DEPARTMENT OF
Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Dental HandPiece Scope

BME 200/300 Final Report

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Client:

Dr. Donald Tipple

Advisor:

Dr. Peter Favreau

Team Members:

Team Leader: Jonah Mudge

Communicator: Hunter Huth

BPAG: Joe Kerwin

BSAC: Yanbo Feng

BWIG: Lucas Ratajczyk

Abstract

Crown and bridge replacements are a common procedure performed by dentists in the US. Currently, when working on hard to reach teeth, such as the back molars, dentists have to rely on handheld mirrors and their intuition in order to perform the procedure. There are a few designs at this point in time that seek to solve this problem. However, all of these designs focus on designing a drill handpiece that has this optical capability integrated into the handpiece itself. Our team has designed an apparatus that can be easily attached and detached from the drill, facilitating easy implementation with existing drill heads. Along with its detachability, our design integrates multiple digital filters that can be easily added and removed in order to enhance the viewing of the tooth. The design is meant to reduce cost of the product while allowing dentists to avoid relearning the nuances of a new drill.

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Introduction

In the US alone, there are approximately 15 million people who have crown or bridge replacements for missing or damaged teeth, and this number is increasing at a rate of nearly 500,000 each year [1]. With such a large number of procedures being performed annually, it is important that dental professionals maintain the highest standard of accuracy and safety to avoid failed operations or possible injury to the patient. During crown implant procedures, dentists are often confronted with difficulties viewing the teeth of interest. They may observe the location of the operation site and the hand piece with a mirror, but depending on the size of the patient's mouth and the location of the teeth, consistent viewing can be nearly impossible, forcing the dentist to rely on intuition to complete the procedure. A camera capable of showing a live video feed of the operation site could remove this difficulty, allowing dentists to operate without the risks associated with blind handpiece use.

Current devices designed to address this issue include US5049070A, consisting of a dental drill with a integral camera and optics [2]. US5049070A has an elongated body attached to the hand piece where the camera cable is connected to its proximal end. The cable in this design is runs externally down the handpiece body and controls the operation of the video imaging units and light source for the camera [2]. EP2891467A1 is another dental drill design including a built-in camera and numbers of small LEDs around the camera [3]. This design has a similar external shape to US5049070A but different inner design. It implements a color camera module stored inside the handpiece. The color camera module consistents a camera units with a condensing lens, a color imaging sensor which can output color image signals, a set of small LEDs surrounding around the camera unit. Different from the US5049070A, the camera module in this design is attached and fixed at the internal wall of handpiece on the side where the drill locates. US5251025A is a completely different dental camera design from the previous two designs. This design has the camera module designed into an individual handpiece separated from the dental drill [4]. The individual handpiece contains a camera set at an angle from the handle axis at the distal end of the handpiece, an imaging device and a color filter built inside of the body of the handpiece, and two cables with two different ways of signal outputting. US5634790A is also a design with integral camera [5]. This dental/medical instrument is structurally similar to EP2891467A1 and contains a imaging system including a CCD camera inside the handpiece body. Distinct from the previous existing devices, US20120040305A1 is a collection of methods of combining the camera and dental instrument [6]. This collection includes several methods such as a detachable external camera module and built-in camera module inside body of instrument and describes the advantages and disadvantages of these methods [6].

During crown implant procedures, dentists need to have a view from the top of the drill instead of the bottom of the drill because the vision of a camera underneath the drill can be interrupted easily by teeth, but the camera on the top of the drill can provide uninterrupted vision of the working site between the gums and the tooth. As a result, to allow dentists to have better viewing of the working site during the crown implant surgery and free them from relying on intuition to complete the surgery process, a camera system capable of showing an uninterrupted live video feed of the operation site is needed to remove the surgical difficulty, allowing dentists to operate without the risks associated with blind handpiece use.

Background

The moist environment of the mouth, and the humid air from breathing, leads to challenges while trying to implement a camera or other electronic components. To prevent moisture from interacting with these water-sensitive components, marine heat shrink was purchased that shrinks and creates a waterproof seal when heated. The marine heat shrink is intended for use in marine environments, in which the water pressure is far greater than that experienced in the human mouth, meaning this seal should withstand the intended environment of this product. An additional benefit of using the heat shrink sleeve to seal the electronic components is that it holds the camera's ribbon cable in position, preventing unintended and potentially hazardous movement.

Figure 1. 8.5mm x 11.3mm Spy Camera for Raspberry Pi with 289mm long cable offered by Adafruit Industries [7].

Shown in Fig. 1 is a camera offered by Adafruit Industries, which satisfies the requirements for this project. The camera needs to be attached to the Raspberry Pi Camera Board via the small socket on the upper surface of the board to function. The sensor of the spy camera has a 5 megapixel native resolution and the capability to produce a 2592 x 1944 pixel still image. This camera can support up to 1080p with 30 fps, 720p with 60 fps or 640x480p with 60 or 90 fps video. Extra flex cable can be connected to the cable of the spy camera to extend the length of the connection.

Though the video feed from the camera can simply be projected onto a computer screen, the images shown on the real-time display can also be processed to allow the dentist to see a clearer picture of the drilling site than with a naked eye. While performing a crown preparation, the dentist drills through the white/grey enamel to the inner, yellow layer of dentin. The dentist would benefit from being able to see enhanced contrast between those two layers to determine when the tooth has been drilled to a sufficient depth. A warming filter can be used to highlight this contrast. A warming filter emphasizes the appearance of warming colors of red, yellow, and orange, and it could allow for increased visibility of the exposed dentin [8]. OpenCV is an open source software that contains libraries for image processing and analysis [9]. This software can be applied to color detection and can detect the yellow tint of the dentin. OpenCV has libraries to detect and convert images that assign HSV values to each pixel. This value includes a hue number, saturation number, and value number to each pixel, and a threshold can be placed on the image that highlights all pixels within this range. In this application, the real time video feed could increase the brightness or supersaturated pixels in the yellow range.

Where the size of the camera attachment is concerned, some common dental drills have cylindrical heads with dimensions of ~13 mm in diameter by ~12 mm in height [11]. Thus, the camera mount must have a cross sectional area on the order of less than ~2 mm^2 for it to be unobtrusive when mounted on the dental drill.

Our client, Dr. Donald Tipple, is a practicing dentist in the southwest Madison area. Dr. Tipple described to the team that sometimes, after an unsuccessful attempt at using a mirror to provide a clear line of sight to a procedure area in a difficult area in the patient’s mouth, dentists must rely upon their intuition and a mental image of the procedure area in order to perform the procedure, frequently stopping and checking their progress to ensure they do not remove too much or too little of the tooth. As this is tedious and time-consuming, he requested that we develop a method of attaching or combining a camera to/with the dental drill so that the dentist can instead rely upon a live video feed of the procedure area in such situations.

Preliminary Designs

The drill encapsulation shell design concept shown below in figure 2 uses a 3D printed shell that fits tightly to the dental drill. This would encase the wires and electronics to prevent water damage to the electronics, and would prevent entanglement in the wires during operation. The protrusion on the top of the drill holds the camera, which is angled towards the tip of the drill and is covered in a lens with a solution coating that prevents water build up and fog formation. The wires lead to a computer that holds a display that has settings to change the brightness of the drill along with any post processing filters.

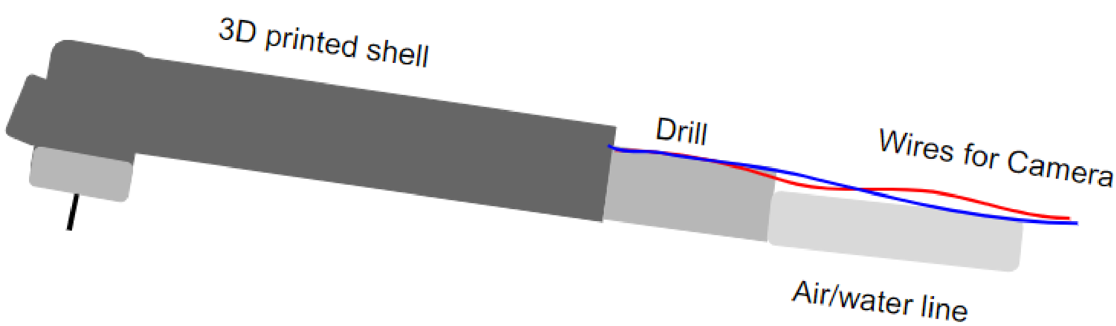

Figure 2. This design 3D printed shell (dark grey) fits over the dental drill (grey) with only room for the wiring and camera underneath. The wires would then be strapped along the hose (light grey) that holds that air and water tubes.

The Directly Mounted Plastic Housing design is displayed in Figure 3. This design incorporates a small, uninvasive 3D printed housing attached directly to the downward slope on the head of the drill. Mounting the housing and camera onto the natural slope of the handpiece allows for a unique viewing angle while remaining small and unobtrusive. However, being directly attached via only 3D-printed plastic with loose wires running down the drill-piece caused possible safety concerns. The strengths of the design are in the small profile and the cheap cost for manufacturing.

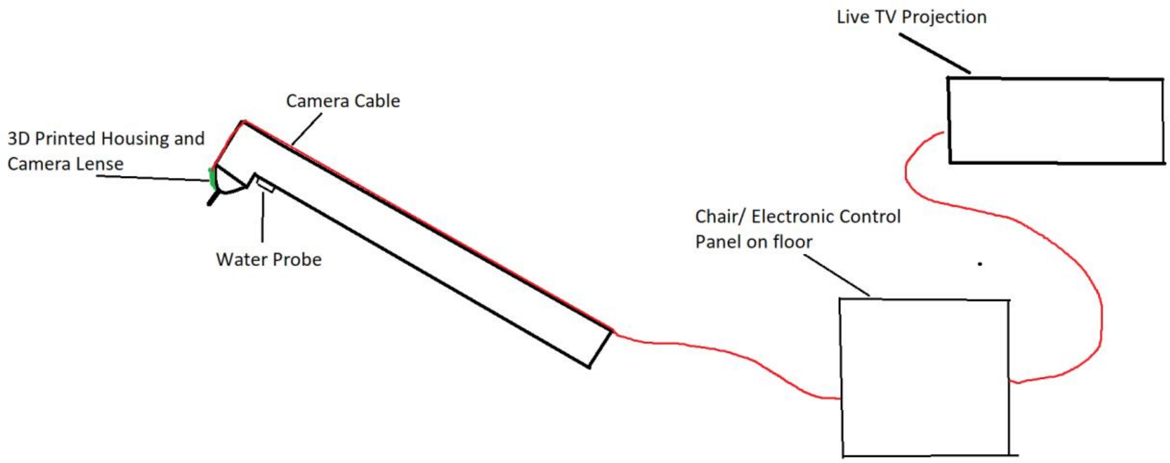

Figure 3. The Directly Mounted Plastic Housing Design (Design 2) with all components labeled.

The Angled Holder Design (aka Design 3) consists of a 3D printed plastic camera mount that is strapped onto the sides of the dental drill head and has the camera lens angle such that it is pointing directly at the tip of the drill (Fig. 4). The relative insecurity of the straps significantly damaged the safety score. The holder appears to be approximately the same size as the drill head, damaging its size score. However, its viewing angle was the best of all the designs as it deliberately extends further and more explicitly seeks the best possible viewing angle.

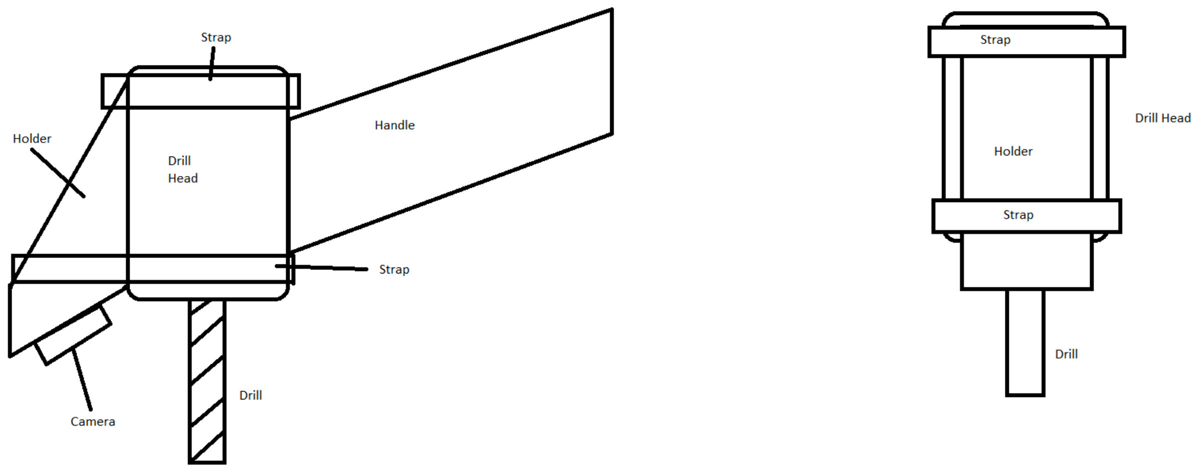

Figure 4. The Angled Holder Design (Design 3) with all components labeled**.**

The integrated lighting design in (Design in Figure 5) requires a 3D printed metal drill head with an extra housing for the camera and cable, which is used to replace the old drill head. The housing of the camera needs to have an angle from the axis of the body of the dental drill to ensure that the lens of the camera can focus on the working place of the drill. Also, this design requires the rearrangement of the components in the inner structure, which is difficult in terms of technique. In this design, there are four small LEDs around the camera, which is redundant because there is already a light source on the original dental drill handpiece. Also, there is a small cavity in the design to protect the lens, which makes the head of the dental drill hard to clean, leading to low score in sterilizability of this design. Due to the fabrication and erection difficulty and the low score in sterilizability, this design was not selected. However, the idea of 3D printing of metal could bring professional effectiveness if there was no production difficulty because the printed part is rigid and durable.

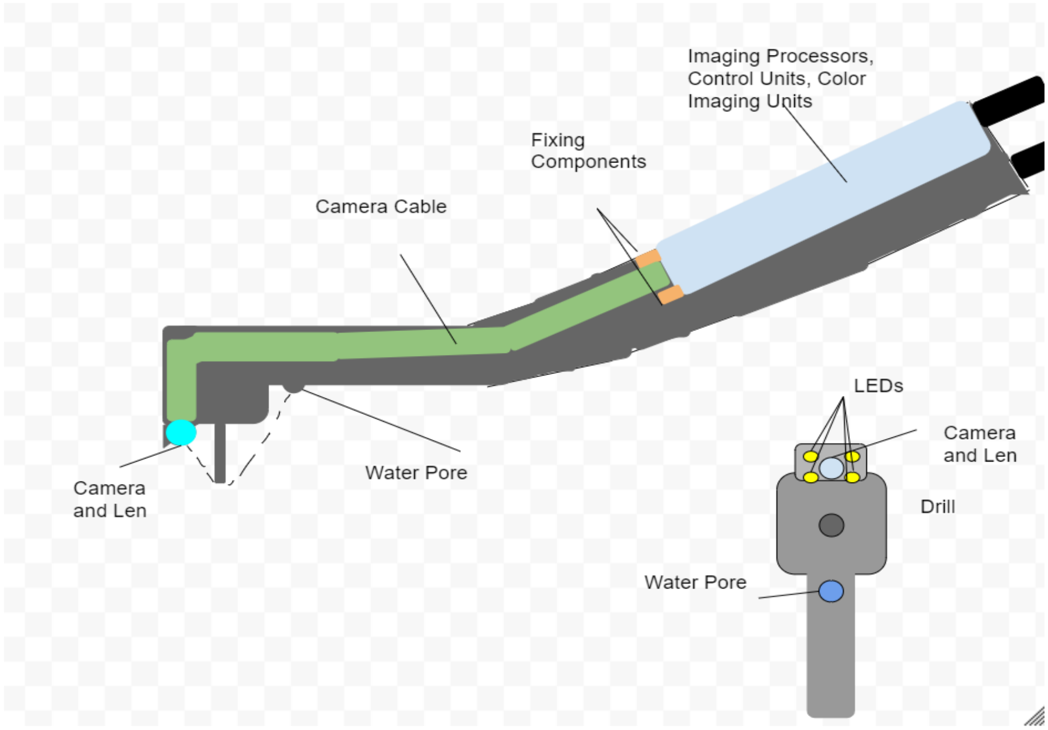

Figure 5. This concept includes LEDs to provide additional visibility around the operation area. The video processors, color filters, etc. are integrated into the handle of the dental handpiece.

The modular design (Fig. 6) utilizes a 3D-printed camera mount designed to snap on to the head of the dental handpiece. This makes it very easy to implement in dental offices, as the installment would consist merely of attaching the camera to the drill and aligning it. This design also makes use of visual post-processing through an Arduino (or similar device) to apply a color filter to heighten the enamel-dentin contrast during the operation. This image would then be projected to a screen for the dental professional to look off of over the course of the procedure. The lens of the camera would also be coated to prevent loss of vision from water and debris. The overall cost of this design would be financially very feasible, due to the cheap cost of 3D-printing and consumer electronics. There is a small safety consideration surrounding the possibility of the camera mount slipping, as it is snapped on. However, this could be remedied using another 3D-printed piece to stabilize it from the opposite side of the drill. The field of view from the camera granted by this design is also more than adequate for the operation, and the line of sight directly to the drill tip allows for excellent viewing of the operation site. Where size is concerned, this design also performs very well, as the camera plus its housing should not extend more than a few millimeters from the drill head itself, minimizing the chances of contact with the patient's mouth. The detachable nature of the camera mount also lends itself towards easy sterilization, since both components, the camera/mount and the handpiece, can be cleaned separately.

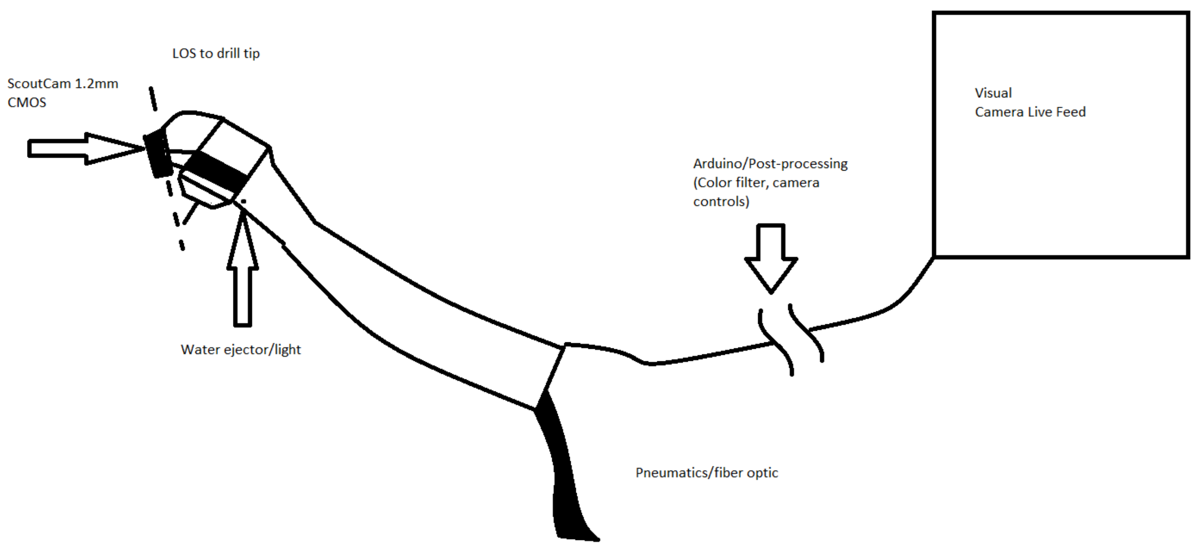

Figure 6. The modular design concept consists of a plastic, 3D-printed camera mount which is snapped on to the handpiece. The data from the camera is then filtered for color contrast and sent to the video screen in real time.

Preliminary Design Evaluation

Criteria (weight)	Design 1 Hunter	Design 2 Joe	Design 3 Lucas	Design 4 Yanbo	Design 5 Jonah
Ease of Use (25)	5/5 (25)	5/5 (25)	5/5 (25)	5/5 (25)	5/5 (25)
Safety (25)	5/5 (25)	3/5 (15)	3/5 (15)	5/5 (25)	4/5 (20)
Viewing Angle (15)	4/5 (12)	4/5 (12)	5/5 (15)	4/5 (12)	4/5 (12)
Size (15)	3/5 (9)	4/5 (12)	3/5 (9)	4/5 (12)	5/5 (15)
Cost (10)	2/5 (4)	5/5 (10)	4/5 (8)	4/5 (8)	5/5 (10)
Sterilizability (10)	5/5 (10)	3/5 (6)	3/5 (6)	3/5 (6)	4/5 (8)
Total (100)	85	80	78	88	90

Figure 7. Design matrix including scores for each of the design concepts above.

Design 1 was one of the safest designs and was easily sterilizable but was also bulkier and more costly, reducing this design's overall score. Design 2 was one of our most cost effective designs and had fairly good viewing angle setup and unobtrusive size. However, it was not as safe or sterilizable as most other designs. Design 3 had the best viewing angle of all designs but was lacking in nearly every other category. Design 4 was a very good design all around but it was slightly bulkier and more expensive than Design 5 and was not so easily sterilized. Design 5 was the highest scoring design in our design matrix so we are using it as our proposed final design. However, we will likely work on improving Design 5's safety rating by incorporating some aspects of Design 4.

Proposed Final Design

Design 5 consists of a small clip-on camera mount that is both easy to fabricate, easy to install, and effective. Because of these features, it received the highest score on the design matrix. One added benefit of the easy fabrication is that it will allow us to iterate through the design process (something we rarely get to do in one semester) because we should be able to have a viable prototype much sooner than if we had decided to pursue another design.

Fabrication/Development Process

Materials

- Form 2 Durable Plastic - The Form 2 printer was chosen for this project, and therefore the Form 2 plastics, due to their ability to provide high quality surface finishes with tight tolerances. The durable versions of Form 2 plastic are a solid replacement for nylon and provides great detail at small dimensions, which is exactly what was needed.
- Raspberry Pi Spy Camera - This camera was chosen specifically for its compatibility with Raspberry Pi. Other than that, this camera model was chosen because it was a cheaper model which would work better with prototyping rather than spending a lot on a high tech camera initially.
- CapraZyme Vegetarian Enzyme Supplement for Men and Women - This form of amylase was chosen due to it's easy availability to purchase along with the simplicity of use. The capsule simply slipped apart allowing access to the enzymes inside which then could be easily mixed into water for enzyme resilience testing on the device.
- RS Raspberry Pi 7-Inch LCD Touch Screen Case, Black - This case was chosen because it is published and sold by the Raspberry Pi company itself. Along with this, the case fit the dimensions of the touchscreen we purchased.
- Element 14 7" Pi Touchscreen LCD Display - This touchscreen was chosen due to its compatibility with Raspberry Pi and its ability to register 10 touchpoints. The

touchscreen had all of the ports and software that was needed to run the Raspberry Pi and it was cost effective with good reviews.

- 42 Pc Marine Heat Shrink Tubing Assortment With Case - The heat shrink was chosen due to it being marine heat shrink which gave it some level of water resistance which is exactly what was needed for this project. Along with this, its application onto the prototype was extremely simple and therefore easy to change as needed.

Methods

- 3D printing

The 3D printing process starts with taking a Solidworks file and then exporting it to the .STL file type which is compatible with the Preform software that the Form 2 3D printers use. Then, the prototype is created in the software and the supports necessary for printing are generated. The supports that were auto-generated by the software always clogged up key points on the prototype, so they would have to be moved to areas on the device where they could be removed without compromising the structure of the prototype itself.

Once the design was prepped for printing on the Preform software it had to be converted to the preform file type in order to give the printer the command to print. Once the file was converted, a simple informational file was filled out that detailed the type and amount of material that was to be used so the worker's in Makerspace knew and could keep track. Then, the 3D printer was linked to the computer system and the print started. Post print procedures included wetting down, and then heating the newly printed plastic piece.

- GUI and software development

The software for the camera interface was written to be simple, convenient, and intuitive for the user to control the camera. The graphical user interface (GUI) was also written for the camera parameters to be rapidly changed to shorten the total dental operation time. The interface allows the user to control brightness, saturation, contrast, and light sensitivity along with the ability to take a screenshot of the patient's teeth if necessary. These parameters were found to be vital for obtaining a clear picture in varying light conditions.

The electronics were controlled by a raspberry pi because it is cost effective and easily modified to allow for simple design and prototyping. The program was written in python to utilize two programming libraries that python provides. OpenCV is an image processing library [9] and composed the code structure between the GUI interface, and the camera. Tkinter is a GUI software package for python [10] and was implemented because it had convenient functions for building and controlling the graphical user interface. Tkinter was used for the frontend, and OpenCV was used for the backend. The software was designed by first placing the software packages into the same python virtual environment, which allowed for both of them to be accessed by the dental scope python project. The project used three classes; one controlled the camera interface, one controlled the GUI, and one was the driver class that initiated the camera and GUI class.

Final Prototype

Camera Mount

______After several iterations based on Design 5, the final prototype (Figs. 8 and 9) was created. The basic design is very similar to the proposed final design, with the exception of the 3 modular lock-in ports located on the top, left, and right of the camera mount (Fig. 10). This feature exists to ensure that the user of the device is able to perform restorative surgery regardless of what side of the mouth the operation site is on; if it is on the left side of the mouth, for example, then the dentist can simply move the camera and attachment (Fig. 11) to the right side of the dental drill and proceed unhindered with the operation.

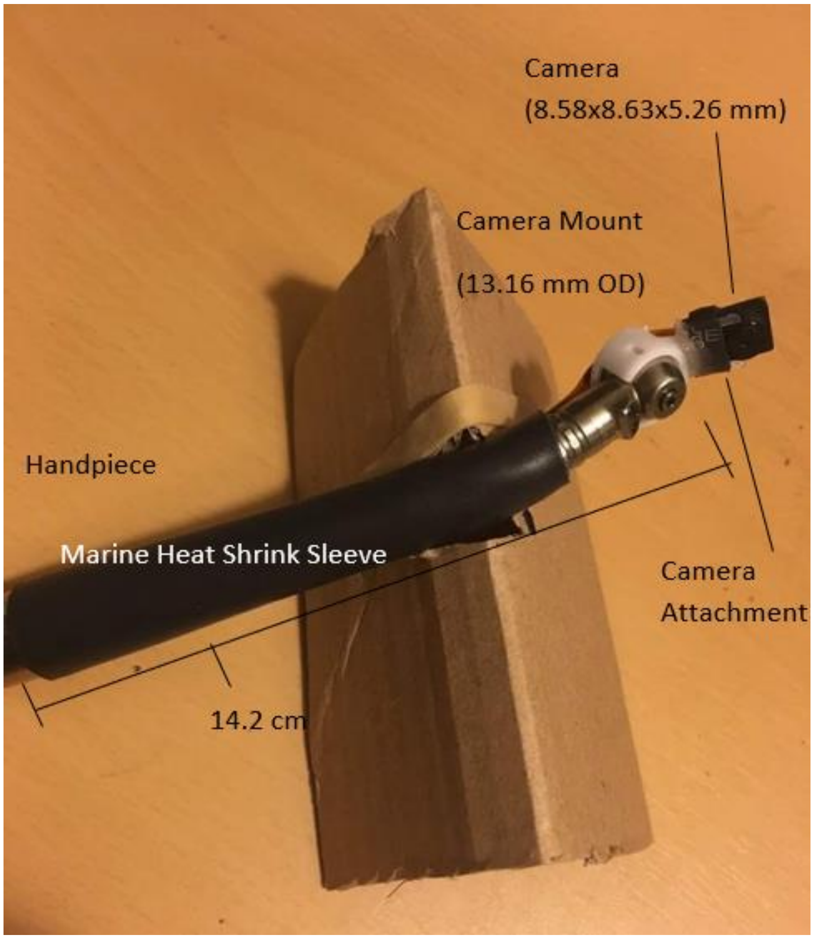

Figure 8. Completed prototype design focusing on the dental handpiece attachments. The 3D-printed parts can be seen on the right side of the image, supporting the camera.

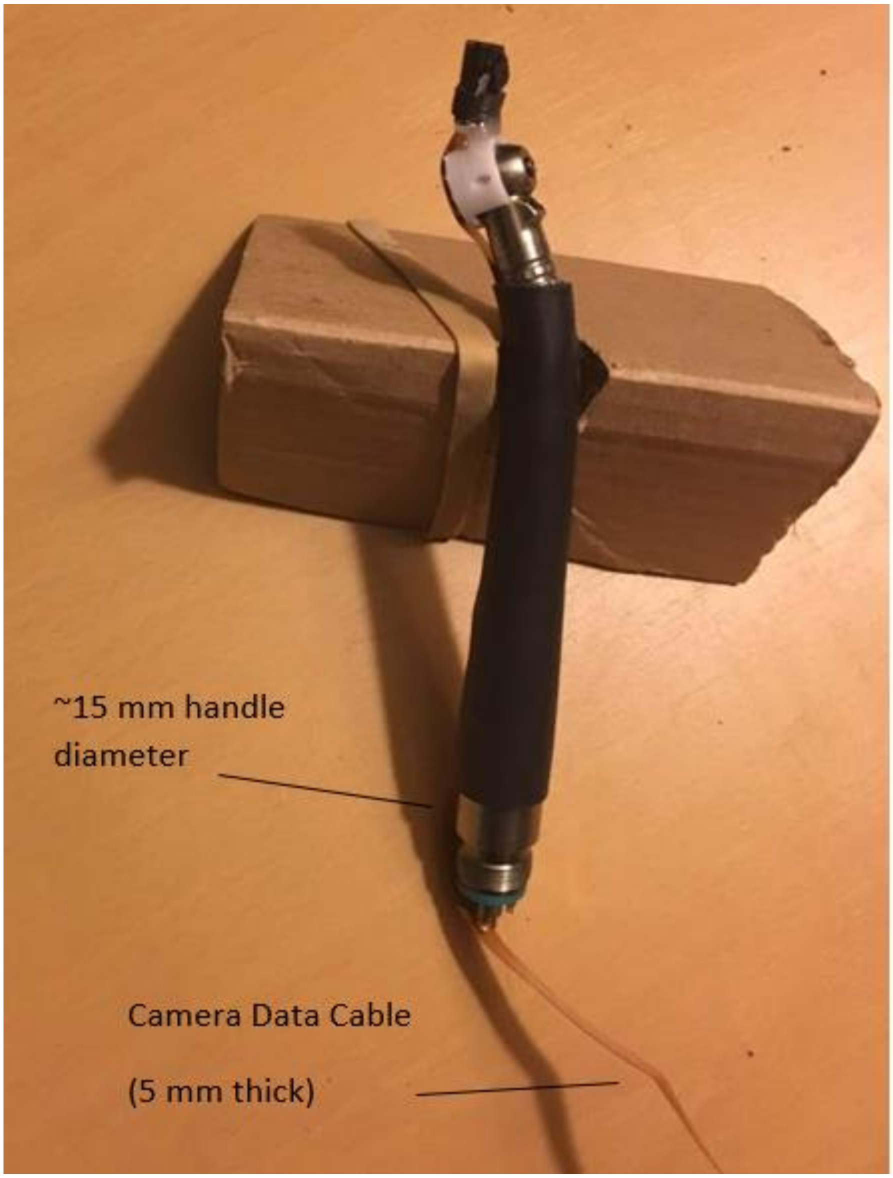

Figure 9. Vertical viewpoint of the final prototype design focusing on the base and data cable.

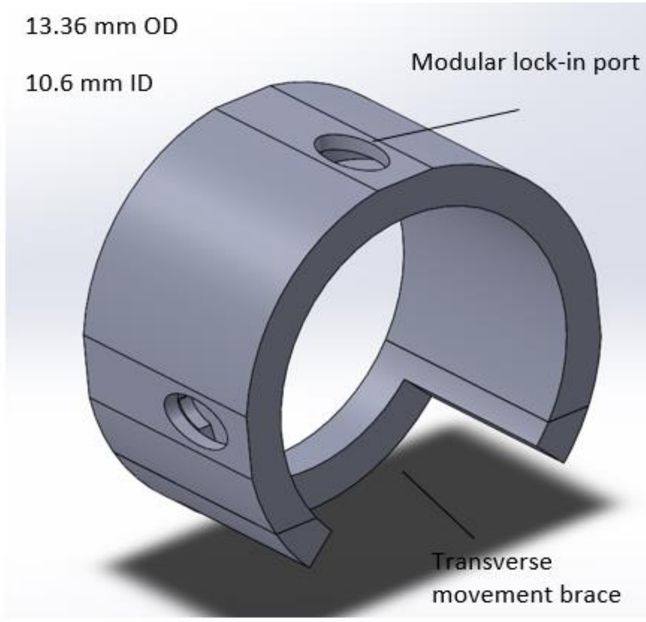

Figure 10. SolidWorks rendering of camera mount featuring modular lock-in ports. The camera attachment can be inserted into a port and rotated clockwise to lock it into place. There are three of these ports to facilitate camera placement in locations convenient for the dentist depending on what side of the mouth the dentist is operating on.

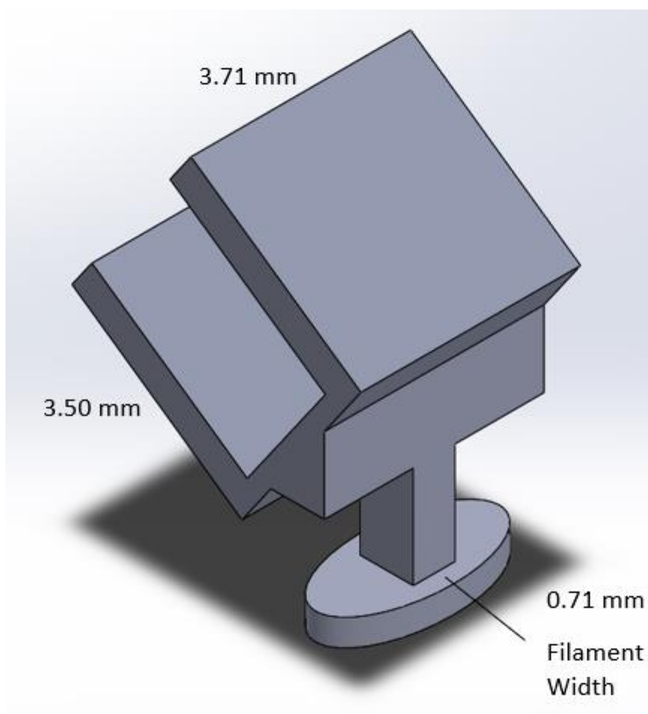

Figure 11. SolidWorks rendering of camera attachment. The oval piece on the bottom of the part can be inserted into ports on the camera mount, allowing it to be turned and locked in place.

Screen/Coding

The GUI was displayed on a 7" touchscreen display, which allowed for the most convenient and easily accessible interface for the user and can be seen in Figure 12 below. The program had scale bars for the brightness, saturation, contrast, and light sensity. A reset button was provided to reset the camera parameters to normal indoor lighting conditions. The live feed of the camera was displayed at 540x540 pixel resolution at 10 frames per second. 10 fps was chosen instead of a higher rate because a slower frame rate meant the exposure time was longer, which would work better in the low light operating conditions, and prevent overheating of the Raspberry Pi due to excessive CPU usage.

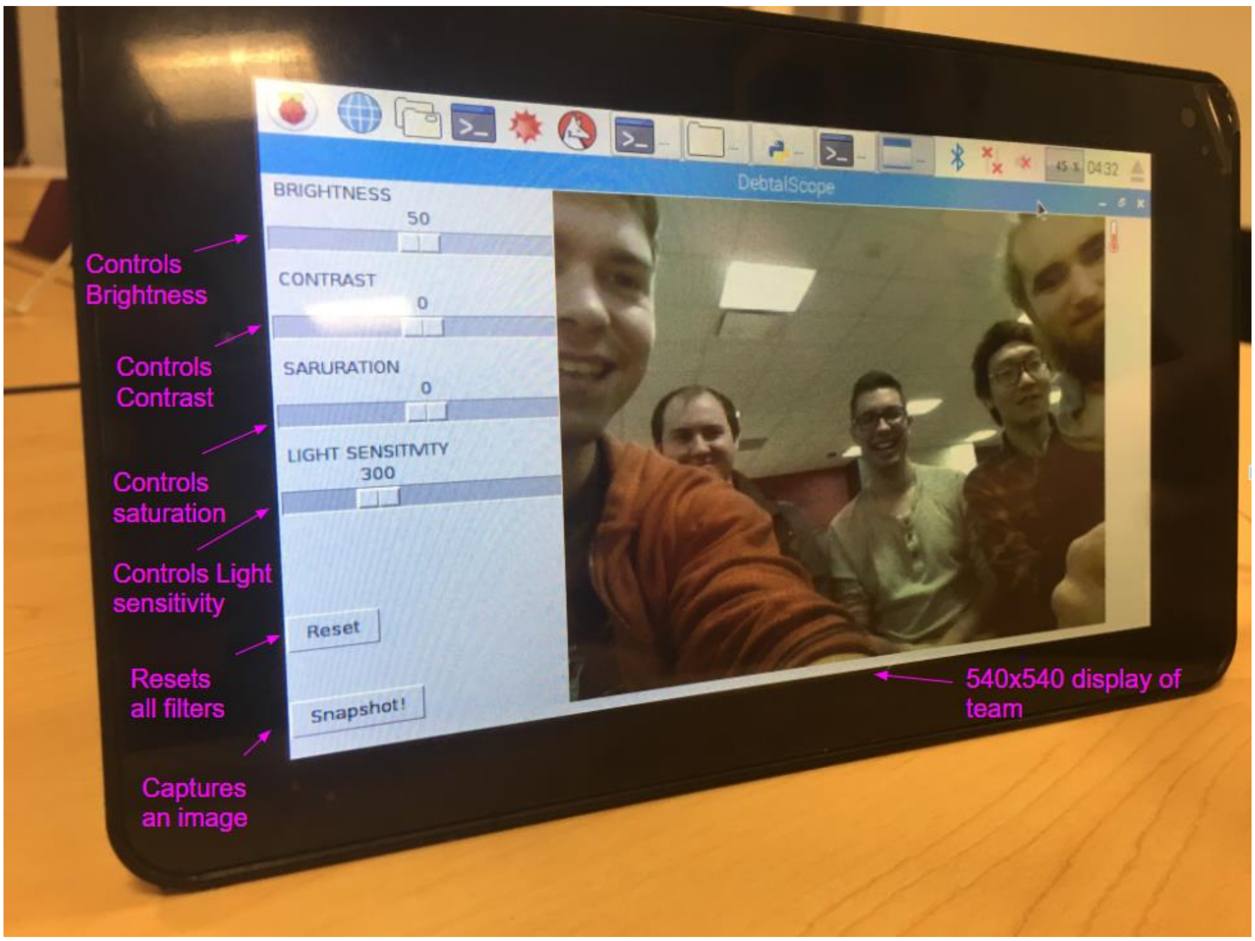

Figure 12. The 7" LCD touch screen display showing the GUI and dental scope operation. The left side of the display shows a 540x540 image of the dental scope capture stream. The right side of the image shows the different parameters that can be set for the camera live stream.

The flow of information between the GUI and the camera can be seen in the flow chart labeled Figure 13 below. The camera class communicates between the GUI and the camera software to control the camera parameters, and Tkinter communicates between the user and the camera class through the GUI. The GUI class controls what the operator sees and monitors what the user inputs while the camera class communicates with the hardware to receive an image and change camera parameters.

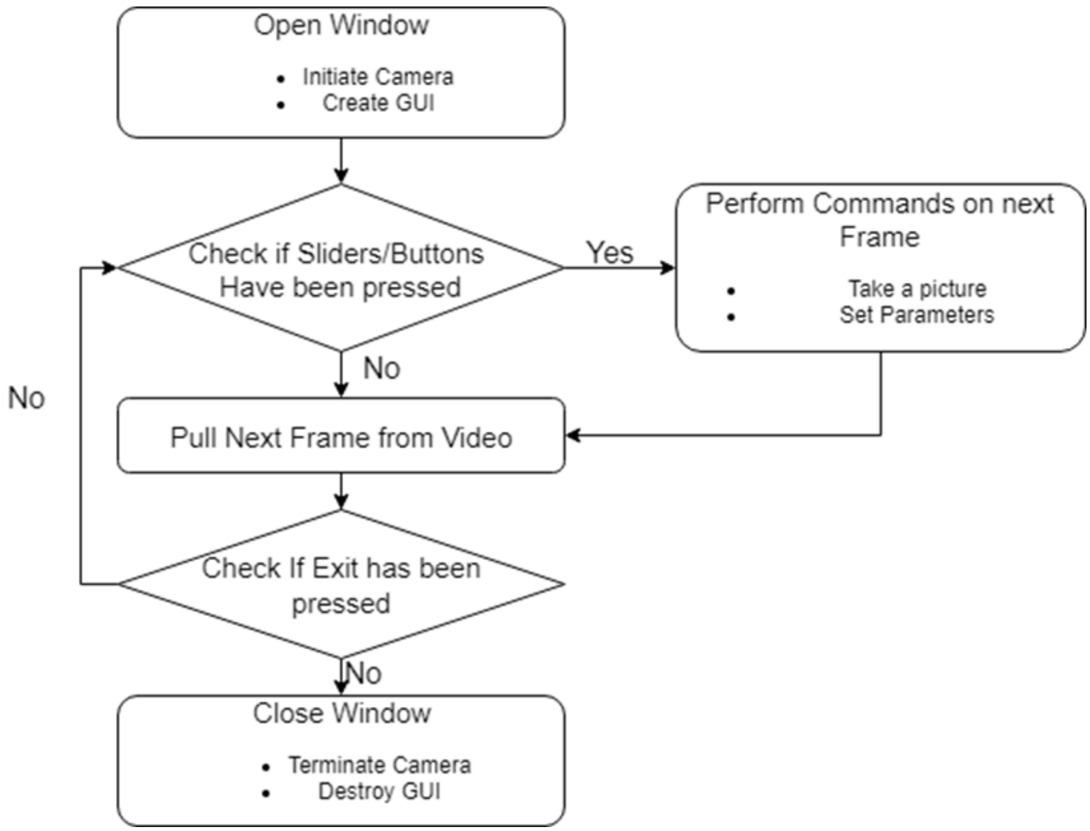

Figure 13. A flowchart of the flow of information in the software design. The driver class opens the window and initiates the other two classes. The GUI receives commands from the user and sends this information to change the camera parameters in the camera class. The camera class takes images from the camera and sends them to the GUI to be displayed.

<u>Testing</u>

______To test the resilience of the form II plastic against amylase, we used a test piece of the plastic and submerged it in a solution whose amylase concentration approximated that of human saliva. Human salivary amylase concentration can reach approximately 1,500 DU/mL on the high end of the spectrum and thus, this was our target amylase concentration (note that SKBU and DU are equivalent FCC units for amylase) [12, 13]. This was done by combining the powder of CapraZyme® digestive supplement capsules, which contain a variety of digestive enzymes including amylase, with deionized (DI) water. As each capsule is reported to contain 4,500 SKBU of amylase, the solution concentration of 1,500 DU/mL was achieved by adding 1 capsule for every 3 mL of water. The solution was stirred on a hot plate set to 35°C to better mimic the flow of saliva and the ambient temperature of the human mouth. The plastic piece was left in the solution for one hour with pictures being taken of the piece at five minute increments to monitor for visible degradation before the end of the trial. For the complete testing protocol, see Appendix C.

Results

The test piece used was the base plate from the 3D printing of the final prototype. The supports were trimmed off with scissors and the piece was filed into an approximation of a rectangular prism with dimensions 10mm by 10mm by 3mm. The mass of the piece before testing was 0.23 g. After the testing was complete, the testing piece had identical dimensions and mass measurements but had been turned yellow. The lack of mass reduction indicates that degradation was negligible over the course of the testing period. The yellow discoloration was likely due to dyes or other components of the CapraZyme® capsule powder because the powder was tan-yellow in color. However, since saliva is not yellow or tan in appearance, this component and its associated discoloration are not likely to be a observed in oral applications. To view the images of the test piece before testing, after testing, and at testing checkpoints, see Appendix D.

Discussion

Based on our enzyme resilience testing, the design is able to withstand the internal environment of the mouth, at least for the duration of one operation. The 3D-printed parts did not degrade, so it can safely be concluded that they do not pose a toxic threat to patients. This means that it should be safe to implement the camera mount and attachment in actual restorative dentistry operations. However, it is important to recognize that much research and testing remains before any definitive steps can be taken towards implementing the full device in actual surgeries. Throughout all testing procedures, proper precautions must be taken to ensure compliance to the standards and ethics of modern engineering.

Without the use of human testing during the prototyping and design phases, ethical issues would mainly arise during use of the product while performing restorative dentistry procedures. Such examples of this could be small cuts and abrasions caused by the camera apparatus basically anywhere in the mouth. This doesn't exactly quantify as an ethical problem as most incidental cuts won't lead to long-term, life affecting problems, but such safety factors should certainly be considered when moving forward with future work on the device. Wounds could get infected, there could be material in the camera, the heat shrink, or the plastic that people's bodies react poorly to, causing life-harming problems. The major ethical issue this prototype poses is the degradation of the plastic in the mouth. It is extremely difficult to test long term exposure to conditions that the device would encounter during repeated use in the human mouth. Therefore, it is possible that after a long time of being used the plastic could begin to degrade during use, leaking potentially harmful substances. Certainly, the knowledge of putting something that could possibly cause extensive harm into numerous patients' mouths poses an ethical dilemma.

Based on these considerations, future design alterations would have to include procedures ensuring the total resilience of the camera mount and camera attachment, and the heat shrink protecting the camera itself, to any kind of detrimental chemical leakage resulting from contact with the internal conditions of the mouth. If this is not possible, then it must be determined, at the very least, the number of operations the parts can endure before such leakage occurs. After these questions are answered, then patient trials can start to be considered.

One possible source of error in the testing protocol is the fact that the solution used was not pH buffered or set to natural saliva pH levels, meaning the lack of degradation may be due to amylase inactivity because the solution pH was outside the amylase functional pH range. Another source of error may be that the test piece's surface area was not very close to the approximation of a rectangular prism, potentially resulting in changes of dimensions that went unrecorded. Finally, the digital scale used to measure the mass of the piece before and after testing had only two decimal places displayed, meaning there may have been slight degradation that was not recorded. While this degradation may seem negligible, over the course of many procedures performed multiple times per week, such degradation may accumulate and compromise the structural stability and/or sterilizability of the product. The sterilizability of the product may be impacted by degradation that forms small pits in the surface (relative depressions) that can serve as sites for bacterial colonization.

Conclusions

During Restorative Dentistry procedures on hard to reach teeth, dentists have to rely on using mirrors along with their intuition. Our team sought to solve this problem by creating a camera holding apparatus that provides a live look on to the desired drilling site. We were able to create a system that attached a small, functioning camera to the head of the drill giving a live look on to the tooth. In the end, we had trouble implementing our locking system into the mobile piece that held the camera head itself. We ended up having to epoxy it onto the collar component of our design. However, our locking system on the collar component worked well and there was no movement or slipping of the apparatus. There were also problems with the initial material ordering process. The first order for the Raspberry Pi camera was not delivered or was lost in between delivery and pick-up. Calls were made to all of the people involved including the company we purchased from and UPS, but the package could not be located. For all future orders we made sure to be waiting at the delivery time in order to avoid future lost packages. Next time, we would've liked to spend more time researching the materials that we ended up using. We kind of got caught up in focusing most of our research onto waterproofing solutions rather than focusing on the plastics we were going to be using for the bulk of our fabrication. In the future, we also hope to be able to find extenders for the raspberry pi that don't start to burn while being used to power the camera. Another major goal would be to create an arm with six degrees of freedom to allow the dentist to move the touchscreen almost anywhere in the operating room. We also would like to refine our camera and operating system to promote higher definition imagery.

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Appendices

Appendix A: Product Design Specification

Function:

The dental handpiece scope should consist of some optical device with the ability to take visual information from the operation site in a dental crown replacement, and project it onto a screen for the dentist to view, while being attached to the dental handpiece. This visual aide should be detailed enough to assist the dentist in completing the procedure with full view of the operation site, increasing the overall safety and efficiency of the technique.

Problem Statement:

During crown implant procedures, dentists are often confronted with difficulties viewing the teeth of interest. They may observe the location of the operation site and the hand piece with a mirror, but depending on the size of the patient's mouth and the location of the teeth, viewing can be nearly impossible, forcing the dentist to rely on intuition to complete the procedure. A camera capable of showing a live video feed of the operation site could remove this difficulty, allowing dentists to operate without the risks associated with blind handpiece use.

Client requirements:

- Create a small uninvasive camera to mount on top of a dental, drilling handpiece in order to make hard-to-see teeth visible.
- The main focus of the project is to create a functioning camera mounted on the dental drill.
- The device can be made of hard plastic, or stainless steel.
- The camera needs to be able to project a live video feed onto a TV screen.
- The camera and surrounding equipment needs to be able to be put into a human mouth without causing harm to the patient or the camera.
- The camera needs to be able to see through water mists and splashes coming off the teeth.
- The camera will need to be waterproof.

- If initial design prototypes prove to be successful, the client would like us to integrate wiring directly into the dental handpiece rather than down the side.

<u>Design Requirements:</u>

1. Physical and Operational Characteristics

a. Performance requirements:

- The dental scope must be able have adequate spatial resolution to capture details of the tooth.
- Must be able to differentiate between the white/grey enamel and yellow dentin of the tooth.
- The chassis must be able to fit on the drill with a minimal size profile.

b. Safety:

- The electronics should not cause electrical shock to the user or patient.
- The device should not have sharp/rough edges that cause unnecessary damage to surrounding gums or soft tissue.
- The dental scope must be sanitizable to prevent bacterial growth.

c. Accuracy and Reliability:

- The dental scope must be able to accurately provide a view of the desired location on the patients tooth.
- The camera must be able to have an accurate autofocus to maintain a clear image of the tooth.

d. Life in Service:

- The device must maintain its structure and function over many daily uses.
- The electronic systems must be resilient for repeated use without breakdown.
- The device should work reliably during normal use for the same period of time as the drill it is attached to.

e. Operating Environment:

- The Camera and electronics must be waterproof to withstand the saliva and water jet during drilling.
- All components must withstand the vibrations from the drill.

f. Ergonomics:

- The camera must not add too much weight to the dental drill handle, reducing the drill's ease of use.
- The camera must interface securely and minimally with the dental drill to ensure waterproof characteristic and reduce the external profile of the camera apparatus.
- The housing of the camera must not cause discomfort and injury to the patients.
- The camera must be fixed rigidly with the drill to prevent disassembling of the camera.
- The shell for the wire that powers the camera must not make the drill hard to handle.

g. Size:

- The camera needs to be able to fit on top of the drilling handpiece without being too bulky as to interfere with the dentists' ability to drill the tooth. 5x5 mm.

h. Weight:

- The camera apparatus needs to be light enough as to not offset the weight and balance of the drill a considerable amount. 2-3 ounces.

i. Materials:

- Glass and stainless steel/plastic for the camera apparatus.
- Hard plastic for the housing of the camera.

j. Aesthetics, Appearance, and Finish:

- Skin safe coating and material for use inside the mouth.
- The apparatus should visually present itself in a way that could cause discomfort to patients. It should integrate nicely with the design of the dental handpiece and not stand out.

2. Production Characteristics

a. Quantity: 1 (prototype).

b. The total cost of the device should be less than $250.

3. Miscellaneous

a. Standards and Specifications:

- No international or national standards need to be met while the device is in the prototype phase of the design process.

b. Customer:

- Customers (practicing dentists) would desire a camera with a minimal external profile to reduce the amount of additional space required to use the drill in a patient’s mouth. They would also want the camera to be waterproof and water-repellant to ensure circuitry security and unimpeded view.

c. Patient-related concerns:

- The device must be sterilized between uses (along with the dental drill) and must be stored in the standard dental drill holder connected to the dentist’s chair.

d. Competition:

- Dental drill integral camera and optics (US5049070A).
- Handpiece with built-in camera and dental treatment method using said handpiece (EP2891467A1).
- Electronic video dental camera (US5251025A).
- Imaging device for dental instruments and methods for intra-oral viewing (US20120040305A1).
- Video dental medical instrument (US5634790A).
- Dental handpiece with observational function (JPH0956730A).

Appendix B: Materials List

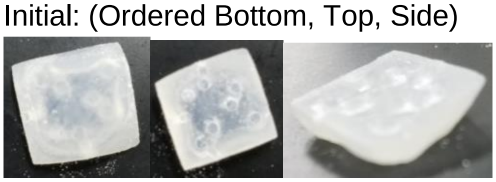
Date of Purchase	Total Spent	URL of Website Bought On	Items Bought	Order #	PIDs	Paid For By	MoP
10/29/2018	$61.85	https://www.adafruit.com/c	Spy Camera for Raspberry Pi, Flex Cable for Raspberry Pi, Cable extender for Raspberry Pi		1937, 214	Joe	Credit Card
11/12/2018	$80.63	https://www.adafruit.com/c	Spy Camera for Raspberry Pi, Flex Cable for Raspberry Pi, Cable extender for Raspberry Pi		1937, 214	Joe	Credit Card
11/29/2018	$48.94	https://www.amazon.com/g	Amylase for spit testing, touch screen case for raspberry pi touch screen	112-1174202-7583412		Joe	Credit Card
	$68.98	https://checkout.microcente	Raspberry pi touch screen	7969263	862243	Joe	Credit Card
11/30/2018	$20.77	https://shop.harborfreight.cc	Heat Shrink wrap	107484192	67598	Joe	Credit Card
	$281.17					Budget: $1000	

Appendix C: Testing Protocol

1. Record the necessary dimensions to calculate surface area of the test piece of plastic (or just the surface area)
2. Weigh the test piece and record the mass
3. Take a picture of the test piece
4. Open 10 CapraZyme capsules and put the powder in a weigh boat or a flask/beaker
5. In the flask/beaker, add 30 mL DI H_2O and a stir bar to the CapraZyme powder
6. On a stirring hot plate, set the temperature to 37 °C and stir the mixture vigorously until all of the powder is suspended in solution
7. Reduce the stirring speed and add the test piece to the mixture
8. After five minutes (or less if notable change has occurred) remove the piece from the mixture and take a picture for records
9. Repeat step (8) twelve times (1 hour total)
10. Thoroughly rinse the test piece with water
11. Record the piece's surface area or associated dimensions
12. Record the mass of the test piece

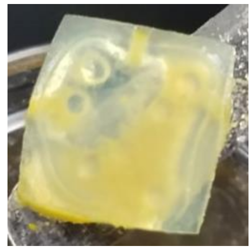
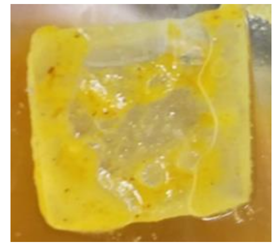
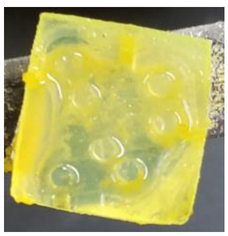
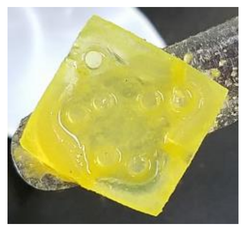
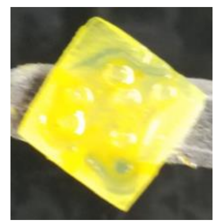
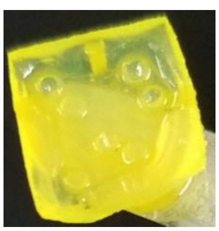
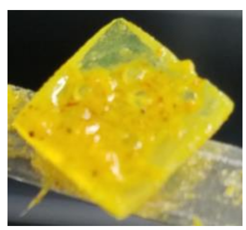
Appendix D: Testing Images

- Initial: (Ordered Bottom, Top, Side)



- Checks (once every 5 minutes):

1	2	3

		
4 	5 	6 
7 	8 	9 
10 	11 	

- Final: (Ordered Bottom, Top, Side)