Affordable and Reliable Video Laryngoscope with Wireless Connectivity

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ABSTRACT

Along with the pandemic situation across the world, the resilience of using ordinary medical devices is limited. Also the demand for medical devices which are used to diagnose COVID-related diseases rapidly increased. Taking all these facts into consideration, a new laryngoscope device was developed with exciting functionalities. The proposed device is affordable and comes with remote monitoring capabilities. An ordinary video laryngoscope uses an expensive camera module to capture video streams, and the proposed device uses ordinary USB camera modules which are cheap and affordable. Therefore, it is even possible to replace/discard camera modules each time after investigating COVID-related patients. The proposed USB camera and Laryngoscopic blades can be easily replaced for a very affordable cost. In the proposed system, a real-time video stream can be remotely monitored in multiple displays, including personal mobile devices. Since the live video footage can be streamed across the world, expertise in the field can monitor and consult promptly. This device broadcasts video wirelessly through LAN (local area) and WAN (wide area) networks in real-time. So far, the device transmits live video streams wirelessly with less than 250ms latency on LAN networks, and 500ms to 1000ms latency in WAN networks. An inbuilt rechargeable power supply will power up the device for ~ 45min in continuous use.

KEYWORDS: *laryngoscope, wireless, anesthesia, covid, telemedicine, disposable, cost-effective, real-time.*

1 INTRODUCTION

Coronavirus (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It is spread through direct contact with respiratory droplets produced by coughing and sneezing from an infected person. Therefore, maintaining a social gap between one another was a top priority.

Laryngoscopy is a visual examination below the back of the throat, where the voice box (larynx) containing the vocal cords is located. Coronavirus symptoms are beginning from the upper part of the throat (M Sorbello, 2020). Video laryngoscopy reduces ambiguity and improves first-attempt intubation success. Also, they are used to inspect the damages and diseases of the upper parts of the throat. Due to the higher cost of ordinary laryngoscopes and their lack of reusability, it is even harder to discard after investigating COVID-related patients. Therefore, there are two main issues with this ordinary laryngoscope, safety issues arising with COVID-related patients and affordability issues with higher demand for the existing video laryngoscopes. Ordinary laryngoscopes are capable of replacing the

Laryngoscopic blade after being used for one patient but when it comes to COVID-19 related patients, this replacement is not enough.

The proposed design uses ordinary USB camera modules which are cheaper and affordable. Therefore, the whole part that is contaminated to the COVID-related patient can be discarded or replaced completely. Other than this benefit, real-time video streams inside the throat can be remotely monitored in multiple displays, including personal mobile devices. Since the live video footage can be streamed across the world, expertise in the field can monitor and consult promptly.

1.1 Literature Review

One of the main requirements of the design is that there should not be any transmission delay between the transceiver and the display. This can be done easily by using high-performance hardware components, which results in increasing the design cost exponentially. Many countries have allocated funds for improving the reliability of medical devices during this period. Air ventilators, laryngoscopes are some of the popular medical devices that have attracted the attention of many organizations.

Most of the laryngoscopes that are designed to use in the pandemic situation have wireless video transmission capability with smart mobile phones (Gautham Sonal, 2019). The main drawback of this design is the transmission delay due to interference with another electronic device's wireless connection. Table 1 shows some devices that use inbuilt Wi-fi modules.

Table 1: Existing devices with their transmitters

Device Name	Transmitter
Wireless Ear Endoscope Otoscope	ESP8266
W-LAN MRI scanner	Realtek RTL8710
LYCEUM Ear probe	EMW165
Novel Video-Laryngoscope	Realtek RTL8710

As mentioned in table 1, each device used several types of wireless transmitters. For example, Raspberry Pi 3+ integrates BCM2837, IEEE 802.11 b/g/n and Orange PI zero uses ER819, IEEE 802.11 b/g/n. There are common characteristics to be considered when selecting the Wi-Fi module on the microcontroller for transmission. Table 2 indicate those characteristics and their background.

Table 2: Characteristics of Wi-Fi modules

Name of the Characteristic	Description
Protocol/ Standard/support	The modern wireless LAN standards that are included: 802.11 a/b/g/j/n/p/ac/ad. Each standard has different specifications and designers have to choose best according to the application.
Operating frequency	2.4GHz (2.4 – 2.483 GHz) – 802.11b/g/n 5 GHz (5.15 – 5.725 GHz) – 802.11a/h/j/n/ac 2.4GHz (5.85 – 5.9 GHz) – 802.11p
Transit Range	The range of Wi-fi networks depends on the number type of access points being used. The network range depends on the protocol employed, the overall power of the transmitter and the nature of obstructions and interference in the surrounding area.
Data rate (Max Throughput)	The theoretical maximum data rate of a Wi-Fi module could be from 1 Mbps (802.11 b) to 6.75Gb/s (802.11 ac). The best data rate should be selected by considering the thread-off and the application.

Whether the laryngoscope is wired or wireless, the camera that is used by the system has the same characteristics. A list of cameras along with specifications, which are uses for some common endoscopes are given in Table 2.

Table 3: Camera used by common endoscopes

Endoscope Model	Diameter	Sensor	Resolution	Frame rate (FPS)
KARLSTORZ Endoscope	5.5mm	CMOS	320 x 240 640 x 480	30
King vison Laryngoscope	8.0mm	CMOS	720 x 480 1280 x 720	30/60
Cold light endoscope	3.2mm	M.CMOS	320 x 240	15/30
TL-601 Laryngoscope	5.5mm	M.CMOS	640 x 480	60

Almost every camera has a CMOS sensor, and the average resolution is 640 x 480. The ideal frame rate is 30 and the diameter of the camera is between 3.2mm to 8.0mm. NVL - Wireless Image transmitting laryngoscope designed by the Anesthesiology Department of Central Hospital, New Mexico (TL-601 Laryngoscope, 2014) used ESP32 camera module for the laryngoscope design. The main drawback of this design is that the quality of the video is poor. ESP32 has a camera module that is connected through an SPI connection. King Vision Laryngoscope (king systems, 2017) uses a 5MP macro camera with an anti-fogging treatment for clear vision.

Wireless communication is the most popular communication method in medical electronic devices. (Rube, 2019). It enables healthcare professionals to be more watchful and connect with the patients proactively. Modern devices contain lots of electronic devices such as sensors, microcontrollers to communicate and track the device status and process.

A group of researchers (Rube, 2019) in the institute of medical science and technology in Scotland built a wireless MRI scanner that can communicate with the magnetic room while maintaining a sterile environment. Wireless ultrasound scanners are started to replace conventional scanners due to their reliability, portability, and affordability. As Clarius health care states (Checn, 2020), a wireless ultrasound and tablet is the most appropriate type of ultrasound equipment to evaluate individuals with the coronavirus and can be covered in single-use plastic for fewer contaminations.

2 METHODOLOGY AND RESULTS

2.1 Methodology

As the proposed design contains three main parts, laryngoscope module, receiver with display, and GUI/cloud network, each part needs to be discussed separately. Overview diagram of this system is mentioned in Figure 1 below,

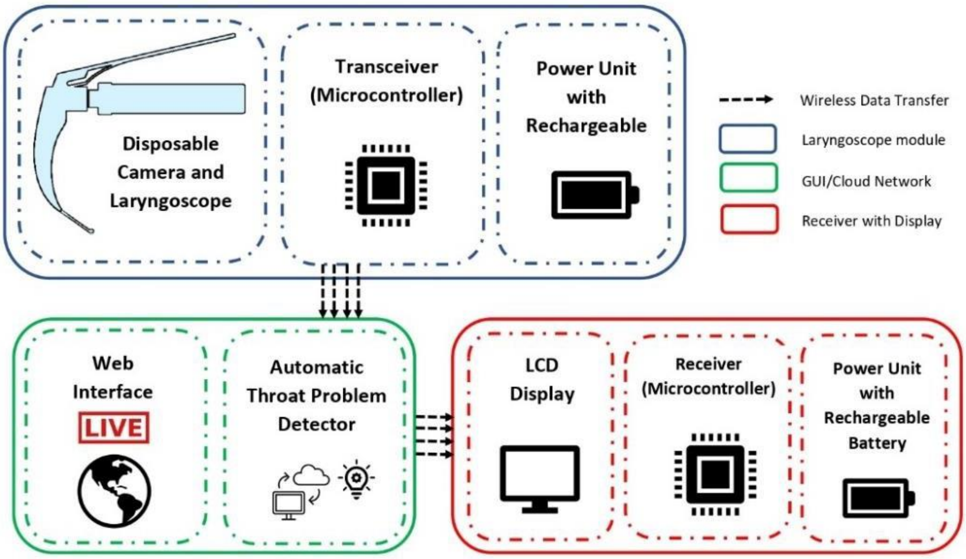

Figure 1. Laryngoscope Module

1. Laryngoscope module (as Transceiver)

As mentioned in the overview diagram above, this module consists of three subsections, a disposable camera with a laryngoscope blade, transceiver module, and power supply unit. The goal of this module is to capture clear video footage of the throat by using the endoscopic camera and transmit them to the display wirelessly.
A detailed view of this module is given in Figure 2 below,

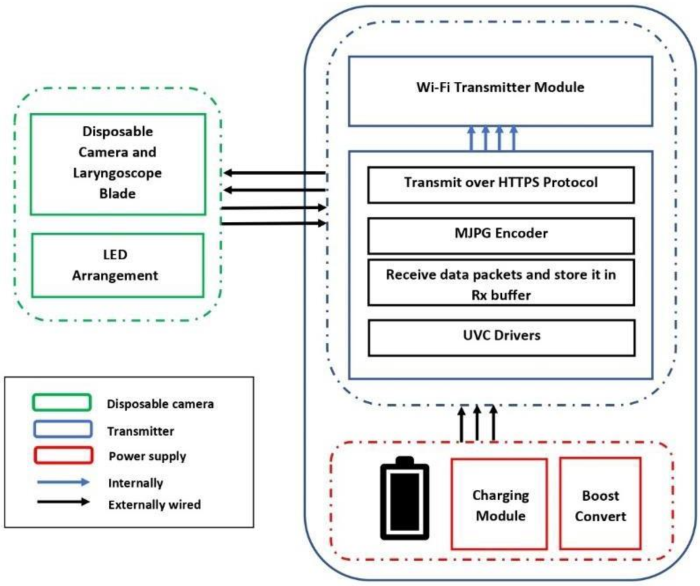

Figure 2. Detailed view of Laryngoscope module

Live video will be captured by the camera and sent to the transmitter through an external wired connection. Here, the Orange Pi Zero acts as the transmitter microcontroller. Once the video is received from the transceiver, it will be streamed over HTTP protocol. UVC (Universal Video Camera) directly produces JPEG data which allows fast and performant M-JPEG streams. This algorithm copies JPEG frames from the camera to an IP-based network. As shown in Figure 2, the power unit consists of a rechargeable battery, a charging module, and a boost converter supply power to the entire laryngoscope module. Also, this whole part can be categorized into two subparts,

- Disposable part - Camera with the laryngoscope
- In disposable part - Transmitter module with the power supply unit

Camera with laryngoscope

The main task of this part is the same as an ordinary laryngoscope but with a safer mechanism and accurate outcome for an affordable cost. Macintosh blade type is used for this proposed device. Adjustable LED set arranged inbuilt on the camera to increase the visibility inside the throat. It can be adjusted manually from the laryngoscope blade. This whole part is disposable, and it can be replaced for an affordable cost. The camera with laryngoscope is given in Figure 3 below,

Figure 3. Camera with laryngoscope

Transmitter

The main task of the transmitter is to get the video from the camera module and transmit it to the cloud network. This should be executed within a short amount of time. Both the power unit and the transmitter are implemented inside the same enclosure. The power unit powers up the transmitter module and all the other components will be powered by using this transmitter. Power unit and transmitter module cannot be disposed of after single use. The camera module and the blade can be replaced or discarded completely after a single-use. Since the transmitter has a USB interface to connect the camera, almost all the aftermarket USB cameras can be connected without the aid of an external interface. This unlocks the capability to connect most of the medical-grade cameras to the device. The portability of this device is much higher due to rechargeable capabilities. Devices can be changed easily by using standard 5V/2A mobile phone chargers. Inside of the transmitter is given in Figure 4 below,

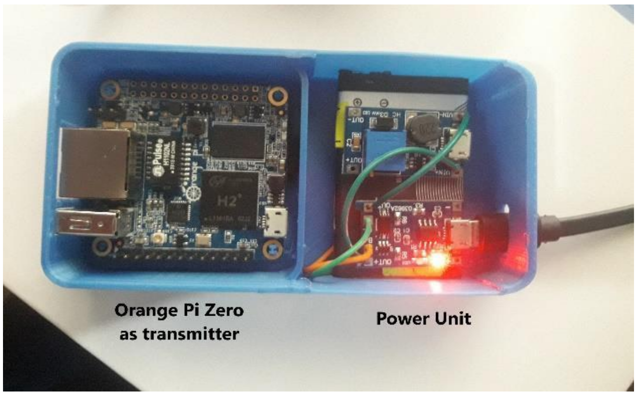

Figure 4. Inside of the transmitter module

The prototype of the final laryngoscope module is mentioned in Figure 5 below,

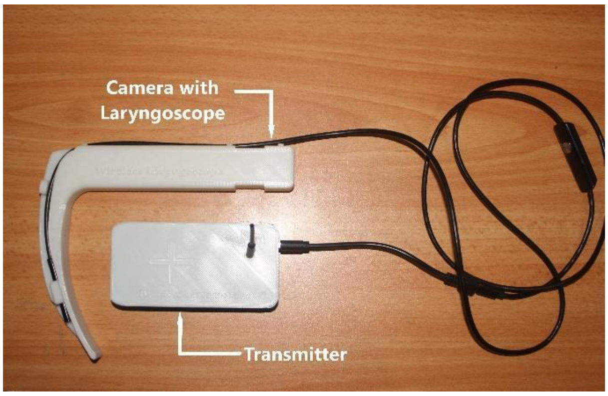

Figure 5. Final prototype of the laryngoscope Module

2. GUI/Cloud Network

This cloud network transmits the video feed to additional monitors. Also, it allows any device with wireless connectivity to stream the video from the laryngoscope wirelessly. The received video from the transceiver is broadcast by a web application over a wide area network where any number of users can log in to the session and watch the video at the same time.

The system's input plugin is a Linux-UVC compatible USB camera in the transceiver section. The Video4Linux (V4L2) driver package is used to connect the camera to the OS. The camera's JPG frames will be captured and streamed as M-JPEG to web browsers through HTTP. To connect to the camera, a HTTP URL can be used as a token. The same streaming port should be port forwarded to the cloud services to stream the video. In the web application, a section called 'LIVE' was developed with immediate access to the receiving video. In this project, static IP was utilized to ensure that the IP address did not change frequently. A snapshot of the graphical user interface (GUI) is mentioned in Figure 6 below,

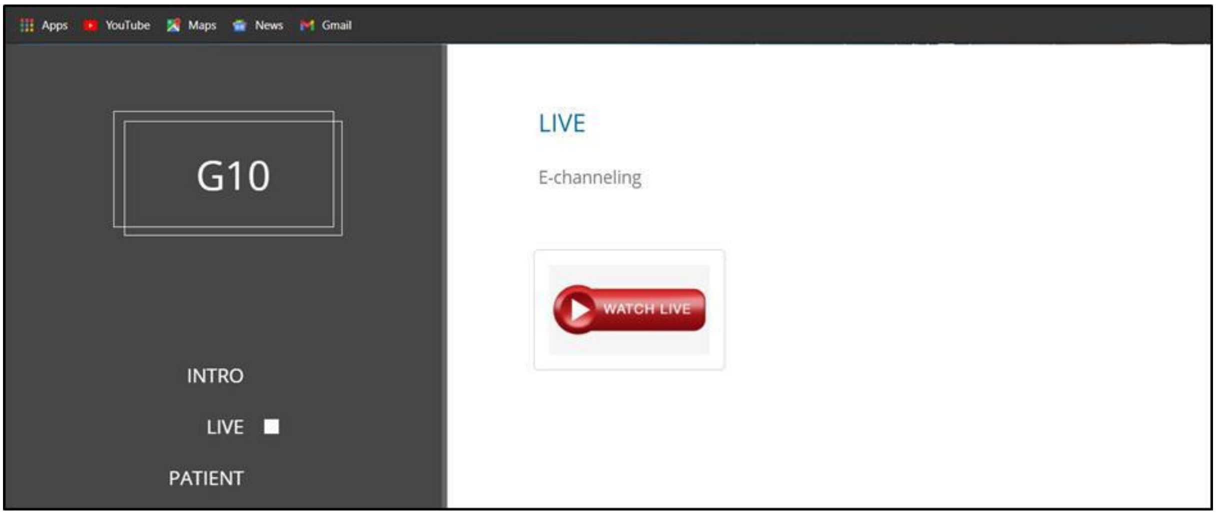

Figure 6. Photo of the GUI

As future improvements, this part can be further extended into several other features. This includes,

- Image processing solution to detect throat problems automatically.

Some of the throat/vocal cord diseases require confirmation through a microscope, while others can be detected by monitoring just the video feedback from the laryngoscope. In the absence of medical personnel, gastroesophageal reflux disease, ulcers, cancer links, inflammation or swelling, blockages, and precancerous abnormalities such as Barrett's esophagus can be detected using a trained AI model. This model can predict the condition of the patient using input data received from the transmitter. The model may be trained and obtain real-time predictions using a Raspberry Pi model 3b or a Jetson nano development kit.

- Can be synced with the hospital database.
- Cloud storage to save patient details along with the video

3. Receiver with Display

This part also consists of three main parts which are LCD, receiver module, and power supply unit. This is the screen that medical officers use to stream live video. It is portable and wirelessly connected to the laryngoscope through WAN or LAN. This can be either used separately with the laryngoscope or can be mounted into the laryngoscope if necessary. Unlike normal LED screens, this device can stream the video from a laryngoscope wirelessly. Raspberry Pi 3b acts as the receiver inside this device. A similar type of power supply that uses for the laryngoscope module is used to power up the receiver. Some of the major factors that are considered on this part are the weight and video receiving latency. Latency should be minimized to watch the video in real-time. At the same time, the size should be minimized, because medical offers use this from a single hand, and this will affect the total weight of the blade too. Photo of the device inside and the display of the device is given in figure 7 and figure 8 respectively.

Figure 7. Inside viewer of the receiver module

Figure 8. Receiver with Display

2.2 Results

Final testing was done under 2 phases, the initial test on 1st phase and the final optimized test on the 2nd phase. Table 4 shows the latency of the initial test done on PC via local area network was almost real-time.

Table 4. Latency with Resolutions

Resolution	**Phase 1**	Host OS: Windows 10 Browser: Microsoft Edge 11 Network: Wi-Fi Object: Kodak camera	**Phase 2**	Host OS: Windows 10 Browser: Microsoft Edge 11 Network: Wi-Fi Object: Calculator
	Latency(seconds)		**Latency(seconds)**	
320 × 240	Less than 0.5		Less than 0.5	
640 × 480	Less than 0.5		Less than 0.5	

The following Table 5 shows the latency of the initial test done on mobile via the local area network.

Table 5. Latency with Resolutions (Mobile)

Resolution	**Phase 1**	Host OS: Android 9.1 Browser: Google chrome Network: Wi-Fi Object: Kodak camera	**Phase 2**	Host OS: Android 9.1 Browser: Google chrome Network: Wi-Fi Object: Calculator
	Latency(seconds)		**Latency(seconds)**	
320 × 240	Less than 0.5 and 1.0		Less than 0.5	
640 × 480	Less than 0.5 and 1.0		Less than 0.5	

The following Table 6 shows cloud network latency.

Table 6. Cloud network latency

Resolution	**Latency (seconds)**	**Framerate per second (FPS)**
320 × 240	Less than 0.5	30/15
640 × 480	Less than 0.5	30/15

Photos of the completed transmitter module, disposable camera, and blade are given in Figure 9,

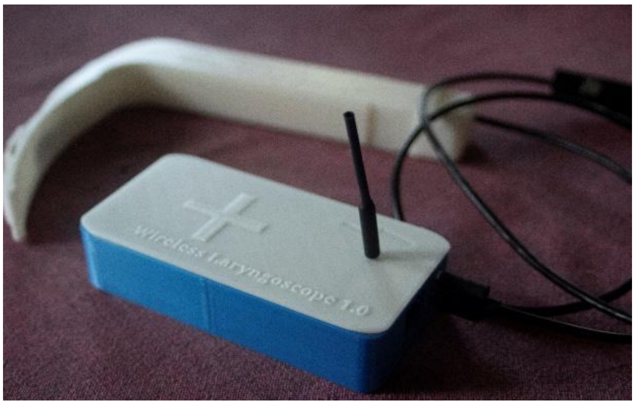

Figure 9. Complete prototype

Figure 10 and Figure 11 are the sample photos taken from the final product.

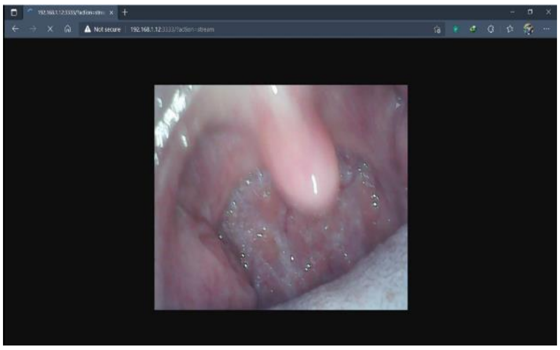

Figure 10. Sample photo 1 taken from the prototype

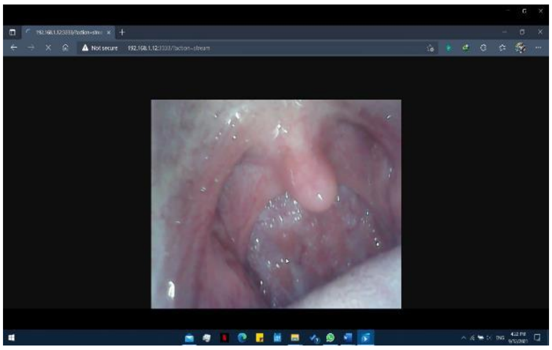

Figure 11. Sample photo 2 taken from the prototype

In Sri Lanka, a typical laryngoscope costs between 200,000 and 600,000 LKR. The entire design was accomplished while keeping the overall cost to a minimum. The cost of the complete product is 10 340 LKR in total. An ordinary video laryngoscope costs roughly Rs.400 000 on average. The proposed solutions’ cost is 2.6% of the ordinary laryngoscope. Furthermore, a traditional laryngoscope had to germicide the Laryngoscopic camera and the blade each time it was used, while our device includes a low-cost disposable camera that can be discarded after one usage.

3 CONCLUSION

In comparison to existing laryngoscopes on the market, we have developed this device to address the safety difficulties that standard video laryngoscopes confront in a pandemic situation and are far less expensive, making them more accessible to developing countries. Upgrading the ordinary laryngoscope with wireless connectivity is the proposed solution for safety risks. It minimizes medical officials' safety concerns, but the video stream's reliability is reduced as a result of the transmission lag in wireless latency. This latency was minimized to less than 0.5 seconds after multiple tests and optimization approaches, which is practically real-time and adequate for laryngoscopy. The developed wireless laryngoscope is 2.6% of the average cost of the ordinary laryngoscope. Mounting a portable wireless screen on the blade that will guide the medical officers to get the maximum visibility of the throat, using of transparent cover on the camera to overcome health issues that can be occurred due to the use of a consumer-grade camera, developing AI model to automatic detection, and implementing a battery level indicator to increase the user-friendliness are some future improvements that can be carried out by this device.

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