

Novel Low-Cost Portable Digital Laryngoscope

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Abstract

In this paper, we propose a novel portable laryngoscope design based on Raspberry Pi microcontroller and optical instrumentation. At present, medical diagnosis for the following symptoms including fever, sore throat and throat inflammation, doctors normally use a spatula and a torch to see patient's pharynx. Although, this method is practical and suitable for some illnesses, there are, however, several drawbacks including (1) this cannot be included in patient's medical record, (2) cannot be shown to patient to explain and discuss about their symptoms and (3) of course for some chronic diseases, such as, throat cancer and chronic throat infection; these diseases require doctors to frequently take photos of patient's throat to diagnose and determine how progressive the disease is. Currently, there are several digital portable laryngoscopes in the market, these are still, however, too expensive to be employed in Thai medical system. Therefore, we propose a novel low-cost portable laryngoscope design that requires very few optical components and a low-cost microcontroller system. We demonstrate the capability of the invention by taking a photo of a mock throat and pharynx canal. These photos are automatically stored in the laryngoscope and ready to be transferred to medical record and database through the picture archiving and communication system (PACS).

Keywords: *medical instrumentation, laryngoscope, biomedical optical imaging, portable digital laryngoscope*

บทคัดย่อ

ในบทความนี้ได้นำเสนออุปกรณ์กล้องสำหรับตรวจและถ่ายภาพช่องคอแบบใหม่ที่สามารถพกพาได้ ออกแบบโดยอาศัยไมโครคอนโทรลเลอร์ อุปกรณ์แสงและทัศนศาสตร์ ในปัจจุบันการตรวจวินิจฉัยโรคในสถานพยาบาลต่างๆ เมื่อมีผู้ป่วยเข้ามารับการรักษาอาการเจ็บป่วย มีอาการไข้ หรือ อาการอักเสบ บวมแดงบริเวณลำคอ แพทย์จะตรวจโดยใช้ไม้พายและลงบริเวณโคนลิ้นและลำคอของผู้ป่วย ถึงแม้ว่าในทางปฏิบัติ วิธีนี้เป็นวิธีที่สามารถใช้ตรวจอาการต่างๆดังกล่าวได้ดี แต่ยังมีข้อเสีย ได้แก่ (1) ไม่สามารถเก็บบันทึกเพื่อเป็นส่วนหนึ่งของเวชระเบียนได้ (2) ไม่สามารถแสดงภาพให้ผู้ป่วยเห็นเพื่ออธิบายอาการที่เกิดขึ้นได้ และ (3) สำหรับอาการโรคเรื้อรัง อย่างเช่น โรคกระแ้่งลำคอ และอาการติดเชื้อในลำคอ โรคเหล่านี้ต้องอาศัยการรักษาอย่างต่อเนื่อง จำเป็นต้องมีการถ่ายภาพเพื่อประเมินพยาธิสภาพและติดตามผลการรักษา ซึ่งปัจจุบันอุปกรณ์กล้องสำหรับตรวจช่องคอแบบดิจิทัลและพกพาได้มีราคาแพงเกินกว่าทุกสถานพยาบาลรัฐในประเทศไทยจะเข้าถึงได้ ดังนั้นผลงานวิชาการนี้จึงได้นำเสนออุปกรณ์กล้องสำหรับตรวจและถ่ายภาพช่องคอแบบใหม่ที่สามารถพกพาได้ ที่มีราคาถูกกว่าท้องตลาด อาศัยหลักการออกแบบทางแสงและทัศนศาสตร์ และควบคุมด้วยระบบไมโครคอนโทรลเลอร์ จากผลการทดสอบประสิทธิภาพของอุปกรณ์โดยการถ่ายภาพช่องคอที่จำลองขึ้นมาพบว่าสามารถถ่ายภาพด้วยระบบดิจิทัลและบันทึกภาพแบบอัดโน้มนิดสำหรับเก็บเป็นเวชระเบียน และใช้เป็นฐานข้อมูลในระบบการจัดเก็บและสื่อสารข้อมูลภาพทางการแพทย์ (PACS) ต่อไป

คำสำคัญ: เครื่องมือทางการแพทย์ กล้องสำหรับตรวจช่องคอ การถ่ายภาพชีวการแพทย์ อุปกรณ์กล้องสำหรับตรวจและถ่ายภาพช่องคอแบบพกพาได้

1. Introduction

Since 1854, when the first indirect laryngoscope was invented by Manuel García using 2 mirrors and sun light as the external light source to view the larynx in a human subject (García, 1854). The laryngoscope has been dramatically developed since then, where digital portable video laryngoscopes have become commercially available in the market (Su et al., 2011; Levitan et al., 2011). Although digital laryngoscopes sold in the market are very convenient, there are still several issues needed to be addressed; for example, pharyngeal wall injuries and sterilization for the equipment. These portable digital laryngoscopes are still, however, too expensive for Thai medical system. Thailand is one of the countries with limited medical resources and there is no manufacturing industry in Thailand that manufactures these types of medical devices. Most of laryngoscopes used in Thailand are of an old-fashion with no video

recording function. There are also some hygienic concerns on cleanliness of laryngoscope blades (Surasarang, 2016) and handles reported done by medical units in Thailand (Limpisophon et al., 2014).

At present, for medical diagnosis for the following symptoms including fever, sore throat and throat inflammation, doctors normally use a spatula and a torch to see patient's pharynx. Although, this method is practical and satisfactory for some illnesses, there are, however, several drawbacks including

- (1) this cannot be included in patient's medical record,
- (2) cannot be shown to patient to explain and discuss about their symptom and
- (3) of course, for some chronic diseases, such as, throat cancer and chronic throat infection; these diseases require doctors to frequently take photos of patient's throat to diagnose and determine how progressive the disease is.

Therefore, in this paper we propose a novel low-cost portable laryngoscope design that requires very few optical components which can be manufactured in house at the Faculty of Biomedical Engineering, Rangsit University and a low-cost microcontroller system. Our proposed design addresses the mentioned issues by making the tip end of the device disposable and a spatula which can be attached to the tip if images of the deep throat are now required. We demonstrate the capability of the invention by taking a photo of a mock throat and pharynx canal. These photos are automatically stored in the laryngoscope and ready to be transferred to medical record and database through the picture archiving and communication system (PACS).

2. Objectives

The objectives of the proposed portable digital laryngoscope design are:

1. To develop and construct a novel portable digital laryngoscope
2. To provide the portable digital laryngoscopes to workforces in healthcare professions assisting them with accurate and reliable devices. The portable digital laryngoscope enables users to capture and store the photos taken by the device to be included in patient's medical record.
3. To manufacture this portable digital laryngoscope at low cost to ensure that this will be affordable for hospitals, public healthcare units and mobile units in resource-limited countries.

3. Materials and methods

The proposed design can be categorized into 2 major parts, which are (1) optical instrumentation and (2) electronic design.

For the optical instrumentation, the imaging system consists of a pair of projection lenses (Lens 1 and Lens 2 and Lens 3), a beam splitter, a white light source, a mirror and a CMOS camera as shown in Figure 1. The details for each components can be found in Table 1.

Figure 1(a) depicts the optical illumination path from the white light source to the patient's neck, where the white light is emitted from an LED which the light is then collected by Lens 1 to ensure the light throughput to the throat is sufficient. The light is then passed through the beamsplitter. Although the beamsplitter throws away half of the light, the beamsplitter allows us to have the light illumination and the image formation through the same optical path through Lens 2 and Lens 3. The light is then projected into the throat through a very small lens Lens 3. For sanitation, the tip of the device and the equipment body can be sterilized with disinfectants. Especially the tip including Lens 3 can be disposed and replaced with a new one.

Figure 1(b) shows the image formation optical path, where the light is reflected from the throat is then collected through Lens 3 and Lens 2 and is then passed through the beamsplitter and the throat canal image is then formed on the CMOS camera. The CMOS camera used in this design is a peripheral device of Raspberry Pi Model B microcontroller powered by a rechargeable portable Lithium-ion battery. The camera enables us to integrate the optical imaging system with an electronic and microcontroller system. The images obtained from the 5MP Raspberry Pi camera are then stored in the Raspberry Pi memory card. The size for one image is around 5.28MB stored as BMP before converting into Digital Imaging and Communications in Medicine format (DICOM) to ensure that the images are compatible with picture archiving and communication system (PACS).

Note that for low-cost industrial scale manufacturing process in the future, we have developed a low-cost optical lens fabrication process, where lenses can be shaped and formed using a 3D printer. The detailed fabrication process will be published elsewhere.

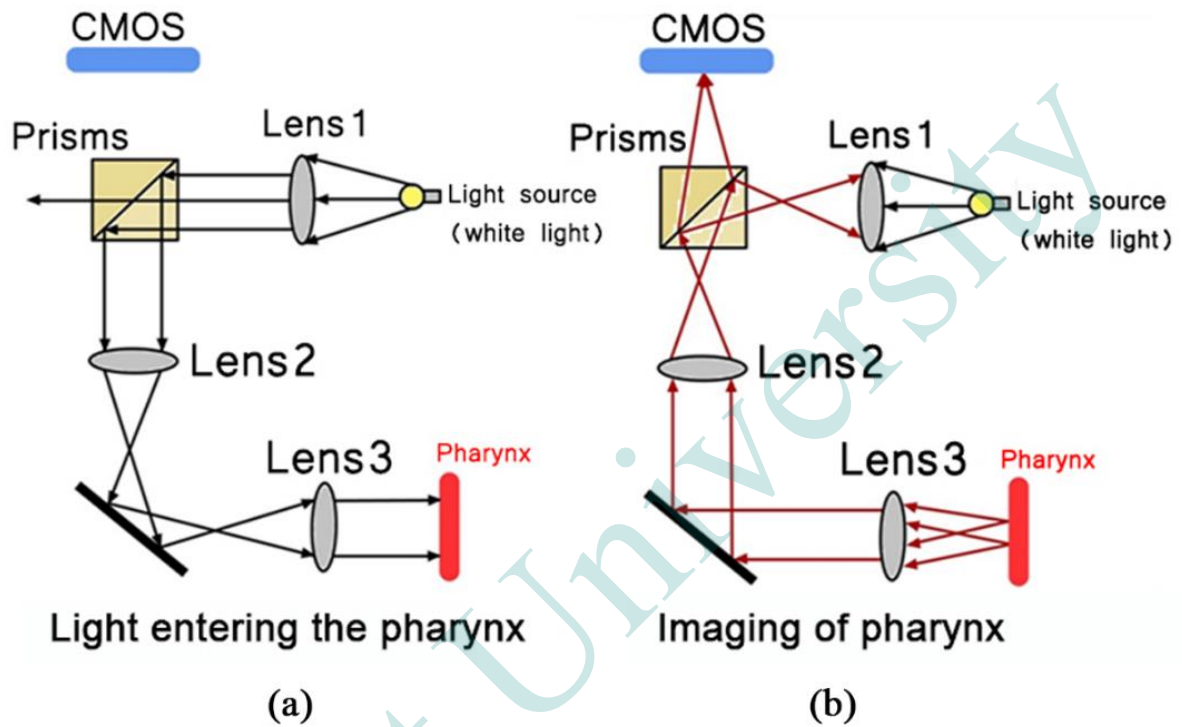


Figure 1 Optical instrumentation, optical light paths for (a) light illumination from the white light source and (b) light collection from the throat and image formation at the CMOS camera

Table 1 Optical components employed in the Portable Digital Laryngoscope

Components	Details
Lens 1	Light collection lens to collect the light from the white light source Diameter of the lens = 50 mm Focal length = +50 mm
Lens 2	Projection lens for suitable magnification of the image Diameter of the lens = 25.4 mm Focal length = +75 mm
Lens 3	Laryngoscope tip this is capped with medical grade disposable cap Diameter of the lens = 3 mm Focal length = +100 mm
Beamsplitter	A standard 1 inch non-polarizing beamsplitter
Mirror	A standard 1 inch diameter Aluminum mirror
CMOS camera	Raspberry Pi Camera Module Rev 1.3 (CMOS, Complementary Metal Oxide Semiconductor) with 5 MP resolution
White light source	A white light LED with 10 mW optical power

For the microcontroller system, we have employed a Raspberry Pi 2 Model B V1.1, where the CMOS camera can be interfaced and controlled to the Raspberry Pi. The Raspberry Pi were installed with NOOBS operating system, where all the control software for data and image acquisition were written in

Python. The software has its operation and flow control as described in Figure 2. The captured images can be displayed through an attached 5” touchscreen LCD panel as shown in Figure 3.

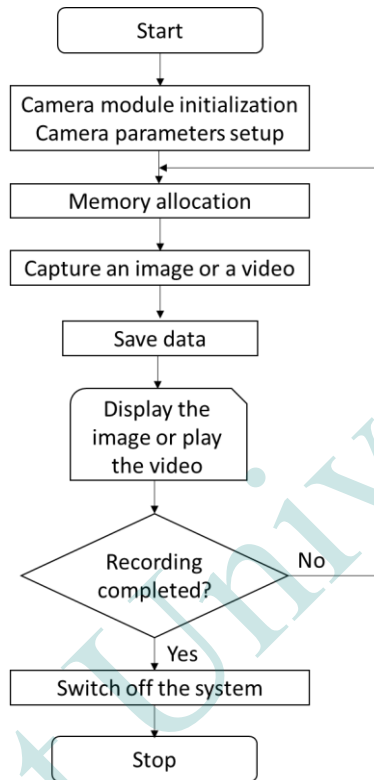


Figure 2 The control software flowchart

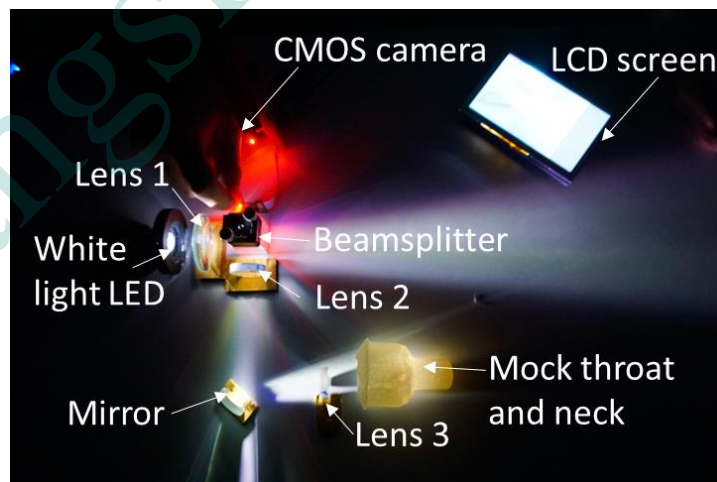


Figure 3 Optical arrangement and peripheral devices before assembling bits into a completed portable digital laryngoscope

To demonstrate the capability of the proposed portable digital laryngoscope we built a mock throat canal using silicone rubber matching the size of the opening mouth entrance and length of the mouth cavity and throat canal. The internal wall of the silicone was painted by orange color representing the color of the mouth cavity. The mock throat canal consists of two parts; firstly, the oral cavity and secondly, the throat cavity as shown in Figure 3. The mock throat canal has the entrance of 4.5 cm in diameter; this represents

a typical size of human's mouth (Zawawi et al., 2003). The length of the larger cup is 7.0 cm representing the length of the oral cavity. For the smaller size tube representing the throat canal, it has the length of 5.5 cm and painted at the end of the tube to represent the position of larynx as shown in Figure 4.

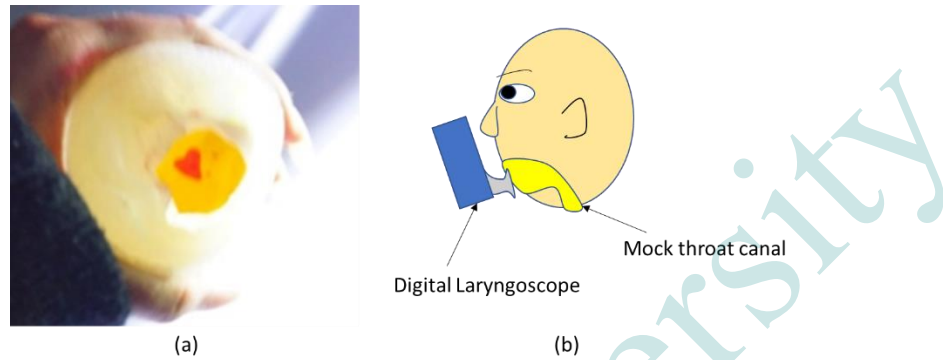


Figure 4 (a) a 'heart' symbol at the end of the mock throat canal and (b) mock throat canal position and camera position in experimental setup

4. Results

Figure 5 shows captured images of the mock canal and the display screen of the portable digital laryngoscope. It can be clearly seen that the images taken from the instrument are sharp and very low noise. This photo is automatically saved in laryngoscope and ready to be transferred to medical record and database through the picture archiving and communication system (PACS). We are confident that this optical configuration with a low-cost microcontroller system will enable us to manufacture this high quality portable digital laryngoscope. The weight of the proposed design is around 400g and this equipment is powered by a rechargeable portable Lithium-ion battery lasting for at least 5 hours for one time of fully charged battery.

In terms of the cost and quality, our proposed design would cost around 3000 THB to produce one unit, which is very cost effective compared to the typical price of 2000 USD for a portable digital laryngoscope in the market; the resolution and battery lifespan of the proposed laryngoscope are better than commercial products.

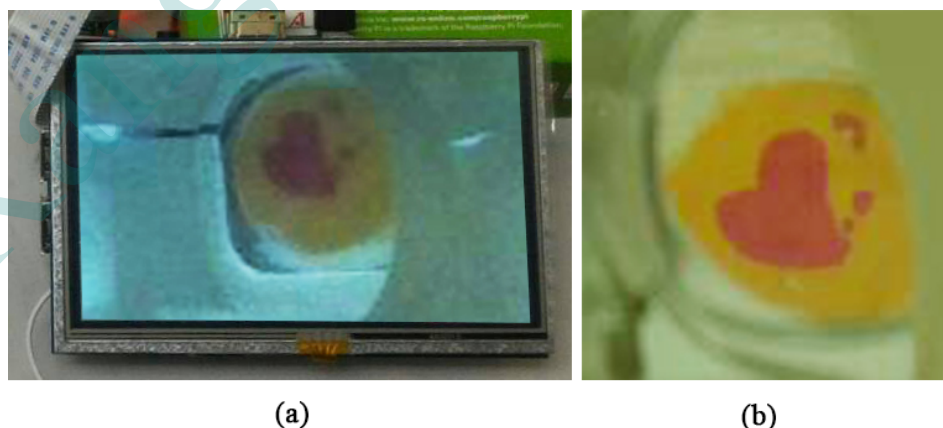


Figure 5 (a) the display screen of the portable digital laryngoscope and (b) captured image of the mock throat canal

We have planned to disseminate this design through commercialization. Of course, there are still several issues that need to be addressed in term of product design, production cost and capturing patients' throat images portfolio. Of course, this medical practice needs to be carried out by certified medical

healthcare professions. At this stage, we have come up with an ergonomic product design as shown in Figure 6 assembling all the optical and electronic components as shown in Figure 3.

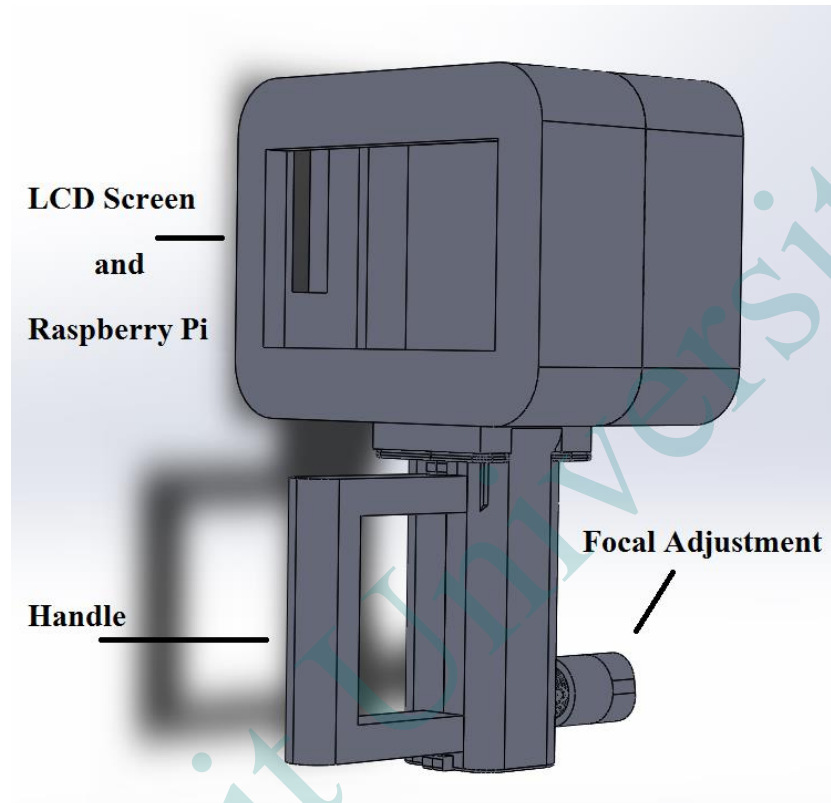


Figure 6 A 3D drawing of our proposed completed portable digital laryngoscope

5. Discussion

Having mentioned earlier that medical practices using this laryngoscope need to be carried out by certified healthcare practitioners. This will be disseminated through our existing research network collaboration with Faculty of Medicine Ramathibodi Hospital, Mahidol University. Results from the collaborative research will be published in another publication.

We have also filed a patent to protect the design and the next stage after the medical validation is, of course, to commercialize the design.

6. Conclusion

In this paper, we have demonstrated the capability of a simple optical configuration and a low-cost microcontroller based portable digital laryngoscope. The optical configuration allows the optical illumination and image acquisition to be carried out through the same optical path lens, therefore this design requires less number of optical components. We have also designed a control software to control the CMOS camera to capture and store images. The capability of the laryngoscope was illustrated by capturing images of a mock throat canal made of silicone. The obtained images have a very good optical resolution and very low noise. The next stage of this project will be carried out by certified medical practitioners for medical validation through our research network collaboration.

7. Acknowledgements

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