

# Dual Handheld and Video Functional Otoscope for Veterinary Educational use

Sam Tan, Andrew Slayton, Haoming Fang, Aaron Marattil

Department of Biomedical Engineering, University of Wisconsin - Madison

The dual handheld and video otoscope project is a device that aims to improve the otoscope training process for students in the University of Wisconsin-Madison School of Veterinary medicine. An otoscope is a medical device used to evaluate the ear canal and eardrum using illumination and a speculum inserted into the ear. Traditional otoscopes use magnifying lenses to display an image to a user, limiting the viewing party to one. Some modern otoscopes use a camera to provide live video playback to display the image to the user on a small screen on the otoscope. Neither design allows for real-time supervision by an educator during training by the student at the same time. The dual handheld and video otoscope device aims to facilitate this real-time supervision by incorporating video streaming to an external monitor. Previous iterations of the device, developed by earlier teams, featured a beam splitter to provide both optical and video views, but suffered from insufficient illumination and lack of wireless functionality. The current project improves on these aspects by incorporating an optical fiber system for brighter, more focused lighting and a wireless camera for enhanced ease of use. Additionally, the new design maintains the essential features of a traditional otoscope, ensuring seamless transition for veterinary students. The ongoing development aims to improve device durability, enhance illumination, and implement wireless streaming capabilities.

# Introduction

## Motivation

Existing handheld otoscope designs in veterinary practice either lack the ability to stream live video during examinations or sacrifice the traditional lens view, which is crucial for hands-on simulation training. The goal of this project is to improve upon the previous design by developing a more robust handheld otoscope that integrates wireless live video streaming while maintaining the traditional optical view. The device will allow faculty to monitor and assess student-performed examinations in real-time. Additionally, the design will be refined to enhance its durability and lighting, addressing issues identified in the initial prototype.

The integration of live video capabilities into a traditional otoscope design has the potential to significantly enhance the training of veterinary students in otoscopic examinations. Currently, training relies heavily on the use of live animals, which can be both challenging for students and stressful for the animals, especially without adequate guidance. The new design allows for real-time feedback from instructors, enabling students to refine their techniques with greater accuracy and confidence. This minimizes the risk of causing discomfort or harm to animals during training. Additionally, the ability to record and playback examinations offers students the opportunity to review procedures in detail, further improving their understanding of otoscopic diagnosis. By reducing reliance on live animal practice and enhancing the overall training process, this innovation contributes to better veterinary education and improved animal welfare, ultimately leading to higher standards of care in clinical practice globally.

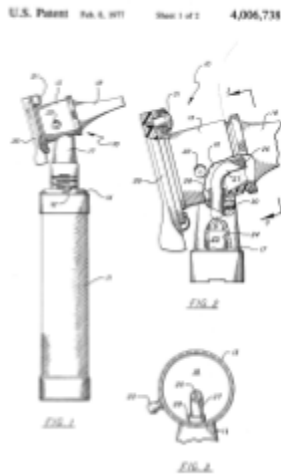


Figure 1: Structures of Handheld Otoscope [1]



Figure 2: EndoWorld Video Otoscope [2]

Current methods and devices for otoscopy training primarily involve the use of handheld otoscopes, as shown in Figure 1. These traditional devices are widely utilized in clinical settings but have a key limitation: they do not allow instructors to provide real-time assessment and feedback. As a result, trainees often struggle to master the precise techniques needed for accurate ear examinations. Without immediate guidance, they may unintentionally develop improper habits or fail to fully comprehend what they are observing. Additionally, improper use of the otoscope can cause discomfort or pain for the animals.

Video otoscopes, such as the one depicted in Figure 2 [3], present an alternative for otoscopy training. They offer benefits like the ability to record examinations for later review [4] and a slightly higher level of accuracy [5]. However, these devices often operate differently from the optical otoscopes commonly used in clinical practice, which can lead to a disconnect between the training environment and real-world applications. This discrepancy may hinder students' ability to smoothly transition into clinical practice.

# Background

## Design Components

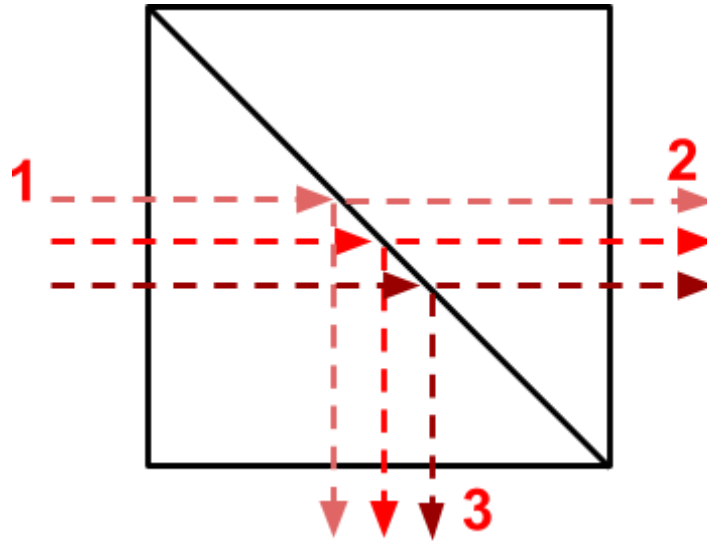


Figure 3: Beam splitter

The beam splitter, fifty percent transparent and fifty percent reflective mirror, is an essential component of the design. This idea concept was first introduced by the work done by the previous team who worked on this project, see appendix A figure i) for prototype references. The beam splitter allows the team to achieve the image duality as requested by the client. Any light/image entering the beam splitter, as shown in Figure 3 labeled 1, will be split into two identical images: one going through the beam splitter, as shown in Figure 3 labeled 2, and can be seen behind the beam splitter. This is crucial to resemble similar features to a traditional handheld otoscope, from the structural design to the way of use. Another image is reflected downwards through the beam splitter, as shown in Figure 3 labeled 3, and this image was captured by a camera placed below the beam splitter that would allow live feed to an external monitor. The next crucial component that allows the otoscope to function in a dual way is the

camera. Previously, the camera used wire and connected to the external monitor in a way that interferes with the user's comfort, as the wiring is semi-rigid that wouldn't allow too much motion and counteract any bending thus not ideal to implement. A bluetooth live feed camera is needed to solve this problem. Such cameras should have high resolution and frame rate to the maximum possible extent, and allow smooth image quality when displayed.

Another crucial component is optical fiber. This is so that there can be an external light source provided by the otoscope when viewing inside the ear canal. The optical fiber is a acrylic or similar transparent material covered by a plastic coating to guide light within the otoscope so that the actual light source, LED, can be hidden within the handle part of the otoscope.

## Design Specifications

The detailed design specifications can be found in the Product Design Specifications in Appendix B. The device needs to have very similar weight compared to the traditional handheld otoscope, and the structural design resembles the traditional handheld otoscope to the greatest extent possible to ensure smooth transition for veterinary students during training and examinations. The ideal weight of the device should be between 0.45 to 0.90 kilograms and size should proceed as outlined in the Product Design Specification as measured and determined based upon the Welch Allyn Pneumatic Otoscope. The differences in image quality and magnification between viewing through the lens and viewing through the monitor should be kept to a minimum to allow teaching faculty to accurately depict their students' performances. The device should include a bright external light source used to assist the camera and to ensure proper video relay ability. The camera used in this device should be wireless.

# Methods

## Materials used

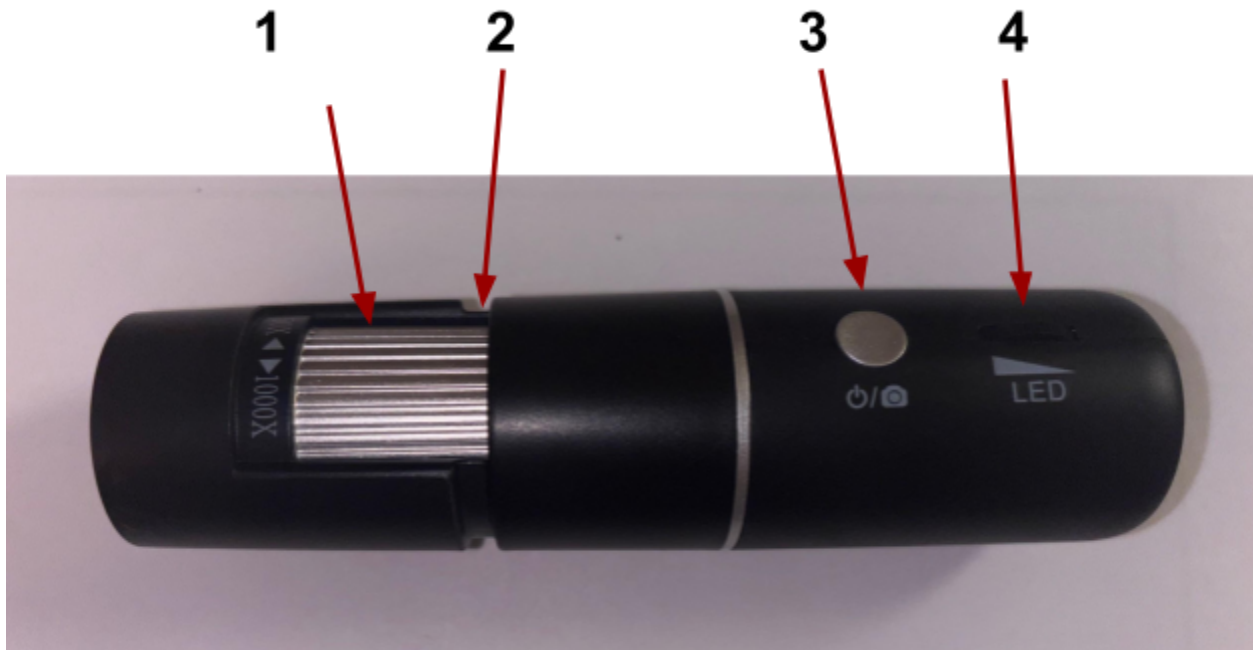


Figure 4- Microscope camera. 1- Manual Focus Adjustment slider. 2- Snap and Lock guiding track for otoscope casing. 3- Camera Power Button/Snapshot feature. 4- LED intensity adjustment

The camera is an essential component of the otoscope. Previously, the team used an auto-focus endoscope camera by Teslong. This camera raised issues as the semi-rigid wires caused discomfort to the user and reports from survey data showed this was one of the major contributions to a lower score of user comfort. The auto-focus feature also caused wrong behavior when using the camera feature. Thus the team this year decided to move towards a wireless option for cameras. The team chose the Wireless Digital Microscope Handheld Camera by Takml [6], as shown in Figure 4. This camera has a manual focus camera and is compatible with the iPhone and multiple desktop/laptop interfaces. The greatest resolution achievable by this camera is 1980x1080. The beam splitter is another key component to allow for the dual feature

of the otoscope. The beam splitter, as mentioned in an earlier section, is a fifty percent transparent and fifty percent reflective (50R/50T) glass cube that is able to split incoming images into two directions, allowing for simultaneous viewing of the same image. The beam splitter cube for this otoscope has a side length of 20mm and is able to fit within the otoscope head without altering the overall size of the otoscope. The team determined that 50R/50T would result in the most accurate image in the camera when compared to when looking straight into the lens part. Another very important material of the otoscope is the optical fibers. This is used to correctly guide light sources to the tip of the specula. Previous survey results showed that design lacks brightness, thus the team decided to abandon the old LED method and implement the optical fiber to guide a brighter light source within the handle of the otoscope for best brightness. Otoscope casing was done on SolidWorks and 3D printed through MakerSpace. It is determined that PLA-CarbonFiber [7,8] provides the most balanced material properties including stiffness, strength, and toughness. A more detailed expense can be found in the Appendix C.

## Design Process

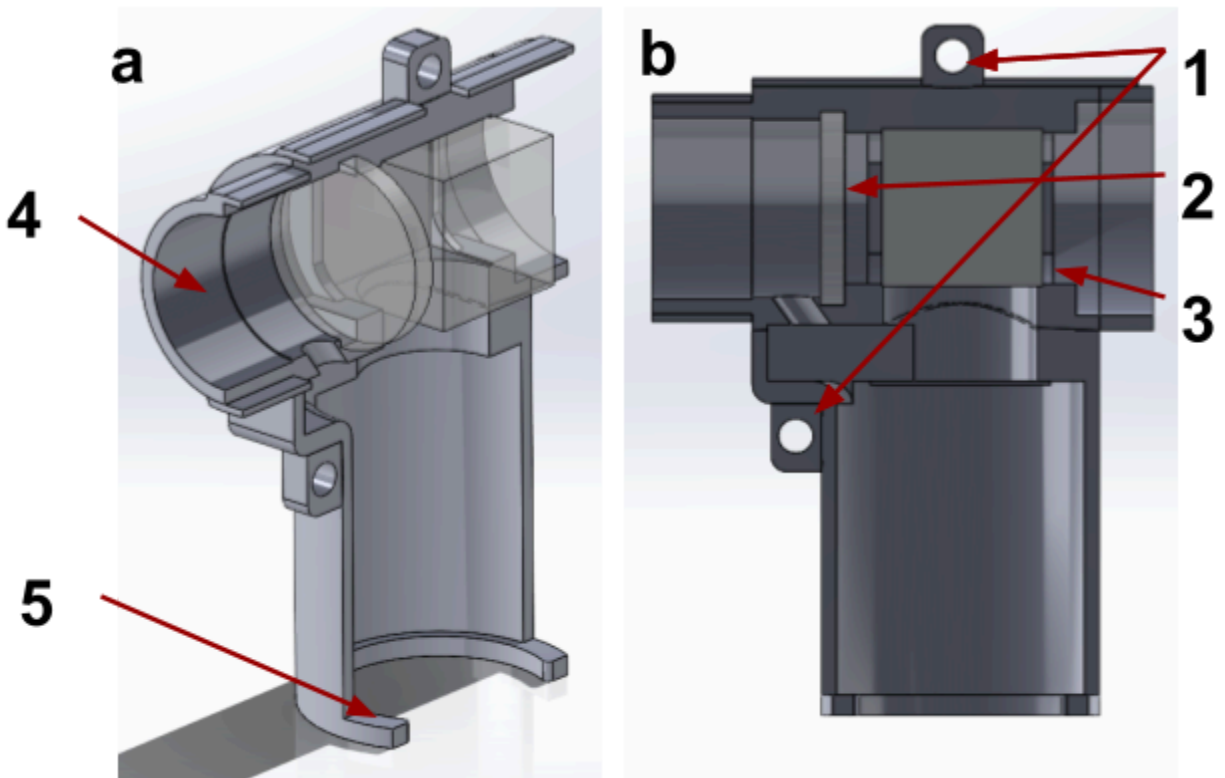


Figure 5: Otoscope SolidWorks model. a) 3D view of the model. b) side view of the model. 1- screw holes, 2- Lens, 3-Beam splitter, 4- Specula placement, 5- Camera snap feature

The beam splitter cube is positioned at the center of the otoscope head, close to the viewing window. The otoscope camera casing is split in half to allow for easier assembly: all components are placed in one half of the casing and the other half is snapped on to create a fully enclosed casing for protection of optical components. Then screws will be placed through the holes designated as shown on Figure 5b,1 to secure the parts. The SolidWorks modeling in Figure 5 above showed the orientation of components that is the most optimal, taking the otoscope shape into account to avoid unnecessary components and structures that could contribute to the bulkiness of the design. The original placement of the lens on the traditional handheld otoscope is behind the lens, however, this is changed due to the magnification on the camera. To allow for accurate simultaneous view of the image, both images have to be magnified



thus the placement of the lens is now in front of the beam splitter, just behind the specula. The otoscope casing has taken into account the size of the speculum and mimics the idea of the traditional otoscope and specula placement as shown in Figure 5a,4. The otoscope casing also has a snap-on feature for accurate connection to the microscope camera, as shown in Figure 5a, 5. This feature utilized one of the guiding tracks on the microscope camera, in Figure 4,2, allowing a snap and lock way of connecting the camera to the rest of the otoscope casing using the indentation originally came with the microscope camera.

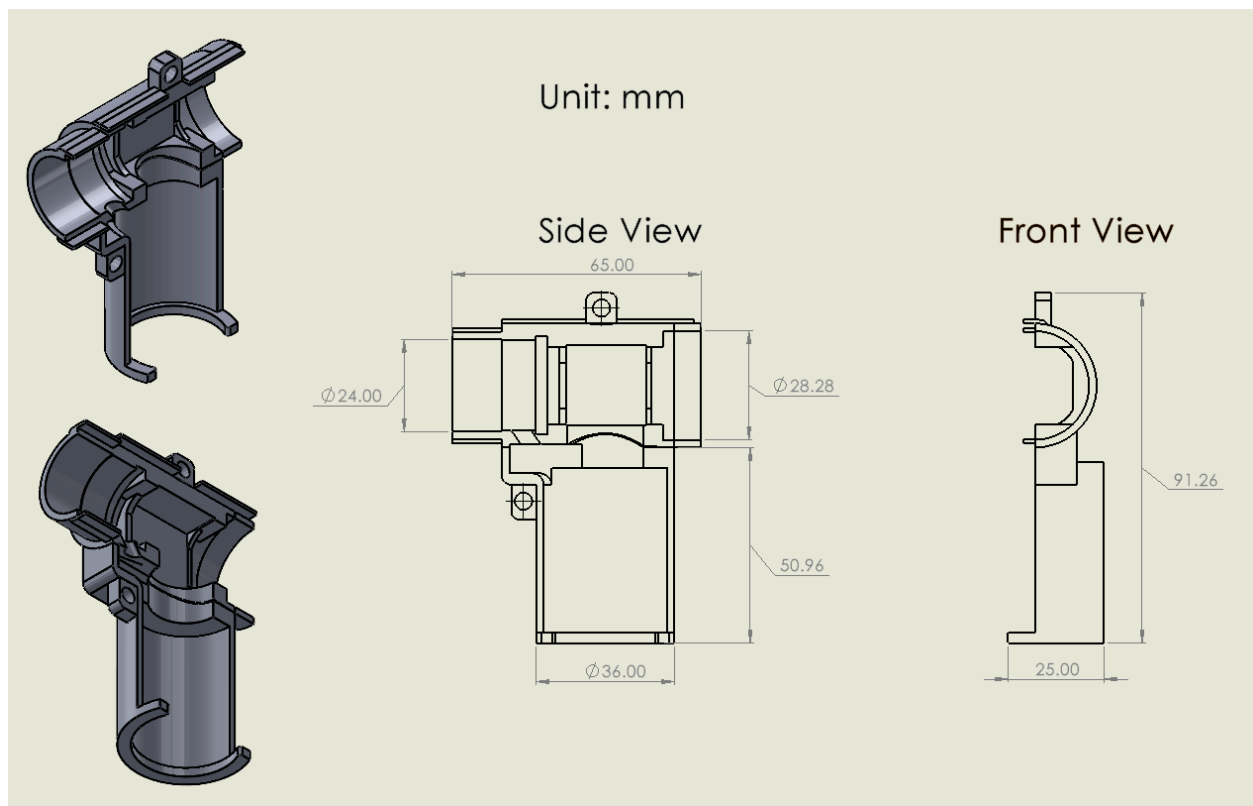


Figure 6- Otoscope model SolidWorks drawing

## Color calibration test



Figure 7, color calibration sheet

The color calibration test was conducted to identify how close the quality of image on the otoscope is, when compared to an advanced camera such as the iPhone camera, which is the ultimate standard for image accuracy. Eight different colors were picked, Red, Yellow, Green, Cyan, Blue, Magenta, White, and Black as shown in Figure 7 above. Their corresponding standard RGB values were recorded. Under the same lighting conditions, a picture was taken using both the otoscope camera and an iPhone camera and uploaded to Photoshop/image analysis software to obtain an average RGB value for each color, from the image on both devices. It was known that due to printing variation, lightning conditions, and other factors, the values obtained this way will deviate greatly from the standard electronic RGB values given by the software without any lightning effected. Thus, the team utilized an iPhone camera as a calibration tool and a standard value to compare to. Through this color calibration test, the team will be able to

identify the image accuracy of the otoscope camera and how different it is compared to an iPhone camera.

## Illumination Brightness Test

The brightness of the otoscope's illumination source was evaluated to address the key feedback from the 2023 prototype, which indicated insufficient brightness during use. Testing was conducted to compare the illumination levels of the 2023 prototype, a standard otoscope, and the newly designed dual otoscope. The results of the brightness testing are presented in figure 15, which displays the measured lux levels for each illumination source.

To ensure consistent and reliable measurements, a photography Lux app from GmbH was used to record the brightness levels. The illumination source was positioned at a constant distance of 6 cm from the sensor during all tests. Measurements were taken in a controlled dark room environment to eliminate any external light interference and ensure accuracy. Ambient light in the room was measured prior to testing and found to be minimal at 11 lux, confirming it would not significantly impact the results. This setup allowed for a direct and unbiased comparison of the brightness levels produced by the three different designs. Through this test, the team aimed to validate the effectiveness of the new illumination system in addressing the shortcomings identified in the previous prototype.

# Results

## Final Prototype

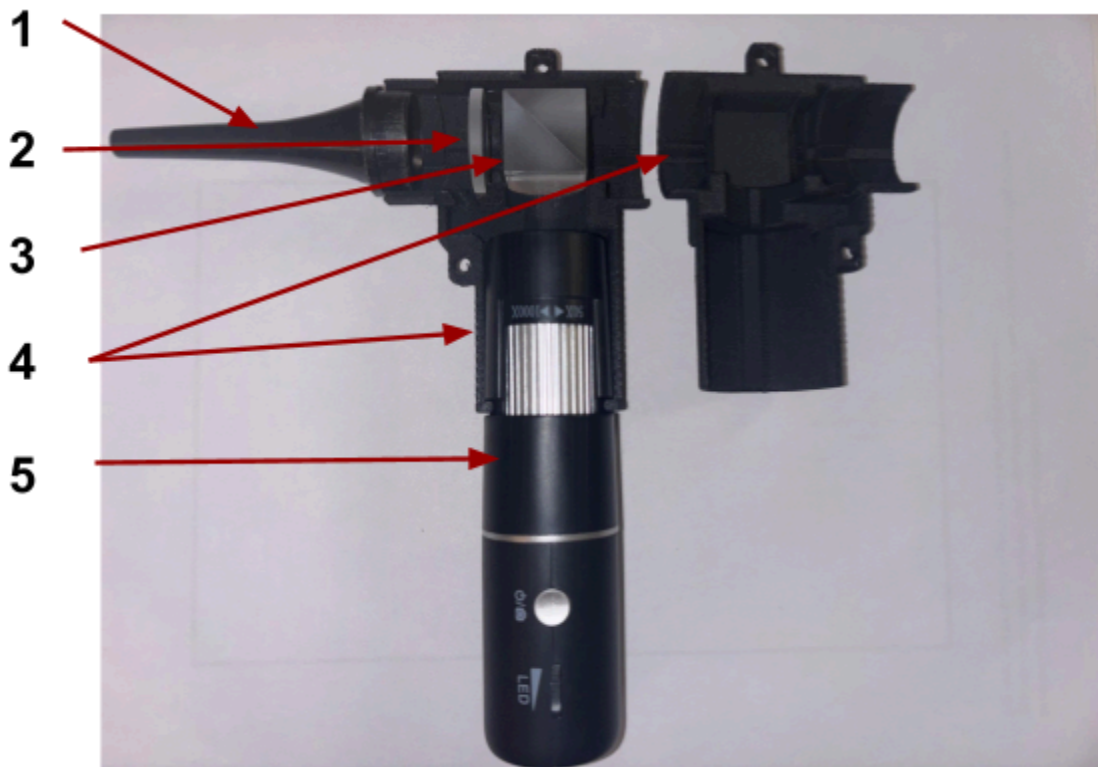


Figure 8 - Final assembled otoscope prototype. 1- Speculum, 2-Lens, 3- Beam splitter, 4- Otoscope casing, 5- Otoscope camera.

The final prototype of the dual handheld and video otoscope is shown in Figure 8. The final design of the dual handheld and video otoscope incorporates several key components, labeled in the image. The device features a speculum at its tip, designed for safe and precise insertion into an animal's ear canal. This ensures accessibility to the examination area while minimizing discomfort for the animal.

A plano-convex lens is utilized to magnify the image, allowing for clear observation through the optical viewing window and for capturing images with the integrated camera. The lens ensures optimal optical clarity for both direct visual examination and video capture.

A beam splitter helped achieve the design's dual functionality. This optical component divides the incoming light, directing a portion of the light (and corresponding image) through the lens and toward the optical viewing opening for real-time observation. Simultaneously, the remaining light is directed downward toward the camera. This configuration allows the practitioner to use the otoscope as a traditional handheld device while capturing live video for instructional purposes.

A significant improvement from previous designs was the replacement of the endoscope camera with a handheld wireless microscope. This updated camera module is equipped with built-in focal adjustment, integrated wireless video streaming capabilities, and an illumination system embedded as a ring of LED bulbs around the camera. These features simplify the overall design by eliminating the need for separate lighting components, as well as the battery unit needed for the lighting. The design also increased usability by keeping all the original adjustable features of the microscope, such as focal range and light intensity.

The optical fiber system is strategically placed to redirect the upward light emitted by the handheld wireless microscope toward the opening of the speculum. This redirection ensures that the light is focused precisely within the animal's ear canal and does not interfere with the image, improving visibility for both optical and video observations.

All components are securely housed within a 3D-printed casing, consisting of two interlocking pieces secured via screws and bolts, with a snap feature to prevent rotations of the camera. The casing is ergonomically designed for ease of use and ensures durability in a

veterinary training environment. The modularity of the casing allows for straightforward assembly and disassembly, facilitating maintenance and potential future modifications.

## Color Calibration Test Result

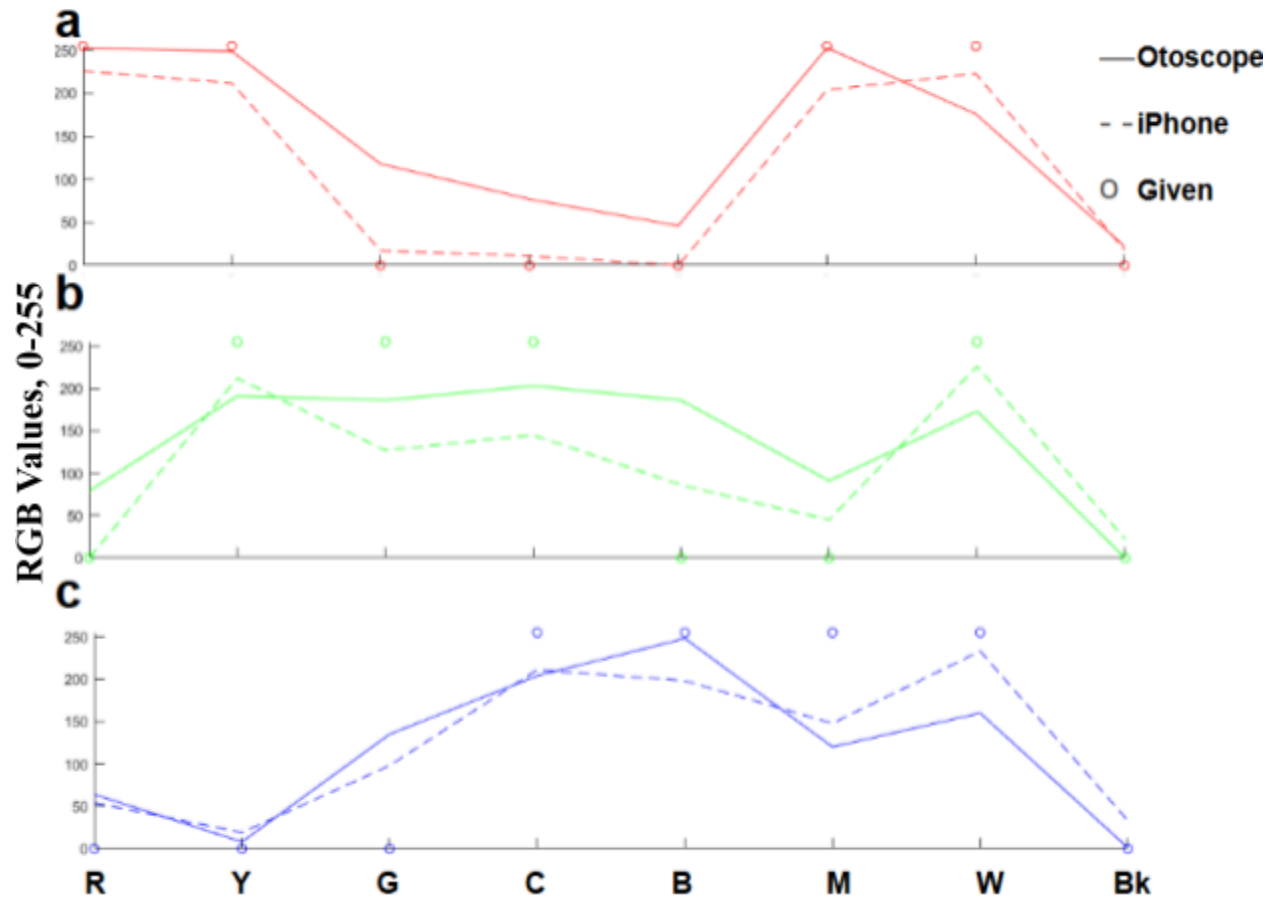


Figure 9, a) R-values, b) G-values, c) B-values. R-Red, Y-Yellow, G-Green, C-Cyan, B-Blue, M-Magenta, W-White, Bk-Black.

The result from the color calibration test, as shown above, was obtained by plotting the RGB values separately on Matlab, for each color tested, by the method of image. The given standard electronic RGB values for each color were plotted as circles for reference. The comparison was made mainly between the otoscope camera and the iPhone camera on each value spectrum, and mainly focused on the magenta, red and yellow range as these colors most accurately depict the color environment that the otoscope will encounter within an ear canal. The

otoscope camera showed a very consistent trend and relatively small deviation to the iPhone camera, indicating some level of accuracy, especially in the Blue values on all colors tested. There are some levels of over-exposure on the otoscope camera, as represented by a higher level of R and G values, indicating that the picture is brighter. When comparing the values on the Red, Yellow, Magenta range, the otoscope camera showed a better performance than the iPhone camera as it is closer to the given R-values, this suggests a good level of accuracy using the otoscope camera under specified conditions when comparing to an iPhone camera. Detailed experimental data can be found in Appendix D.

## Illumination Brightness Test

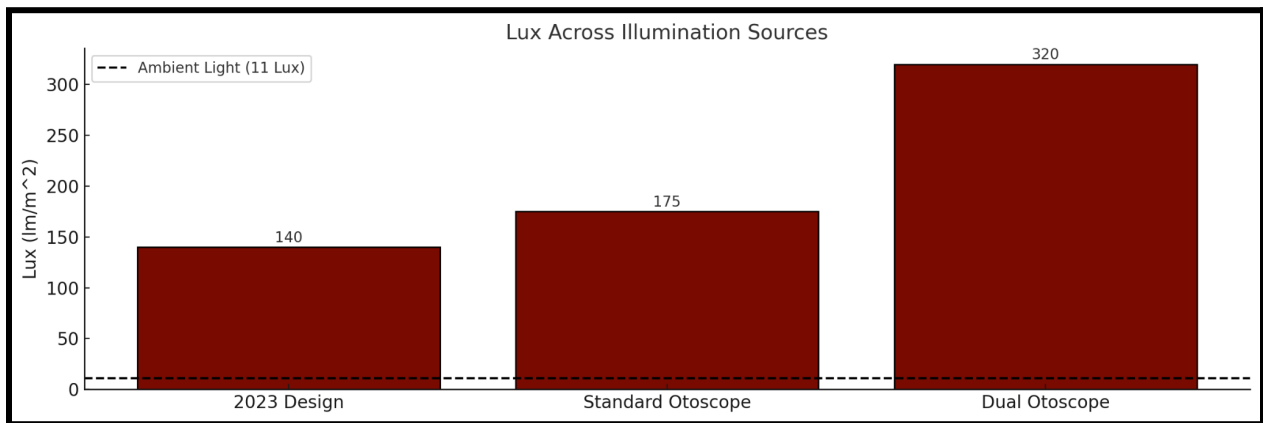


Figure 10, Illumination Source Brightness Testing Results.

The test revealed significant improvements in brightness for the final design, with an illumination level of 320 lux, compared to 140 lux in the 2023 design and 175 lux in the standard otoscope. This substantial increase demonstrates that the newly designed illumination source is capable of delivering adequate brightness for effective otoscopic examinations. Furthermore, the final design features an adjustable illumination control, allowing users to fine-tune the brightness to match the illumination of a standard otoscope when desired. This adjustability ensures

compatibility with various clinical and teaching scenarios, addressing the needs of both veterinary students and instructors.

The enhanced illumination, combined with its adjustability, confirms that the new otoscope design successfully overcomes the limitations of the previous prototype and provides a more effective teaching tool for veterinary education.

## Discussions

While there aren't any direct ethical considerations to adding live video capabilities to a handheld otoscope, there are concerns about the ethics of practicing on live animals. This is common practice to help students learn how to properly use the otoscope and conduct examinations. Additionally, an otoscope examination may not always be what's appropriate for every patient. It's important to take into account a patient's individual circumstances and needs, as well as their cultural and religious beliefs, to best serve them. The American Veterinary Medical Association (AMVA) provides a set of ethics standards for veterinarians to abide by [9]. Relevant ethics codes should be followed to ensure fair and ethical patient interaction.

A Color Calibration test was conducted in order to ensure accurate image quality could be achieved with the handheld microscope. Additionally, a Illumination Brightness test was conducted to determine if the new optical fiber design would be brighter than previous designs. This is an important design requirement that was a shortcoming of previous designs. For both tests, the exact position and orientation of the phone camera or otoscope could have affected the results of the test. Due to human error it is likely that the exact position and orientation was not perfectly consistent between tests, causing inaccuracies in the results. Nonetheless, the device performed satisfactorily in both tests conducted, satisfying the image quality and brightness



design requirements. As such, there are no design changes to be made after testing regarding the handheld microscope or the optical fiber. The design is also wireless, previous designs were unable to satisfy this requirement. One shortcoming of the design is its sturdiness. The device will be used by multiple users and as such must be able to withstand constant use and any drops or accidents. This is something that should be modified in the future.

Looking ahead, this otoscope prototype can serve as a distant diagnosis tool for veterinary use. Considering the videos are live or recorded, with proper internet connection the device can support further tele-diagnosis by health professionals. Such an idea provides more opportunity for teaching purposes or situations where in-person diagnosis isn't permitted. This also has the potential collaboration with artificial intelligence to bring diagnosis further beyond.

## Conclusions

The main goal of the project is to design a novel handheld otoscope with live video capabilities. Currently, handheld otoscopes only allow the user to view inside the ear. This prevents others from double-checking the user's observations or following the examination of the user. This makes it much more difficult to learn and teach proper otoscope examination technique. In order to fix this issue, a new otoscope will be designed, containing a beam splitter and camera to record the otoscopes view. Previous designs fell short of expectations due to a dim LED reducing visibility inside the ear. The best way to resolve this problem is by using an optical fiber. This will allow a larger, more powerful LED to be used without occluding the users view in the specula. The previous design can also be improved upon by implementing a wireless camera which will make handling the device more easy.

Testing shows that the optical fiber does allow for more lux than previous and traditional designs. This demonstrates a significant improvement from a major failure of the previous design. The Color Calibration test determined similar if not improved image quality with a handheld microscope when compared to an Iphone camera.

In the future, fabrication of the final design must be completed. This entails obtaining an optical fiber of appropriate size and securely fixing the optical fiber within the device. Once fabrication of the final design is complete, testing must be conducted to ensure that the otoscope is sturdy and can withstand consistent use. Additionally, surveys should be conducted at the veterinary school, in which respondents are able to use the device and give feedback.

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# Acknowledgements

Dr. Lara Tomich

Dr. Amy Nichelason

Professor Paul Campagnola

# Appendices

## Appendix A: Previously Year Supplementary Designs Models

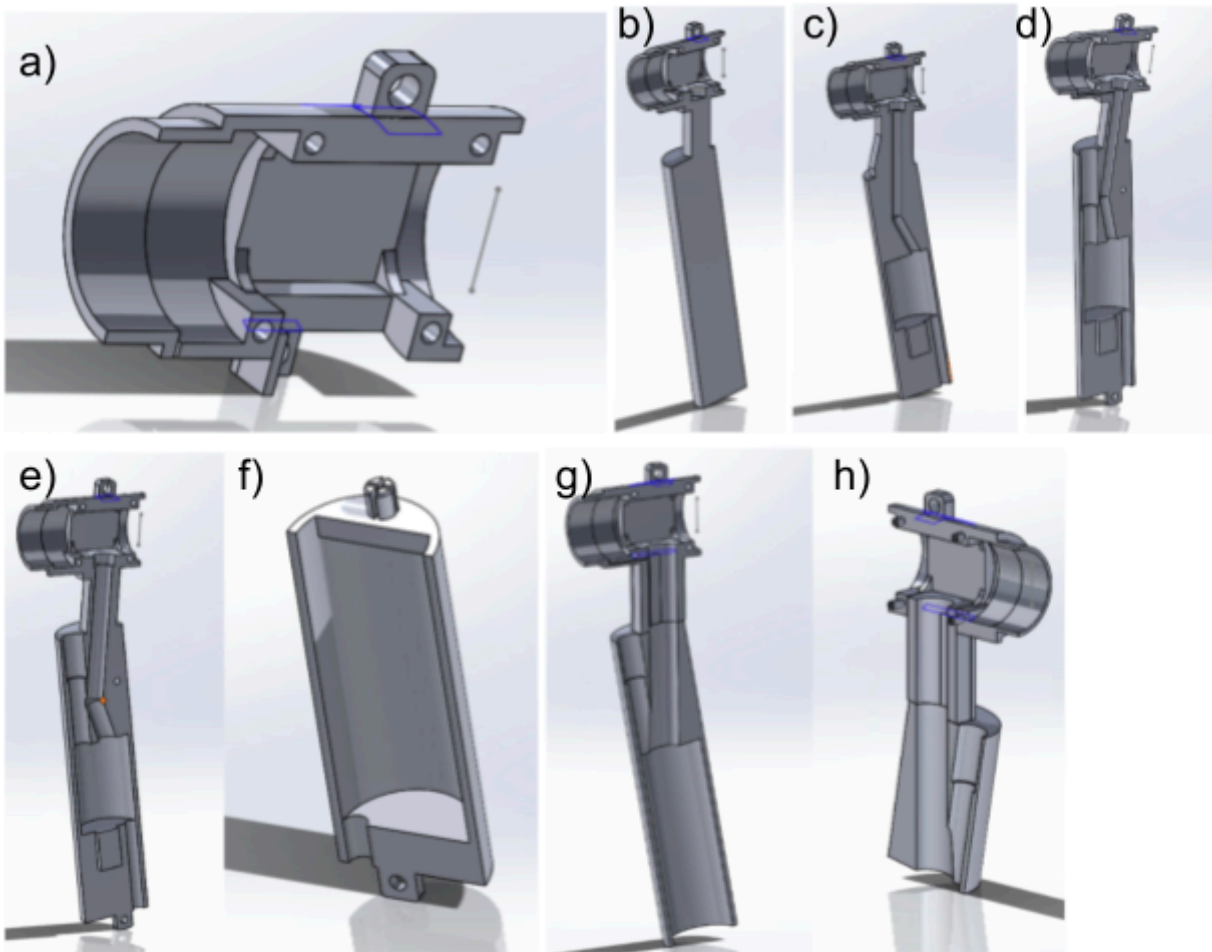


Figure a) Original Otoscope Head Design. b) Otoscope head with otoscope handle. c) Otoscope body with 5.5mm camera track and battery holder. d) Otoscope body with button track e) Otoscope body for 12.5mm camera. f) Battery case initial design. g) Otoscope body alternate design with extra spacing and curve avoided in camera track. h) InitialSymmetrical Cover.

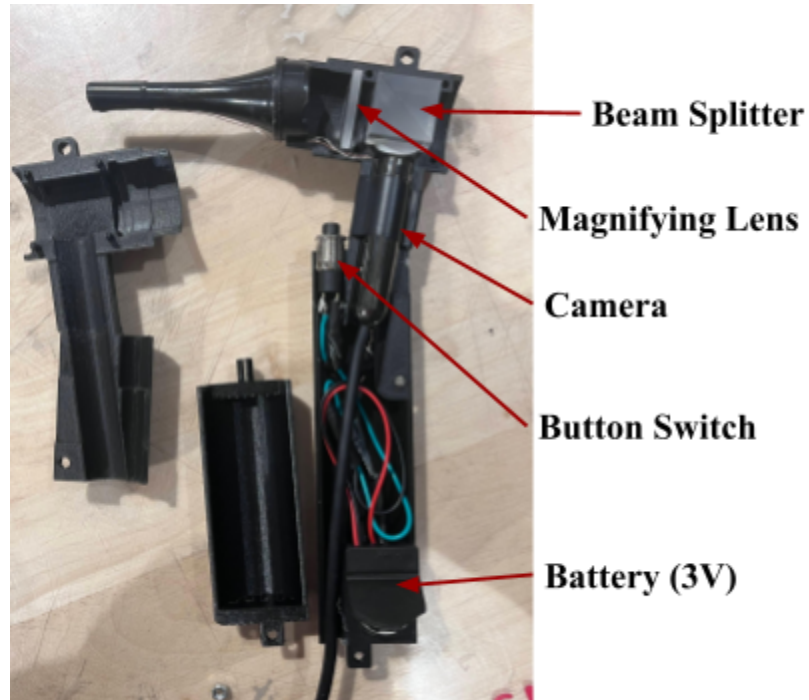


Figure i). Prototype model with labels

## Appendix B- Product Design Specification

Dual Handheld and Video Otoscope - BME 400

Product Design Specifications

September 16, 2024

Team: Sam Tan, Bobby Fang, Aaron Marattil, Andy Slayton

Client: Dr. Lara Tomich

Advisor: Professor Paul Campagnola

Function:

A typical handheld otoscope consists of three main parts: head, tail, and the speculum. The speculum is a thin tube that inserts into the ear canal of animals and is designed to be able to

create light pathways to go through and direct lights into the ear canal. The head of the otoscope is a box with a magnifying lens that projects a virtual enlarged image of the ear canal to the user. The tail of the otoscope is for holding and stores any essential extra components not mentioned yet, such as a battery. Video otoscopes vary greatly. Without the need of a magnifying glass, video otoscopes are much smaller in size, and usually integrate to combine the camera into the specula. The Dual Handheld and Video Otoscope is needed to integrate functions of video otoscope to a typical handheld otoscope for distant viewers. While maintaining the features and the three main parts of a handheld otoscope. Digital camera is needed to feed live.

Client requirements:

The otoscope should have components of a traditional handheld otoscope

The otoscope has video live feed ability

External Light Source

Maintain expenses below the budget

Suitable for existing speculums

Design Requirements:

Physical and Operational Characteristics

Performance requirements: The redesign of the handheld otoscope must meet basic otoscope features, this includes: allow light to emit, reflect, and gather back to the viewer. The video relay to a distant viewer must be stable, smooth. Although no requirements from the client, the resolution and framerate of the camera should maintain industry specification for a video otoscope at a sensor resolution of 1280 x 1024 and frame rate of 30 FPS [1].

Safety: During student examination, a trained handler or veterinary technician should also be present all the time of the examination to assist with collecting data and analysis on performance. This can be the exam instructor as the distant viewer or someone who is familiar with the process and the device. This is to avoid injuries for both students and the animal subject during the

process. The otoscope should also not consist of exposed electrical components and potentially sharp edges that could cause harm to both student and animal subject [2]. Users or students need to check the basic functions and each part of the otoscope to make sure the otoscope is in functional shape and each component on the otoscope is working to their intended function only, prior to the use of animal subjects and handled with care to avoid animal abuse. Users or students also need to consider examination duration to avoid overheating from the light source and possible damage to camera functions.

**Accuracy and Reliability:** Magnifying lenses of the otoscope should accurately enlarge the real image. Image through the lens should resemble similar details to the camera captured images. A minimum of 50 percent accuracy should be achieved when two images overlap and are compared. This is that when pictures taken through the lens, and on a digital device, both images show similar features and quality.

**Life in Service:** Oscopes tend to have long lives in service, the product should run 10,000 exams without major failures. The battery life should be sustained one day in a vet clinic each time fully charged if batteries are used. If not, the otoscope is expected to be plugged in at all times during use.

**Shelf Life:** Power off, disconnect all electrical connections when not in use and store properly. If batteries are used, store them in a dry environment. Storage temperature limitation between  $-20^{\circ}\text{C}$  and  $55^{\circ}\text{C}$ , humidity limitation of 10% and 95% [3].

**Operating Environment:** The otoscope operates between the temperature limitation of  $10^{\circ}\text{C}$  and  $49^{\circ}\text{C}$ , humidity limitation of 30% and 90%, atmospheric pressure limitation of 500hPa and 1060hPa [3].

**Ergonomics:** The device will feature a comfortable grip, intuitive controls, and an optimally balanced weight distribution to reduce strain on the user's hand and wrist. The product should not be bulky and avoid sharp edges and corners for user comfort. Additionally, the ergonomic design will take into account the ease of cleaning and maintaining the otoscope to uphold the



highest standards of hygiene in clinical settings. If batteries are used, the design should resemble similar features to allow change of battery.

**Size:** The size of the otoscope will be based on the size of the otoscope gifted to us by the client. The brand of the otoscope is Welch Allyn Veterinary Pneumatic Otoscope [4]. Its measurements are 196.48 mm in length, 24.5 mm long on the top head, and 30.92 mm in diameter. Different sized ear speculum are placed at the front of the otoscope. This device will be portable because it will be used for everyday use.

**Weight:** This device will range from 400 to 900 grams based on the materials chosen for the camera and video transmission to the monitor. This device needs to be lightweight due to students having to carefully examine animals with it, as well as to better mimitate the handling of regular hand held otoscopes. Additionally, the weight distribution should also be similar to regular ones.

**Materials:** 3D printers from the UW maker space will be used to print 3D prototypes of the product [5]. The printing method chosen will most likely be FDM/FFF methods. Prototyping material will most likely be PLA, for its cheap price. Final product can be printed from resin, as it allows finer details but costs more. Other essential materials that will be used include: 9V battery (AAA), microLED, button switch, beam splitter, and magnifying lens. Additionally, for enhanced durability, it may be explored switching to metal for the outer surface in the final design. This would increase the product's resistance to wear and impact, ensuring a longer lifespan and more robust performance in demanding environments.

**Aesthetics, Appearance, and Finish:** The appearance and finish should remain mostly similar to currently in used ones for recognizability.

#### Production Characteristics

**Quantity:** One

Target Product Cost: Cost of a typical video otoscope on the market is relatively inexpensive, around \$25.99 to \$49.99 [6]. Although the client does not have a target cost of the product, maintaining the cost relatively close to the market price is ideal and friendly to all labs and teaching faculties. Final prototype costs including all materials expenses are expected to be around \$350.

#### Miscellaneous

Standards and Specifications: The product will not be mass produced, so there's no manufacturer-required standards. According to the FDA otoscopes fall into the generic category and do not need FDA clearance. Manufacturers are required to register their device. [7]

Customer: There is a slight preference for the camera feed to be wirelessly connected to the monitor/viewing device, however it is completely adequate to have a wired connection for the video feed. Additionally, a recording function to be able to review footage is desirable. Lastly, there is a preference for having the viewing experience be on a monitor rather than a cellular device.

Patient-related concerns: The otoscope cannot harm the patient in any way and must be as comfortable as possible for the user and patient while being used. The patient should react the same way as it reacts to previously used otoscopes.

Competition: Many video otoscopes and handheld otoscopes are available to purchase online. Their price varies based on functionality. However, these designs are often for human use, options for animal otoscopy are not often available to pick and choose from. Out of those available, some are either handheld otoscopes with no video feature, or video otoscopes that aren't handheld for student examination. One competing design is the Wispr Digital Otoscope [8]. This video otoscope is a close replacement for the handheld otoscope, and comes with video function in replacement for the lenses. However, this does not satisfy the lens requirements and is extremely costly considering the teaching faculty and budget for animal exams.

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