et al, involves the use of a single or double camera set up. Analysis occurs via taking a 2D image of the printing 3D object. The image of the printing part is then compared to a 2D shape model. Some rectification occurs (on the computer) and then image comparison (of what is printing to the model) takes place. This occurs via subtracting the actual image from the model image, "If the difference of subtraction is greater than 5%, there is an error; otherwise, there is no error flagged [21]".

Laser Speckle

Laser Speckle is a term used to describe "a random granular pattern [22]" that occurs when "when a highly coherent light beam (e.g. from a laser) is diffusely reflected at a surface with a complicated (rough) structure, such as a piece of paper, white paint, a display screen, or a metallic surface [22]". When shone off of a particular layer of a print, the speckle would have a certain appearance. If that was then compared to the real-time print of the part, it could be seen whether deviation had occurred. The use of a laser speckle would give the user information on the status of an entire layer of a print job.

Laser Line Projection

Laser Line Projection works on the same principles as outlined in laser speckle projection. However, instead of comparing a speckle of points it would simply require a comparison of the location of a reflected laser line. Again the "proper" placement of the reflected line would be required to compare to the line reflected off of the object printing.

Due to the reasons outlined above, we will not be further exploring acoustic, sonar, thermal and infrared options. Line laser projection, laser speckle projection and optical sensors will be further explored in the Design Options and Recommendations section.

Project Objectives and Quantitative Goals

As described in the project definition, materials are often wasted as the produced object does not match the envisioned design, during an unsuccessful FDM print run. FDM failures cause time delays and produce an excess of wasted material as different types of defects are formed, ultimately increasing capital costs. Therefore, the main objective for this term is to develop a proof of concept that will minimize material waste and maximize efficiency. This is done through sensing defects during an FDM print and stopping the print when a large enough defect is spotted, that may lead to the “spaghetti monster”. Once this is established, defining a defect-detecting method that can easily recognize these specific types of defects can be achieved.

There are constraints that will be followed more strictly from the problem definition. The method chosen should be a non-contact process, meaning that if a defect is being produced during a print run, the sensor should be able to detect it and stop the process automatically without user interference. Another constraint is the cost of the sensor solution; it should be no more than an FDM printer (around $300-400 CAD). Most importantly, it must be able to sense failures that may lead to a “spaghetti monster” and stop the print immediately. Furthermore, the solution should be versatile in that it is compatible with various types of FDM printers. Lastly, the material used for printing will be restricted to PLA filaments. The type of sensory method is the free variable, as it is being manipulated such that the project objective and each constraint are met.

As mentioned in the Project Definition, 35% of materials are wasted during FDM printing. 55% of that is due to printing failures [6]. The goal of this project is to reduce those numbers by a minimum of 5% each.

Design Options and Recommendations

Possible Methods of Identification

Measurement techniques traditionally employ either a regular geometric pattern or a constant as a base transducer [23]. The change of the regularity of the pattern is then converted into some measured quantity. After careful research into various methods, some used in industry and some not, we selected three promising options to explore in more detail. These options are:

- Laser Projection
- Speckle Metrology
- Optical

Laser Line Projection

Laser line scanning technology is an accurate, contactless and fast method currently employed in the inspection of the localization of surface abnormalities on large surface areas [24]. This technology is widely used in the manufacturing industry because of the low weight and compact size of the scanners, allowing easy integration with robot systems [24]. Figure 3 below shows an example of a laser line scanner used in industry. Besides purchasing an off the shelf scanner which can be expensive, this method provides the option to create a custom scanner with a camera, line laser and a filter.

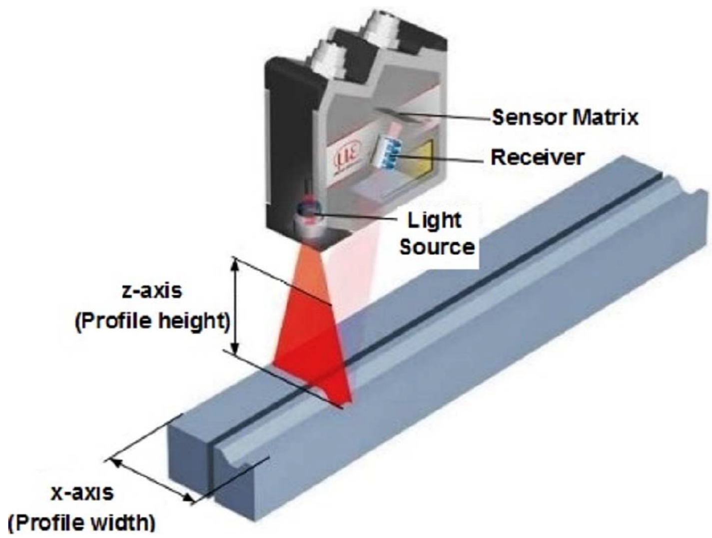

Figure 3: A Micro Epsilon Laser Line Structure [24]

Laser line scanning technology works on basic geometric optical principles to accurately detect surface abnormalities (defects). Simply put, a laser line is projected onto the surface being inspected and the reflected light is picked up by the camera for analysis. From the original CAD model, the average position of the laser line can be determined as a function of height (layer number). This position is then compared to the real time position of the laser to determine if there is an undesired shift. The change in the z-direction on the print surface translates to the change in y on the 2D image received by the camera. For this method, defect detection is classified in two ways. Points of interest; those points that deviate from the from the average by more than 0.4mm and if the reflected line is not in the same position as calculated from the CAD model.

Benefits and Downsides

The laser line system presents advantages mainly in terms of speed. The cost of custom equipment is also affordable and can be justified considering the cost of the printer. It is a fast, non-contact method capable of achieving high resolutions. The simple commercial scanner shown above has 1280 points in the line profile [21]. For our application in detecting when to stop the FDM printer based on a significant defect, this precision will suffice. Also, due to the fact that this is based solely on geometric optical principles [25], it is relatively easier to understand and apply as compared to the laser speckle, which will significantly help when troubleshooting.

However, there are also some disadvantages to this system which can lead to inaccuracy and uncertainty. Surface reflectivity issues are the most prominent because of the optical nature of the technology. Other issues are environmental effects such as light conditions or dust, shadowing might also occur when a part of the object or printer lies in the path of the projected laser line to the camera [24].

Laser Speckle Projection

Speckle metrology or laser speckle metrology is currently used in metrological measurement of metals [23]. When a coherent laser beam is shown on an optically rough surface, the reflected wavelets from each point on the surface come together to form a complicated pattern. The formation process is analogous to ripple patterns on the surface of a pond that has been disturbed by raindrops or some other object [23]. To apply this technique, a laser beam is used to illuminate the surface of interest and depending on the information sought, a section of the volumetric speckle pattern is selected and photographed. When the surface is deformed, the speckle pattern moves accordingly. The displaced speckles are photographed again and then superimposed on the first image to obtain a specklegram [20]. To delineate the speckle displacement, a narrow laser beam is sent at the points of interest and their corresponding far field diffraction spectrum received on a screen.

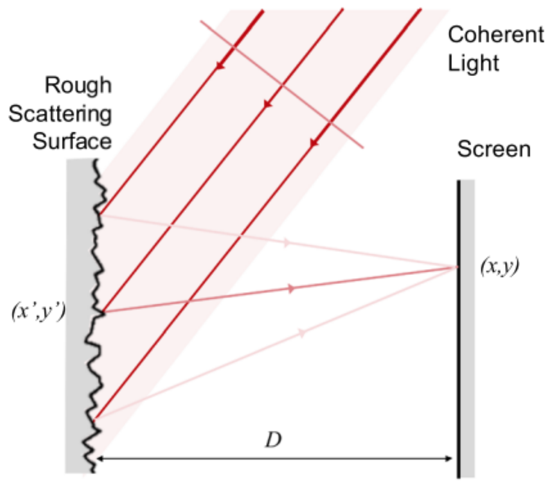

Figure 4: Simple Schematic of the Laser Speckle Principle

Figure 4 above shows a simple diagram of how the laser speckle principle operates. The collimated beam and wide spot size is essential for fully developed speckles [26]. This method will work for this project by comparing the specklegram generated from each layer with what is expected and analyzing for any deviations.

Benefits and Downsides

The main advantage obtained with laser speckle projection is the three dimensional image of the surface that is received. This allows for a higher precision when scanning the print layer and thus increases the probability of detect defection. This precision however requires that a lot of data be processed at each layer which will require a faster processor most likely at a higher cost.

Optical

Optical sensor technology makes use of one or more cameras alongside a computer based image processing system. These sensors are useful as they have the capacity to detect detachment, missing material flow, as well as deformed objects as they pick up on horizontal movements of the part as well as uneven vertical growth. Due to the prevalence of cameras, optical sensors have been successfully used in a variety of different setups to detect errors in FDM printing.

Baumann et al made use of an "auxiliary thresholding algorithm [20]" which received the footage from the cameras and "segment[ed] the digital image into binary images with a clear distinction between the object and the background [20].” To ensure that only relevant footage was obtained the layout of the printer was carefully measured, important pieces such as the print head were identified, and the video frame cropped. Differential images (in this case the difference between three images) were generated to detect errors. During “an error free print the object does not change its horizontal location but will only grow vertically [20].” In the event of a horizontal movement in the differential images, an error is detected and will likely result in the part needing to be discarded. To test the accuracy of this method the machine was first run several times properly to ensure that no errors were detected. This was then followed by the printing of two different faulty test objects. The first sample was examined “with 5 objects printed without cutting the filament flow in order to ensure that no false positive detection occurs and with 5 objects printed with the filament flow cut off mid-print in order to ensure positive recognition of the failure detection [20]”. From this, “four out of five objects [were] correctly classified as failed (80% detection rate for material flow failures) [20].” The second sample was examined by printing a triangular object with a very small base “10 times undisturbed with the object toppling over randomly 6 times [20].” Out of the six failed objects “four objects [were] correctly classified as failed resulting in 60% detection rate for object detachment [20].” Several times a part was classified as a “temporary failure [20]” during the print run however this was “corrected within a time span of 30 to 90 seconds [20]”.

Another method was demonstrated by Nuchitprasitchai et al with both a single camera and double camera set up. In this case, a 2D image taken of the printing part is compared to the 2D model STL file on the computer. Great care and attention is taken to distinguish background which is “removed and rendered white [21]” and the object being printed. “Next a region of interest (ROI) is calculated from the image by converting the color image into a gray-scale image, and then converting it into binary image. The object area in the binary image is converted to be white in color used as the ROI; otherwise, it is converted to be black [21]”. Rescaling, rectification and edge detection are then completed before comparison of the images. “After rectification, any errors in the process are detected by subtracting the simulated 3D [STL model] object image from the actual image [image of the printing part]. If the difference of subtraction is greater than 5%, there is an error; otherwise, there is no error flagged [21]”. “This method (100% detection) [21]” correctly identified any parts that had a size variation of greater than 5% from the model. For adding a second camera to the setup, the same method of operation as for the single camera is used. However special care must be taken to match the 3D space between the 2 cameras. Additional models- Scale invariant feature transform (SIFT) and Random Sample Consensus (RANSAC) are employed for this purpose. In terms of accuracy between using one or two cameras, "The size error percentage of two cameras is less than the shape error percentage of single camera. However, the calculation time of two cameras setup is greater than that of the single camera setup as the two-camera setup provided the width and height error. There are more error details for the double-camera setup than the single camera that provided only the total shape error [21]”.

While both of these methods may be different in terms of setup and interpretation, it must be noted that in both cases the majority of the work went into distinguishing the printed object from the background.

Benefits and Downsides

One of the major benefits of using Optical sensor technology is that it has successfully been used before in very similar applications to this current project- experiment could be modeled after a number of previous works. However, on top of good cameras being quite expensive (out of our price range) one of the downsides of using this technology is that the field of view is limited to a single side of the print. This can make defects hard to distinguish and identify if they are not present on the side being examined. Also if the FOV is from the top looking down onto the part, depth and contrast can make errors hard to detect. Nuchitprasitchai et al mentioned that "this system would be improved if it was applied to all sides of the printing object. For future research, this error detection system [should] be implemented and extended from the basic approach into 360° around FFF-based 3D printing [21]". Additional improvements were mentioned by the authors Baumann et al where they suggested that the algorithm be further developed for "resilience against lighting changes, [and] marker mis-detection [20]".

From reviewing the advantages and challenges of the top 3 design options, it was decided that laser line projection would be the most promising solution. Rationalizing the decision for the chosen design option came from constraints (budget, method, whether it will sense defect), other considerations include time and resource restrictions. While all 3 options were non-contact, the laser line projection would be the most cost-effective as compared to laser speckle projection and optical sensor. It was noted above that laser speckle projection would not be as cost-effective as line projection. This was due to the fact that it would require an additional computer due to the amount of data. Optical cameras are quite expensive, the FOV is limited, and contrast between the printing part and the background is difficult to achieve. This made it clear that optical sensors were not a promising solution for our team.

While the team has chosen the solution, there are still many details regarding laser line projection that still need to be answered. Firstly, considering the position of the laser and camera will need to be chosen once the team is able to work with the FDM printer. Determining this will articulate whether the laser line will cover the whole print bed or a single portion of the printed object. While we have calculated that the print nozzle has an approximate size of 400um, this value represents the theoretical defect size that the sensor would be able to detect. This value needs to be confirmed upon experimentation with the printer. Understanding and determining how to interface the code with the laser and the CAD model for the object will be a challenge for the team. This will be a key component that once achieved, will connect our solution with the print cycle.

Environmental and Economic Approaches

Life Cycle Assessment

Arguably, Climate Change has become one of the most pressing global issues humanity faces today. As a product of urgency, the concept of having sustainable designs in practice is emphasized greatly in the marketplace. In the engineering sector especially, the process of how an item is produced, or the materials chosen can have a severe impact on how environmentally sustainable it may be in the long term, and as such, affects if the process or material is implemented [28].

To measure these impacts, a life cycle assessment (LCA) can be performed using the Cambridge Engineering Selector (CES) software. Each stage of a products life in terms of energy use, water use, production of harmful by-products and impacts on land are measured [27].

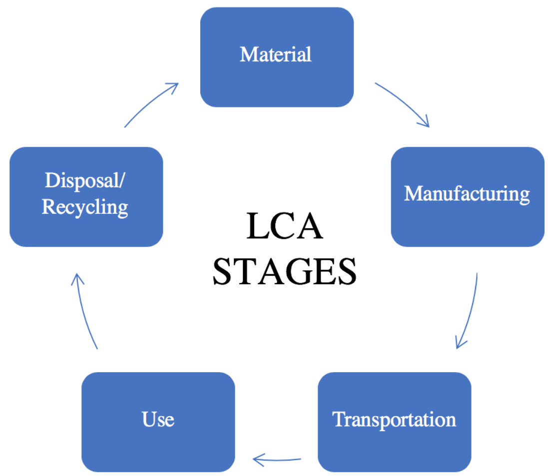

Figure 5: Life Cycle Stages of a Product/Technology [27]

Specifically, LCA looks at two important parameters, the first is the CO_2 footprint which is the amount of CO_2 emitted into the atmosphere upon creating 1 unit of the product [27]. The second parameter is the embodied energy which is the fossil-fuel energy consumed in making one unit of product. Intrinsic energy, which is energy stored in the material that may be recovered or stored into other forms, is also included [27].

A single life cycle is broken down into separate stages of a products life, this is schematically shown in Figure 5. Specifically, from its raw material acquisition, to manufacturing the product, to transporting the final product, to use of the product and finally, disposal or recycling of the product [27].

Methodology

Consequently, as an entirely new, physical component is introduced, additional environmental concerns are also introduced. A full life cycle assessment will be performed on the chosen solution, the laser line projection. As mentioned in previous sections, three components are involved, an optical camera, a laser line scanning device and a filter. As these pieces are all available for purchase individually, a separate LCA will be performed for each component. The impact will be added together to give a total environmental analysis of the project solution. It is important to note that a computer is also required to analyze the data of the laser deviations captured by the camera. As a computer is required to FDM print anyways, an assumption that the laser analysis can be done on the same computer is made. Therefore, a computer will not be included in the LCA of the solution.

It is clear that introducing a defect detection system will present a definite environmental impact. With this system in place, however, there is a possibility that if it is successful in detecting a defect, stopping the machine automatically, PLA material will be saved. This is an important assessment to include as the savings in PLA, could offset the environmental impacts required to implement the detection system. The 34% material waste statistic that was discussed in earlier sections from printing failures, could be reduced further, possibly making the laser line projection solution environmentally friendly [3].

Economics

Evidently, PLA is the most common material used in polymer-fed FDM printers. It is a biodegradable thermoplastic polymer, with a variety of applications in different industries (such as medical, food packaging and automotive parts) [29]. Rising environmental concerns have made the biodegradable polymer industry one of the most competitive, with prices per kg of material increasing each year [29]. Savings in PLA filament could make a huge impact, economically for users. As such, an economic analysis will be performed comparing costs incurred because of PLA waste, without the defection detection system in place, versus, having it in place and avoiding PLA material waste.

Updated Project Schedule

The schedule for the remaining weeks is outlined in Table 1 below. The start of each week has the milestone objective highlighted. The sub tasks below the milestone objectives have been assigned to various group members. The goal of this schedule was to have each group member contribute 6-8 hours of work a week.

The tasks that have been already completed are shown in Appendix A. Completing all these milestones at the scheduled time will lead to a successful solution for this project.

Table 1: Table of tasks to be completed

Task	***Week***	***Completed by***	***Comments***
Complete midterm report and research how the system will be used	7	All	Milestone
Complete midterm report	7	All	Each member had a different section
Research line laser systems on the market	7	Catherine & Jenna	

Make sample objects; some with defects	7	Clement & Sofia	
Test line laser plus a phone camera on the printed objects; what do images look like?	7	Aleisha & Isabela	
Finalize method of using our system	8	All	Milestone
Print objects and try to catch defects on camera	8	Clement & Sofia	
Precision needed	8	Clement & Catherine	Done by analyzing objects we printed
Determine where line laser should be shining on the object being printed	8	Sofia & Isabela	Done by analyzing objects we printed
Determine the language for our code and how to interface with the CAD model	8	Jenna & Aleisha	This is to prove we can write the needed code
Complete a flow chart for the algorithm	8	Catherine & Isabela	
Determine where the system will be placed	9	All	Milestone
Mathematically determine how the angle of incidence affects the system	9	Catherine & Clement	
Compare theoretical values to example images from last week	9	Jenna & Sofia	
Determine how change in height of the object affects the measurements	9	Aleisha & Isabela	
Combine information to determine where the system will be placed	9	All	
Complete proof of concept	10	All	Milestone
Update the algorithm flow chart	10	Catherine & Isabela	May change due to system placement
Film the reflection of the line laser during a print with a defect	10	Clement & Sofia	This should be done in a dark room
Use the video to validate that algorithm will work	10	Jenna & Aleisha	
Prepare final presentation and report	11	All	Milestone
Write report	11	All	Work will be split later
Prepare presentation	11	All	Each member will work on their section
Present and turn in final project	12		Milestone
Edit report	12	Catherine & Jenna	Members that are not presenting
Practice presentation	12	Aleisha, Clement, Sofia & Isabela	Presenters

Risk Assessment

As previously assessed in the proposal report, access to technical resources is still seen as one of the greatest risks for this project. This is due to the fact that additive manufacturing has only recently moved from being a method for rapid prototyping to being a manufacturing process. This means there is very limited published research and exploration into ways to reduce part rejection and material waste in an FDM printer. Another reason why technical resources are hard to find is also because, since this technology is still in its early stages, not many standards and specifications have been set as precedent. Different researchers make different assumption which makes it a challenge to find an idea suitable for our project. Adequate knowledge on the background of this project can be gained but with regards to actual solutions the scope is somewhat limited. Due to this, not all possible routes can be explored (primarily because they are not known) and the solution found even though suitable, may not be the best case. To reduce the risk associated with this, the group plans to periodically seek input from our sponsor with regards to any solution or direction we decide to undertake. This way we are sure to obtain some technical expertise to supplement the research we do. We also plan to spend ample time testing and retesting our proof of concept by intentionally printing defected and complex objects with the provided FDM printer.

Next Steps

While prototyping the laser line projection solution will not be done until the following semester, there are still additional considerations that should be taken beforehand.

The position and angles of the laser and camera must be determined through geometry and mathematical modelling. This will determine whether a single portion of the object is being measured or the entire print bed.

Furthermore, data processing will need to be done to understand how to analyze the picture of the laser line and how to program that information. Finally, we will look into economic factors and the environmental impact of the implemented defect detection system. Detailed analysis of the material wasted if the detection system is not put into place, and compared with the former.

After these steps are taken, a final conclusion on whether or not this is a viable and practical solution for the manufacturing industry, will be made. This will be explored further in the Final Project Report.

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Appendices

Appendix A

The table of tasks completed in the first half of the term is shown below in Table 2.

Table 2: Table of tasks already completed

Task	Week	Completed by	Comments
Initial literature review complete	1	All	Milestone
Problem definition	1	Isabela & Clement	
Defining relevant terms	1	All	Done individually and combined
Research already existing solutions	1	Jenna & Aleisha	
List of all possible solutions	2	All	Milestone
Research all possible defects	2	Sofia & Catherine	
Begin writing proposal report	2	All	Divided among members
Preliminary proposal report written	3	All	Milestone
Complete writing preliminary proposal report	3	All	Divided among members
Finalized proposal report finished and research continued	4	All	Milestone
Finish final copy of proposal report	4	All	Divided among members

Familiarize with physical FDM printer (if available)	4	All	Group activity
Research defect size ranges	4	Catherine, Sofia & Isabela	
Research sensors (prices/precision/existence)	4	Clement, Aleisha & Jenna	
Top three solutions chosen with week 4's research	5	All	Milestone
Combine week 4 research into tables for solution comparison	5	All	Used to determine top three
In depth comparison of functionality of top solutions	5	Sofia, Catherine & Isabela	
In depth comparison of economics of top solutions	5	Clement, Aleisha & Jenna	
Most promising solution chosen	5	All	
Preliminary presentation and midterm report completed	6	All	Milestone
Prepare presentation	6	All	Divided among members
Write report	6	All	Divided among members
Practice presentation	6	Catherine & Jenna	Two presenters