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Sunescope: A Video-guided Intubation System Through a Detachable Imaging Probe

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We have designed a novel apparatus, the Sunscope, which integrates a semiconductor image sensor into a compact video-guided intubation system. This device consists of three separate modules: viewer, console and visual tube. The 4-inch LCD viewer panel displays the real-time video image with optimal view angle. The console is designed with respect to ergonomics allowing comfortable manipulation and internally accommodating the power supply, image processing components and connector platform for both viewer and probe. The distal end of the detachable probe is packaged with a high resolution lens, CMOS sensor, and four LEDs. The proximal end is a 6-pin connector which can be readily removed and attached on demand. The probe is detachable and disposable with length and diameter adaptable to the size of the endotracheal tube. In our preliminary test, the video-guided apparatus helped inexperienced performers to identify the vocal cords correctly and improve the success rate of intubation on the simulation model. With further improvements on the miniature design, all captured images could be transmitted to remote devices through standard wireless transmission and could thus be stored in a specific database station. The wireless technique enables image sharing on multiple devices while a powerful database can provide valuable resources for training, data mining and serial case studies. We demonstrate that the CMOS image sensor combined with advanced reduced instruction set computer machine can serve as a visual aid for tracheal intubation. The disposable station will become a revolutionary technology both in clinical practice and medical education.

1. Introduction

Airway management is a challenging task where skillful techniques and appropriate devices must be well incorporated. Among all the requirements for a successful endotracheal intubation, conventional laryngoscopy is regarded as the most difficult practice because professional training and skills experience are usually insufficiently provided. Inappropriate training and lack of equipment support not only results in inaccurate esophageal intubation but also leads to unnecessary airway injury.¹ One of the obstacles is that conventional laryngoscopy does not reveal the vocal cords as a result of the discrepant anatomic structure or the lack of skill.²,³ To overcome the poor visibility of the vocal cords,
transillumination of the neck with illuminating stylets (i.e., lightwand) has been developed with an overall success rate of intubation between 97.9% and 100%. However, the lack of direct visual confirmation of the airway orifice could lead to unnoticed esophageal intubation until hypoxemia has developed. Theoretically, the potential catastrophe associated with “blind” intubation can be avoided under video-guided intubation when the assistant and supervisor are simultaneously attentive.

Another critical disadvantage of direct laryngoscopy is the hygiene hazard. To obtain a maximal view, the performer (and/or the supervisor) has to place their eyes close to the patient’s mouth. As a result, contaminated exhalations from the patient’s airway may directly contaminate the performer’s face. Thus, endotracheal intubation is known as the most risky procedure for medical staff because the patient’s exhalations are capable of transmitting infectious diseases such as severe acute respiratory syndrome and open tuberculosis. To keep medical staff safe from this iatrogenic possibility, the performer has to stay away from the infectious source as far as possible.

Sunscope® (Medical Intubation Technology Co., Taiwan), named after Professor Sun Wei-Zen, is an anesthesiologist-initiated innovative device, designed to solve these clinically-oriented problems. The complete profile of the technical specifications has been fully implemented while the prototype was successfully tested on an endotracheal intubation model to prove its clinical capabilities. A number of advantages associated with Sunscope®’s design make it superior to the commercially available intubation devices. Moreover, potential practical applications based on the medical image database have also demonstrated consistent results using Sunscope®, which comprises the following:

- a video probe that can improve the success rate of intubation for trainees;
- a disposable probe that can prevent transmission of infection from one patient to another;
- a portable display that can keep medical staff away from the patient’s exhalations;
- a console that integrates video signal input, processing, storage, and display;
- a platform that transmits images to a portable digital assistant (PDA) or remote visual display; and
- a database as a resource for case studies, data mining, and skills training.

2. Design Profile

All technologies applied in this project have been thoroughly researched and are considered to be feasible for developing this integrated medical appliance. Sunscope® includes three separate modules (i.e., visual tube, console, and viewer) as shown in Figure 1. The visual tube is an endotracheal tube which accommodates a video probe, pre-bent stylet, and a 6-pin connector for power and signal transmissions. The console is the main platform of Sunscope® and encompasses the power supply, image processing components and internal circuitry. A viewer performs as the display module of Sunscope®. The captured medical images can be transmitted to a

![Figure 1](Profile of Sunscope®.){:style="width:595.3px;height:793.7px;"}
PDA or remote visual display and stored in a database for advanced applications. Detailed specifications regarding the profile and functional examples are described below.

3. CMOS Image Sensor

As compared with charged couple devices (CCD), CMOS image sensors (CIS) have received much attention over the last decade because of their outstanding quality and performance. Under continuous improvement in noise and sensitivity, CIS is currently accepted to be a more favorable technology than CCD and has the following characteristics:

- lower power consumption (range from 1/3 to less than 1/100 that of CCD);
- lower cost (1/10 of CCD technology);
- on chip functionality and compatibility with standard CMOS technology;
- miniaturization, with high integration level; and
- speed of imaging is relatively high.

The cost and size advantages make CIS the best technology to use for a disposable video component. Moreover, the extremely low power consumption of the CIS component generates less heat and reduces the possibility of tissue burn.

4. Integrating CIS with LED Components as a Self-Illuminating Video Probe

Self-illumination is an important function for a video probe. To maximize its applicability, the diameter and light spectrum must be simultaneously designed. LED is a solid-state illumination component and thus can be fabricated in small sizes and easily incorporated into a printed circuit board. Moreover, known LED components are energy-saving, difficult to damage, and cheap compared with other illumination devices. Therefore, Sunscope® integrates CIS with four white-light LED components placed in the tip of the video tube.

5. Pre-bent Stylet

The design of Sunscope® was initially derived from Lightwand, a rigid but adjustable lighting stylet to guide the process of intubation by transillumination of the neck. This is a standard airway management device recommended by the American Society of Anesthesiologists (ASA). The overall success rate of lightwand intubation is between 97.9% and 100%. In a previous study, we demonstrated that the bendable length of a lightwand should be enough to approximate the individual’s thyroid prominence-to-mandibular angle distance (TMD) to make the intubation smoother. We connected a CMOS sensor to a lighting stylet to formulate our prototype design of Sunscope®. Various sizes of pre-bent stylets attached to the video probe of CIS are available so that the performer can choose an optimal bent length of stylet according to the patient’s TMD to allow smooth intubation.

6. Digital Processing of the Video Signal by Video Decoder

In our design, the console is the mainframe to support the essential functions of medical image processing, data storage, and information communication. To do so, the analog signal captured by the video probe must be digitized before any further process is undertaken. A video decoder transforms the analog video image to an 8-bit digital video signal. Subsequently, the digitized medical images are either transmitted to a separate monitor or stored in a database so that the signal can be further filtered numerically and can be analyzed by various signal analysis algorithms.

7. Constructing the ARM-based Console

Recently, advanced reduced instruction set computer (RISC) machines (ARM) have been applied to develop PDAs, mobile phones, 3G devices, medical devices, and other personal quasi-system devices. The Sunscope® console provides an integrated platform for power supply, image processing and communication capabilities. The ARM-based device is an appropriate option to implement the complicated functions in the hardware of the console. In addition, ARM also supports multiple communication protocols and offers an extendable interface for various communication modules. Furthermore, the ARM-based console of Sunscope® can link with a wireless communication module to achieve wireless transmission. In our design, Linux was chosen as the software development environment that enables us to appropriately trim the operating system. Therefore, the ARM-based console equipped with Linux is likely to perform with the highest efficiency using less space and with lower memory cost.

8. Wireless Video Transmission

The primary aim of Sunscope® is to keep medical staff away from the exhaled airflow of patients, thus
avoiding infections. Therefore, the design also allows medical images to be transmitted to a PDA or remote visual display. Multiple remote monitors are possible for the purpose of live demonstration. In our initial design, the console of Sunscope® encompassed a 2.4-GHz radiofrequency video communication module. In simulation on a manikin, this application has been proven to be a reliable and useful function, using a single transmitter and multiple receivers. However, with wireless regulations in clinical practice under stringent inspection, we will not install the wireless module into the final product until FDA approval has been obtained.

9. Potential Clinical Applications

Although the prototype of the Sunscope® was initially designed as an airway management device, the applications of Sunscope® are not limited to endotracheal intubation. With minor modifications, the inter-exchangeable part of the visual tube can readily be replaced to suit different endoscope systems. For example, anal-sigmoid colon procedures and vaginal-uterine examinations are potential applications. In addition to the visual module, MEMS sensors (e.g., CO₂ and temperature) could also be incorporated while an infrared CIS component may replace the visible light CIS for special diagnostic purposes.

10. Comparison With Commercial Airway Management Devices

Six different types of devices were compared with Sunscope® with regard to specific functions (Table 1). Categorically, the AirwayScope (Pentax, Japan) and Glidescope (Saturn, USA) are video-guided laryngoscopes. The video component of Glidescope and AirwayScope are embedded and fixed on the laryngoscope tip. Thus, their image sensors are not able to guide the intubation once the endotracheal tube has passed the laryngoscope. Moreover, neither of them have an advanced utility for processing the medical image. In contrast, Sunscope® contains a disposable pre-bent stylet video probe to identify the vocal cords, to guide the entire intubation process, and to confirm the final tip position of the endotracheal tube. With extended technological modification, Sunscope® can offer seamless connectors for suction and gas exchange during intubation, wireless communication capability and the capability for captured images to be simultaneously displayed, shared, and stored in a database.

11. Experimental Practices of Manikin Endotracheal Intubation

The prototype of the Sunscope® was tested in experimental tracheal intubations in manikins. Unskilled and inexperienced staff operated the Sunscope® after simple training. A total of five naïve participants (electrical engineers who had never been educated in cardiopulmonary resuscitation) were recruited. Within a few attempts, they were able to identify critical airway structures, i.e., epiglottis, vocal cords and trachea rings. All participants completed the intubation task after confirming that the tip of the visual tube was located in the manikin’s trachea. The overall success rate of tracheal intubation was 100%.

12. Multidisplay Application

An important aim of Sunscope® is to improve the intubation success rate in both clinical practice and teaching. In the traditional teaching of endotracheal intubation, trainees are crowded around the instructor to obtain the best view of intubation. A limited number of tutors are allowed to participate. In contrast, Sunscope® can display real-time
video images of the entire intubation procedure on PDAs or remote visual displays via wireless communication. Therefore, the multidisplay application of Sunscope® can serve as an efficient tool in skills training.

13. Offline Inquiry, Case Study and Data Mining

High quality medical imaging is a critical resource in the era of evidence-based medicine and medical liability. Routine storage of medical images allows offline investigation and subsequent case studies. For difficult airway management, replay of the video images are the most effective teaching material for medical staff to handle similar clinical situations. This is particularly helpful when trainees wish to review their practice and seek professional opinions from different mentors. Recently, numerous image processing and analysis algorithms have been proposed. Accumulated images can help in building a powerful database for large-scale study off-line.

14. Conclusions

Sunscope® integrates CIS and ARM to serve as a useful visual aid for endotracheal intubation. Miniature CIS technology has contributed to ongoing breakthroughs in both clinical practice and medical education. In addition, we are also collaborating with endoscope specialists, gynecologists and otolaryngologists to develop potential applications in various clinical settings. The successful introduction of Sunscope® demonstrates that a clinically-oriented innovation can bring forth practical prototypes through close interaction between medicine, technology and industry.

Acknowledgments

The authors wish to thank the Department of Industrial Technology, Ministry of Economic Affairs, Taiwan, R.O.C. (grant number MEP-95002-963A004) for supporting this research.

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