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ENTITLED

3D Bioprinter

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREES OF

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3D Bioprinter

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Submitted in partial fulfillment of the requirements
for the degrees of
Bachelor of Science in Computer Science and Engineering
Bachelor of Science in Mechanical Engineering
Bachelor of Science in Bioengineering
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3D Bioprinter

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ABSTRACT

The 3D Bioprinter project aims to create a 3D bioprinter that can improve the capabilities of high school teachers to engage students in STEM education. In order to accomplish this goal, the team is working to expand functionality in SE3Ds product line to allow for a better student and teacher user experience and the execution of more interesting experiments. The 3D Bioprinter projects main goal is to create a modular incubating box with a variety of sensors to allow for custom environments per experiment, a clear interface to control the settings, and an automatic image capture system. As the project increases functionality, it also will keep the final deliverable as low cost as possible. These additions to the current SE3D 3D Bioprinter will increase effectiveness in the classroom and allow the target audience, high-school students, to better engage in STEM education activities.

Keywords: 3D Printing, Bioprinting, STEM, Education, Control Systems, Incubation

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Chapter 1

Introduction

1.1 Problem Statement

STEM (science, technology, engineering, and math) fields are a primary focus in education, because there is increasing need for students who have the technical skills to solve real-world problems. A major challenge that many STEM educators face is engaging students in the classroom. The education technology (ed-tech) startup, SE3D, hopes to solve this challenge by bringing 3D bioprinting technology to high school classrooms. Although SE3D has already produced a working prototype, the printer only has basic capabilities and requires further development.

The 3D bioprinter senior design team aims to create a 3D bioprinter that can improve the capabilities of high school teachers to engage students in STEM education. Implementing 3D bioprinters into high schools will generate increased understanding and interest in biology, research, and technology for the students who will soon be Americas doctors, technicians, and scientific pioneers.

In order to accomplish this goal, the team is expanding SE3Ds product line to improve student and teacher user experiences and to expand the possibilities for biological experiments. Table 1.1 shows how SE3Ds current printer can be improved to meet these goals.

Table 1.1: Current Bioprinter Problems and Senior Design Project Solutions

Problem	Solution
Printer lacks advanced features: automated camera, temperature control and humidity regulation - Limits capability of experimentation	Develop a separate, modular incubation unit (The Box) with an automated camera and humidity and temperature controls - Analysis and printing can occur in parallel since functions are not in same physical space - Automatic image capture to analyze experiment over time - Simple user interface to configure and run experiments
Printer only prints with one material - Limits print designs	Design and implement low cost dual extruder
Motion control system relies on specialized 3D printer software and feature-limited hardware - Duet Control Board only supports basic 3D printing operations - External computer necessary for control	Create custom software environment - Distributed control board system to accommodate extra control features Run on built-in computer - Keep low-cost with Raspberry Pi
Operator must manually calibrate syringe extruder - Room for human error	Implement auto-calibration software of the syringe extruder

The goals in Table 1.1 are subject to the following criteria:

1. Usable in a high school lab environment by both students and teachers

2. Safe for all users

3. Low cost

1.2 Background and Related Work

The current bioprinter produced by SE3D, the r3bEL, is marketed towards high school science classes. It prints using a single 5 mL syringe that has to be manually loaded by the user, put into the head of the bioprinter, and calibrated by hand to begin printing. It currently has the capability to print enzyme, alga, and bacterium 2D arrays, chocolate, and cells and scaffolds for 3D tissue engineering. The r3bEL printer can print four 3x3 array tray experiments in about 3 minutes. After it is finished, the experiment must remain on the bed of the bioprinter until it finishes culturing. The user gathers data form the experiment by constantly taking pictures of the experiment as it cultures. To capture more consistent and higher quality images, an SE3D employee created a separate box that block out external light and has its own light source. This small box has a removable ceiling, lined with LEDs, and holds a single Petri dish. A small hole in the ceiling allows a mobile phone camera to be placed over it to capture images of the experiment as it cultures, though it still requires

an individual to operate the camera and capture each image.

Table 1.2: Comparison of Existing 3D Bioprinters

Printers	Features							
	UV Curing	Multi Material	Simple UI	Self Cleaning	Auto Calibration	Modular Incubation	Used for Education	Price
RegenHu	X	X		X	X			250K+
Bio3D		X					X	*
Aether 1	X	X+		X	X			9K+
Inkredible	X	X	X					10K
BioBots	X	X	X					10K
SE3D		~	X		~	X	X	3K

Key
X: has feature
X+ : has advanced features
~ : project stretch goal
* : value unknown

Although the team is enhancing the functionality of SE3Ds 3D Bioprinter, there are currently many similar products that are already available for purchase. Below are the bioprinters shown in Table 2 with an explanation of their key features and price ranges.

RegenHu: 3D Discovery Printer

RegenHu produces a professional printer priced at 250,000+ USD. It supports a wide range of funcationalities and applications. It is primarily used for optimal processing of a broad biomaterial/bioactives portfolio. The device prints using cell-friendly Ink-jet and thermopolymer extrusion using a 2-component printhead. In addition, it has a high precision temperature controller for biomaterial culturing.

Bio3D Technologies: Bio3D Explorer series

Three-dimensional bioprinters have also been developed internationally. Bio3D Technologies in Singapore has a series of printers in their Explorer product line. Designed for educational purposes, the Bio3D has 1 to 4 printing heads available and is lightweight and foldable with a full metal frame. The device is suitable for a wide range of applications and materials. The price was not listed online.

Aether 1 3D Bioprinter

Aether has a 3D bioprinter that begins with a base unit cost of 9,000 USD. The product includes 8 syringes, 2 hot ends, and 10 extruder print heads. It has the widest range of usable materials for printing, from oils to plastics. The device has many useful attachments, like a UV curing light for biomaterial prints. Its extruders are pneumatic-driven.

CellInk: Inkredible Printer

In Palo Alto, California, CellInk manufactures a research grade bioprinter, Inkredible. Inkredible is priced at 10,000 USD for the base version of the printer. It focuses on assisting tissue engineers who use their custom bioink line to create hydrogel structures that allow for efficient mammalian cell culturing. It has been optimized to print skin and cartilage tissue and uses UV lighting to cure the biomaterial. The printer has a clean chamber and heated cartridges.

BioBots 3D printer

BioBots has a desktop 3D printer capable of printing tissues out of living cells. The base model price of BioBots 3D printer is 10,000 USD. It is small and portable to allow for ease of use. In addition, the device has a dual heated, pneumatic driven extruder system for precise printing and uses replaceable syringes for easy material changing. Blue light technology is used to safely cure the biomaterial. BioBots is based in Philadelphia; however, they ship internationally.

After reviewing these printers, it is clear that they are all capable of completing the biological experiments that SE3D desires. The one aspect that they all do not meet, however, is that they are priced much higher than the average high school laboratory budget. Furthermore, these printers require high levels of knowledge in order to operate, which is not a reasonable expectation of high school students. To improve this aspect, the UI must be simplified and easy to use for people with less than a high school education. The closest competitors are Inkredible and BioBots, which are low cost and have simple user interfaces. The 3D Bioprinter that the team is working on improves on this problem by providing the necessary functionality at a more reasonable price closer to 3,000 USD.

1.3   Objectives

The 3D bioprinting team consists of mechanical engineers, computer engineers, and bioengineers. To accomplish the project goals, the team has split the project into three parts: The Box, 3D Printing Feasability Study, and a bioengineering experiment. The bulk of this document will focus on the softwware components for The Box and 3d Printing feasability study, as that will be where the computer engineering work is applied.

- The Box:

    1. Meet with Maya, SE3D CEO to define requirements for the incubating box

2. Make design decisions for functionality included in the box and physical and structural designs

3. Develop prototypes of box, user interface, and controls, allowing users to customize the box environment, begin and end experiments, and automatically capture a series of photos

4. At every stage of development, run tests for proper software and hardware compatibility

5. Share prototype with users in a classroom setting for feedback

- 3D Printing Feasability Study

  - Auto-Homing of Extruder

  - Multi-Material Extrusion

Chapter 2

Requirements

The requirements section defines and qualifies what our 3D printer feasability study and the incubating box must do. We communicated with SE3D to determine the requirements.

2.1 Functional Requirements

Functional requirements define what the system must do.
The incubating box system will:

- support timed image capture at a pre-specified image per time interval

- have an interactive user interface

- allow user to monitor and control light, temperature, and camera settings

- allow users to download captured images

- allow users to save settings as custom environments to be used later

  The 3D printer feasability study system will:

- show feasability of auto-homing of SE3D's syringe

- show feasability of adding a multi-material printing module to an open source printer

2.2 Non-Functional Requirements

Non-functional requirements define the manner in which the functional requirements need to be achieved.
The system will be:

- User friendly and intuitive

- Safe

- Secure

- Reliable

2.3   Design Constraints

Design Constraints are non-functional requirements that constrain the solution instead of the problem.

The system must:

- function without being connected to a desktop or laptop computer
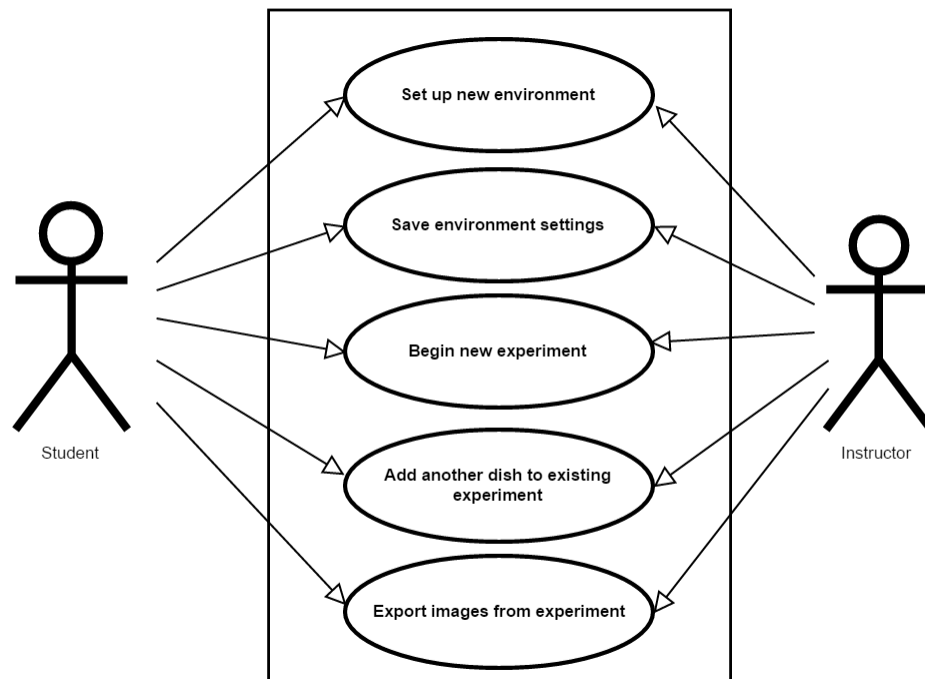
- be low- cost

Chapter 3

Use Cases

Use Case diagrams dene tasks that users will perform to achieve a certain goal when using our incubating box and 3d bioprinter system.

3.1 The Box

Figure 3.1: Use Case Diagram for The Box

1. • Name: Set up new environment

   • Goal: Prepare The Box to have the proper settings for the experiment that the user wants to run

   • Actors: Student, Instructor

- Pre-conditions: No other experiment is currently running

- Steps: Either load settings that have been previously saved, or enter custom light, temperature, and image capture settings.

- Post-conditions: The Box is at currect environment settings for the experiment.

- Exceptions

2.
- Name: Save environment settings

- Goal: Save temperature, light, and image capture settings to prevent repetition in the future

- Actors: Student, Instructor

- Pre-conditions: User has input custom temperature, light, and image capture settings

- Steps: User clicks 'Save Custom environment' and enters an appropriate name

- Post-conditions: Future users will now be able to load this environment for future experiments

- Exceptions: n/a

3.
- Name: Begin new experiment

- Goal: Begin timer and image capture on current incubated experiment

- Actors: Student, Instructor

- Pre-conditions: User has entered proper environment settings, selected which petri dishes are present, and has placed petri dishes in The Box. The Box has been brought to proper temperature.

- Steps: Click 'Begin Experiment'

- Post-conditions: Timer and image capture begins

- Exceptions: n/a

4.
- Name: Add another dish to existing experiment

- Goal: Add another dish to a experiment that is already running

- Actors: Student, Instructor

- Pre-conditions: An experiment must be running in The Box

- Steps: User places dish in the box. Clicks on the appropriate petri dish to begin timer and image capture of new dish

- Post-conditions: New petri dish is added into the experiment and final end time is extended to accommodate

- Exceptions

5.
- Name: Export images from experiment

- Goal: Download images captured during the experiment of a single petri dish for analysis

- Actors: Student, Instructor

- Pre-conditions: A USB drive has been inserted and detected

- Steps: Click 'download images' button, Select the relevant dish, click 'download'

- Post-conditions: Images transferred onto the USB drive

- Exceptions

3.2 Feasability Study

Chapter 4

System Sequence Diagrams

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System Design- The Box

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5.3.2 Justification of Technologies Used

5.4 Technologies Used

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System Design- Feasabiltiy Study

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6.3.1 Justification of User Experience

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6.4 Technologies Used

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