IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received September 2, 2018, accepted October 6, 2018, date of publication October 11, 2018, date of current version November 8, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2875558

A New Procedure for Advancing Telemedicine Using the HoloLens

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This work was supported by the National Broadcasting and Telecommunication Commission (NBTC), Thailand.

ABSTRACT The it relates to healthcare delivery to remote and under-served areas. This is evident in the emergence of many Bluetooth or Wi-Fi-enabled medical devices, such as infusion pumps, smart beds, magnetic resonance imaging scanners, and HoloLens devices, *inter alia*, currently in use in various hospitals and health facilities. However, the shortage of competent operators and lack of specialized physicians and other health workers, especially in rural and remote areas that lack specialist medical services and major hospitals, still poses a great challenge to high-quality health delivery. This research project was to develop a proof-of-concept system by implementing an E-consultation system leveraged on holographic and augmented reality systems, in a typical intensive care unit (ICU) environment, for the prompt and safe delivery of remote consultancy services. The overall system was implemented as a data center controlling a network of devices and a HoloLens consulting system. This E-Consultation approach created an interactive platform between a patient and a doctor and was tested at the surgical ICUs of Buddhachinaraj Hospital, Phitsanulok, Thailand, with six cardiothoracic patients and 14 other accident patients, participating in the study. The adaptability of the system was tested developmentally over a period of one month. Analysis of the results of a satisfaction survey of the collaboration amongst the medical practitioners (doctors and nurses) and the development team showed that the average satisfaction was 4.37 for system usability and 4.5 for the benefits identified and average satisfaction with the development team was 3.87, both out of a maximum score of 5 points. The findings from this research demonstrate the reliability and efficiency of deploying HoloLens and Hologram devices and justify their use in E-Consulting systems in ICU centers.

INDEX TERMS Telemedicine, HoloLens, digital health services, E-consultation, E-learning system, intensive care units (ICUs), augmented reality.

I. INTRODUCTION

A significant problem facing medical services in rural areas is a lack of experienced experts, specialists, or medical officers, which limits the availability and delivery of medical services. E-Consultation Services could prove to be very useful in improving patient services from physicians or other medical officers, especially for patients in rural, remote and under-serviced regions, allowing patients to receive higher quality services and providing greater access to the healthcare services. The E-system increases treatment effectiveness and efficiency by enabling co-consulting and diagnostic services from specialist medical staff who work in the medical center.

Thailand presently faces a shortage of physicians specializing in critical medical care. Rural hospitals in Thailand do not have specialized physicians for the treatment of patients in intensive care units (ICUs). As a result of this shortage of specialized ICU physicians, high-risk ICU patients often receive medical treatment provided by newly graduated doctors who do not have the experience in critical medical care necessary to treat severely ill patients. However, the majority of nurses in ICUs at government hospitals are usually well-experienced in caring for critically ill patients and can therefore assist newly graduated doctors to diagnose and provide medical treatment for these patients in such ways as setting up a ventilator, classifying critically ill patients, monitoring vital signs and blood pressure and many other essential support tasks.

The purpose of this current project was to develop and apply the holographic consultation system, with virtual reality glasses, as a proof-of-concept and to implement such a

system in an ICU in a rural hospital, thereby providing access high-quality medical services to critically ill patients in rural areas more promptly and safely. The project is focused on learning and developing the prototype model as an adaptation of current technology to provide for the health needs of patients, especially in rural and remote areas, where there is a chronic shortage of medical specialists. The system will enable selected specialists at a tertiary hospital or major medical center to provide advice on primary care and health promotion to smaller, local health promoting hospitals or primary hospitals. In our project, we adapted and developed a technological system to suit the demands for remote consultation to improve treatment outcomes, especially in emergency and critical care cases.

The HoloLens device was used as a component of mixed reality (MR) technology that incorporates Virtual Reality (VR) with Augmented Reality (AR). VR technology allows users to see virtual objects with VR devices, and AR technology is for users to see the real environment with AR devices. Thus, devices implemented with MR technology enable users to combine the real world images with the virtual world images.

In the past, the HoloLens has been used in medical academia, in anatomy classes for medical students, and to instruct medical interns when practicing surgery, and to assist in surgery by creating a virtual-reality environment simultaneously during surgery.

Working in the ICUs of two major hospitals, the researchers used HoloLens technology to develop a holographic consultation system to enable consulting in these units. The ICU nurses were involved in the activity, together with specialist medical staff who were on-call as required to participate.

Although the HoloLens devices are more costly than conventional methods currently employed, the benefits of immediate emergency resuscitation of ICU patients can only be seen as being very cost effective, if not in financial terms, but certainly in humanitarian terms. Using the HoloLens means that critically ill patients are treated by specialized doctors with much greater expertise.

II. RELATED WORK

The HoloLens is a high-tech device that is now being used to assist the doctor, by using a wireless data monitor attached to the patient, giving real-time access to the patient's data and enabling immediate review of examination results. Simultaneously, HoloLens allows the live monitoring of patient parameters over Wi-Fi, providing important patient information to the doctor [1]. Holographic real-time 3D is a medical imaging technique that can support heart visualization from coronary tomography. Through this technique, the doctor can analyze the hidden details of the human anatomy and can be used for multi-place medical diagnostics. It is also now considered critical for success in the field of surgery and all clinical treatments [2].

Holographic real-time 3D is also technology that has been applied to the improvement of medical education and healthcare services that include VR, AR and MR. HoloLens is a Mixed Reality technology that is more efficient than only VR or AR in the aspects of affecting depth perception, task completion and social presence [3]. However, before using it, doctors require physical training in the use of HoloLens to avoid simulator sickness, nausea, headaches, eyestrain and disorientation that may be experienced [4]. In previous studies, it has been shown that HoloLens can support medical procedural training and communication skills for all healthcare professionals [3]–[8]. In addition, HoloLens is being used for healthcare services that include training for patients with Alzheimer's disease, and to improve the short-term memory of patients [9]. In cases of viewing magnetic resonance imaging (MRI) images on a HoloLens, it can be a prototype platform for MRI-guided neurosurgery. Preliminary qualitative evaluation has revealed that holographic visualization of high-resolution 3D MRI offers an intuitive and interactive perspective of the complex brain vasculature and anatomical structures [10]. HoloLens is also used in anatomic pathology for virtual annotation during an autopsy and the process of pathological work as well as real-time pathology-radiology correlation [11].

The effectiveness of using the HoloLens in immersive learning, when compared against handheld tablets and desktop setups, has shown that the HoloLens can connect a user's real world and virtual world, and allows for interaction *in-situ* at the spatial position in 3D visualizations [12]. In addition, the haptic perception of stiffness in HoloLens use can create a ''better and softer'' tactile sensation than in VR [13].

In many countries, AR is utilized as a telemedicine platform to improve health-care services in rural areas, especially in situations of emergency management. Some diseases have a ''golden period'' for treatment and these technologies shorten the time to access treatment [14]. In developing countries, the lack of healthcare professionals will benefit from AR tremendously, as a telemedicine platform with an effective training system.

III. METHODS

A. PARTICIPANTS

Participating medical centers were located at Naresuan University Hospital, Buddhachinaraj Hospital, Bangkok Phitsanulok Hospital, and the Nakhon Thai Crown Prince Hospital. Six health promotion hospitals affiliated with Naresuan University Hospital also participated. These were Saohin Tambon Health Promoting Hospital, the Ngew Ngam Health Promoting Hospital, the Wat Phrik Health Promoting Hospital, the Wang Nam Koo Health Promoting Hospital, the Tha Thong Health Promoting Hospital and the Thapo Health Promoting Hospital. Three Health Promoting hospitals affiliated with the Nakhon Thai Crown Prince Hospital are the Nern Perm Health Promoting Hospital, Na Bua Health Promot-

ing Hospital, Na Jarn Health Promoting Hospital. In all, 18 hospitals participated in the project.

Personnel participating in the research project included 2 medical specialists and 15 ICU nurses at Buddhachinaraj Hospital and Bangkok Phitsanulok Hospital.

During the period 1st April 2018 to 1st May 2018, 17 patients participated in treatment programs in which 3D Holograms were used. These patients included 7 cases of Cardiothoracic Surgery, 3 emergency cases, 4 intensive care cases, at Buddhachinaraj Hospital and 3 cases in the ICU of Bangkok Phitsanulok Hospital.

B. ESTABLISHMENT OF A DATA CENTER

In the current project, a cloud-based Data Center was designed and developed and established as the center of a network encompassing the 18 medical centers.

The Data Center connects the information system of each hospital medical center, providing a central data repository and managing the data network. Figure 1 shows the overall networked information system by which each hospital is connected to the Data Center.

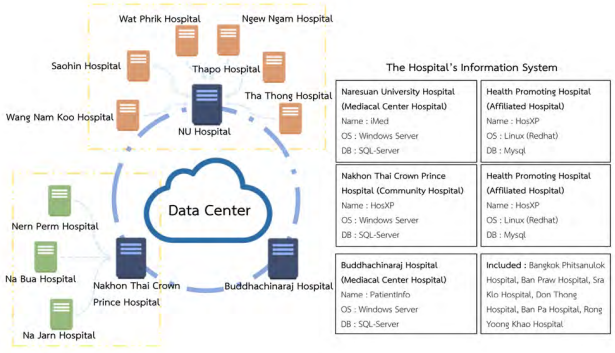


FIGURE 1. Overall information system network of 18 communication hospitals.

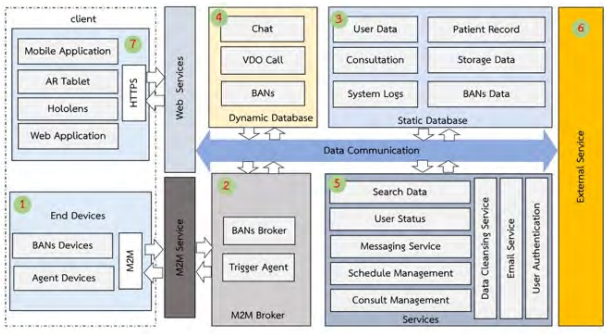


FIGURE 2. Structure of the data center.

The Data Center functioned as an information exchange and provided services for the End Devices; the Clients in this Client/Server network. Figure 2 shows the structure of the Data Center and network, which consists of:

1. End Device is a source or destination device which connects to Data Center,

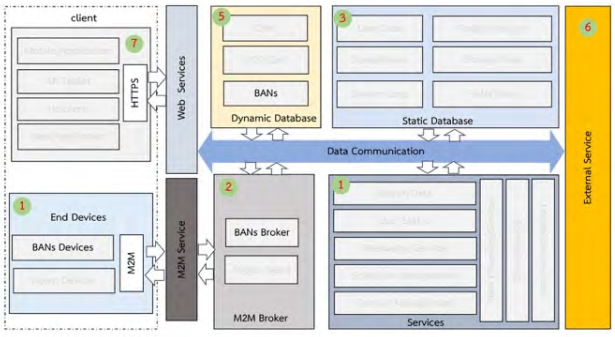


FIGURE 3. Component of the data center, which is relevant to services from body area networks (BANs).

2. M2M Broker is a service to manage communication using the Machine to Machine (M2M) communication protocol,
3. A read-only virtual database connecting to the hospital's information system (the Static Database),
4. A dynamic database that is periodically updated, synchronously updating data over time as new information becomes available,
5. External service, and
6. Clients.

A Body Area Network : BAN is a software service to receive and read the patient's vital signs and other data. A BAN consists of the client devices of a blood pressure sensor, snore sensor, body position sensor, temperature sensor, EMG sensor, ECG sensor, airflow sensor, GSR sensor, and glucometer sensor.

As illustrated in Figure 3, when a BAN device is connected, there is a M2M Broker which manages data communications and maintains the connection to the dynamic data structures of the Data Center, using the external services of the Data Center. Figure 4 illustrates calling an API to upload data from the device to the Data Center. The BAN also includes a Vital Signs measuring device that measures the vital signs of the patient. The connection between the BAN sensors and a mobile application (developed as part of our project) can associate the patient's information and their vital signs in order to categorize the specific information derived from an examination of the patient. The operation to connect patients' information and the information derived from the sensor devices is illustrated in Figure 5.

C. TELEMEDICINE USING HOLOLENS

Hologram technology, using virtual reality glasses, was used as the Telemedicine support technology, applying Mixed Reality, which is the combination of real world images and virtual world images. This system downloads the patients' information and full medical record, and requests a doctor consultation via a Mixed Reality video call through the HoloLens.

(a)

(b)

FIGURE 4. Calling API, (a) BANs cloud, (b) Electrocardiography (ECG) Sensor display.

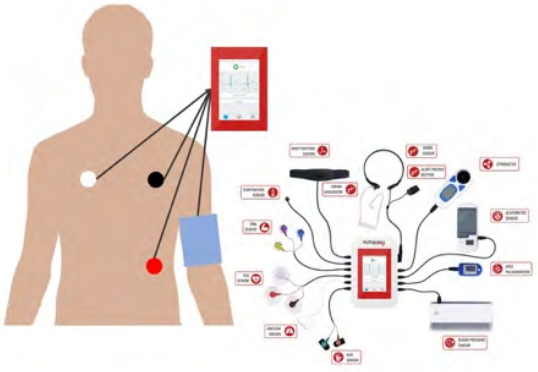


FIGURE 5. The connection of each sensor device to the patient's body to measure vital signs and physiology signs (www.my-signals.com).

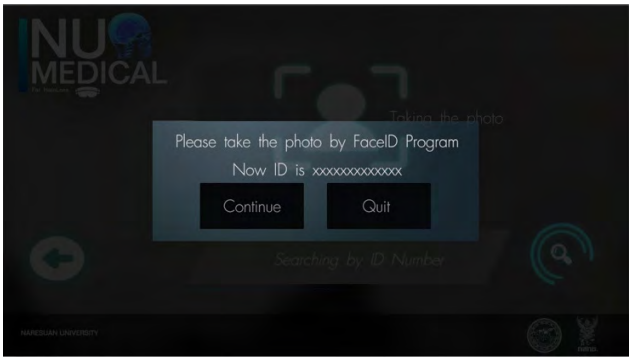
The functions of the HoloLens applications include Login, Patient History Search, Physiology and Signs Display of the patients (BANs). To operate the functions, the patient's information is searched using a Patient Identification Number (PID) or using Face ID, applying a Face Recognition process.

The HoloLens itself has three main functions: to search for and display patient history and current patient information and to make a consult request via a video call.

1) PATIENT HISTORY SEARCH

The search application functions in two ways: search via the PID or search via the Face ID. The user clicks on the 'Identification Number Search' box after keying in the PID.

(a)



(b)

FIGURE 6. Search via Face ID, (a) Face ID picturing by air tab (b) Search result.

The search via Face ID functions by transmitting a picture of the patient (using an Air Tab gesture) to the Data Center, where the system will verify the patient's identity using face recognition, and will then retrieve the patient's relevant information. This is shown in Figure 6.

2) PATIENT HISTORY DISPLAY

When the patient has been verified, their history will be displayed, including personal and medical information (Figure 7). The lower part of the page shows the patient's personal information; the visits section shows medical history, the diagnosis section shows diagnostic history, the order section shows medical history; the labs section shows lab results, and the MySignals section shows vital signs and physiological signals.

Figure 7 shows the page where the patient information history is displayed. For the medical information display, diagnostic history, medical history, and lab results, the link will first appear, showing date and time which is then a Time Stamp for the displayed data. After clicking on the link, the information will be displayed on the next page.

The medical history includes the patient's chief complaint (CC), present illness (PI), physical examination results (PE), body mass index (BMI), body weight (BW), height (HT), body temperature (BT), blood pressure (BP), pulse rate (PR), respiration rate (RR), and oxygen saturation (O_2SAT).

The diagnostic history includes the diagnosis date and the diagnosis results. The prescription history includes the

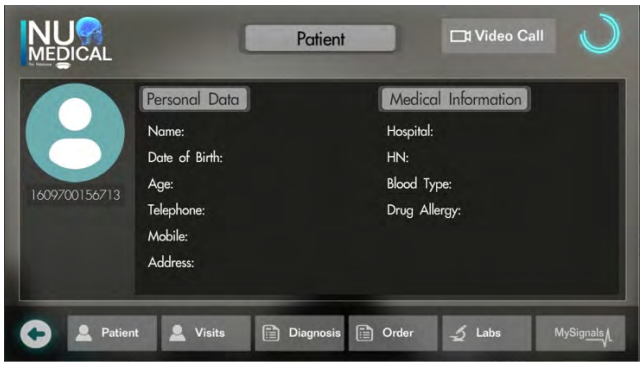
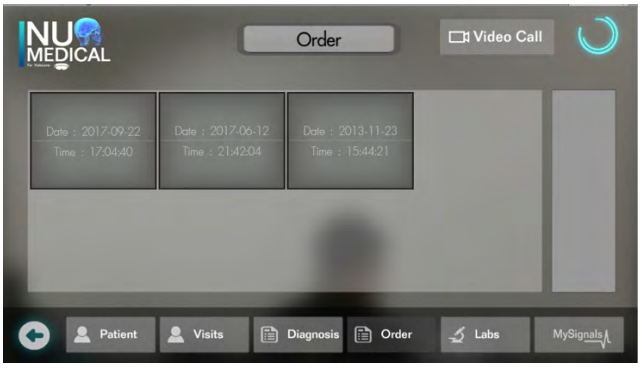
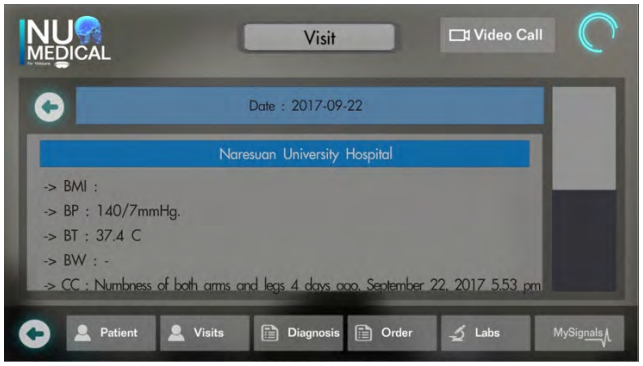


FIGURE 7. Patient's history display page.



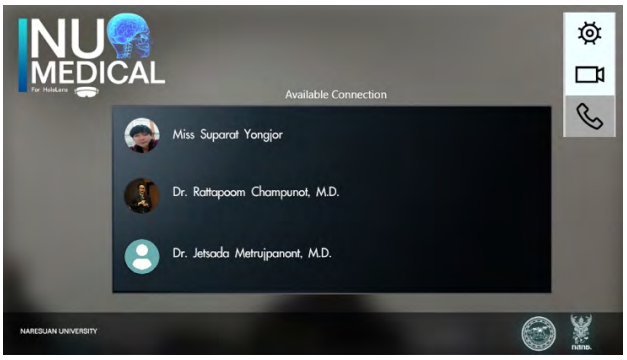
(a)



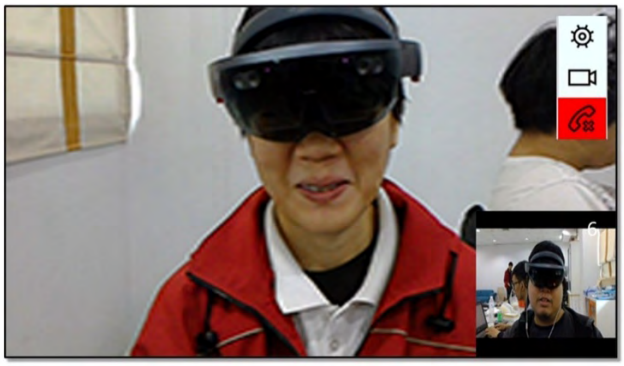
(b)

FIGURE 8. Lab result, (a) Patient's information display page (order). (b) Patient's information display page (Visit).

FIGURE 9. Vital signal display page.



(a)



(b)

FIGURE 10. Video call function, (a) Online members display page. (b) Video call display page.

dispensing date and prescription details, and the lab results include the investigation date and the list of lab results (see Figure 8).

In Figure 9, the patient's vital signs, which are connected to the BAN, will be displayed, which includes main information like temperature, O_2SAT, Scale Weight, Blood Pressure, and ECG graph.

3) CONSULT REQUEST VIA VIDEO CALL

Figure 10 (a), shows the consult request via video call. The user of the HoloLens can select the consulting physician from a list of available specialists. The system will send the signal to the specialist's HoloLens device. When the request is accepted, the system will create a channel for sending messages and voice, and the conversation can commence.

Figure 10 (b) shows the conversation, including interactive video images from the source camera and from the destination camera.

The video call system can be configured according to the user's requirements. Figure 11 shows the configuration page of the video call. Users can configure these four settings:

- Audio Codec : Edit the voice code format. The clarity of voice will be configured.
- Video Codec : Edit the video code format. The quality of the video will be configured.

FIGURE 11. Configuration page.

- Resolution : Edit the resolution of video. The resolution of the sent video will be configured. Of higher resolution is needed, more specification will be used.
- Capture frame rate : Edit the frame rate of the video. The picture number in one second will be configured.

IV. RESULTS AND DISCUSSION

A. HARDWARE

The HoloLens device is a lightweight (579 g), wearable holographic system with high computational power (1trillion calc. per second, 2GB RAM) used for human-computer interaction in pathology. It enables holographic images to be visualized from the user's perspective in a mixed-reality environment. Its components include: a high resolution widescreen stereoscopic head-mounted display (1268 × 720 pixels, 16:9 aspect ratio, and 60-Hz refresh rate) with tinted holographic lenses; a depth camera (120° × 120°), and 4 additional environment and ambient light sensitive built-in cameras; with an integrated speaker and four 2-way communication microphones. Memory and data storage is 64GB internal flash storage with Bluetooth (4.1 low energy) wireless communication, and a battery life of 3 hours during active use and 2 weeks standby time. This device also contains a Bluetooth connected clicker accessory for seamless physical commands interactions in lieu of gaze, voice commands, and/or hand gestures.

The HoloLens operates on the holographic platform of the Windows 10 operating system and also contains the Microsoft application repository. The Windows Store enables direct download and installation of HoloLens applications. The device's interactions interface for the AR environment is leveraged on gaze input (head tracking), gesture (bloom, air tap, press and hold), and voice commands. Photo and video capturing were designed to allow voice commands and instructions using Microsoft's intelligent personal assistant, Cortana.

B. DATA CENTER

Following successful function tests and practice use with the system developed by the research team, the system was installed in 18 cooperating hospitals for medical and nursing personnel to use, importantly for the medical specialists to begin on-line consultations.

As explained previously, the Data Center System is the intermediary for the internal transfer of information comprising of the data system, the usage system, and the patient's information by developing the application connected to the data. In the system testing, it was necessary to install the related equipment to ensure that the system functioned properly. Installing the teleconsulting system included the hardware installation and then allowing user registration via the Admin System.

1) HARDWARE INSTALLATION AND SOFTWARE AGENT

The hardware and software agents are the channels connecting the local 'client' hospitals with the Data Center information system. Each hospital may have a different hardware and software configuration requiring the software agents to be configured specifically to each hospital. At the central hospital, this is under the control of the IT staff and system administrators, which ensures that the software agent can be simply and conveniently installed. However, at a local hospital, there is usually, or often, insufficient computing and server resources, and little technical expertise. To overcome this problem, Raspberry Pi devices were used as the hardware agent connecting the hospital to the server located at the central hospital. This resulted in the management of the information to be error-free, with fewer problems being experienced on the local server.

2) REGISTRATION VIA ADMIN SYSTEM

User registration was via the admin system which categorized users according to a hospital group, known as the Contacting Unit of Primary Care (CUP). In this project, three CUPs were available at Naresuan University Hospital, which incorporated six hospitals. Buddhachinaraj Hospital's CUP included four hospitals, and Nakhon Thai Crown Prince Hospital's CUP included four hospitals. In all, eighteen hospitals were included in the system. Each hospital required a system administrator who manages the information of the CUP to which they belong.

Overall, 116 medical and nursing personnel participated in the consultation system.

C. IMPLEMENTATION OF HOLOLENS

The researchers conducted the consulting system via HoloLens for ICU patients in Buddhachinaraj Hospital. As discussed, there is a shortage of critical care doctors in the Thai health system which leads to a high rate of risk rate of degeneration and death of ICU patients. There is also a shortage of well-experienced ICU nurses, but even so, the ICU nurses in the system are well able to care for critically ill patients and are capable of assisting in respirator installation, critical patient separation, and vital sign and dynamic rate of blood monitoring to support even doctors who are not experienced. By using the telemedicine system that we have developed and proven the inexperienced doctors can still consult and swiftly obtain advice from specialist practitioners either internal to the hospital or remote.

TABLE 1. Version updating of the consulting system via HoloLens.

Date	Details
June-August 2017	• Develop Unity 5.6.0 • Develop the system using the HoloLens Toolkit v1.5.6.0 • Develop the UI as a 3D App • Develop the API for downloading information from Firebase by using Node.js to display it on the page • Develop the FaceID API. • Develop Video Calling by using Plugins WebRTC Video Chat
4 Sep 2017	• Upgrade to Unity 2017.1.1 • Upgrade to HoloLens Toolkit v1.2017.1.1
4 Sep 2017	• Change to the 2D App UI.
5 Sep 2017	• Add the information search system and display all the data
6 Sep 2017	• Modify all UIs
14 Sep 2017	• Add the Log-In system
22 Sep 2017	• Develop Video Call by conducting PeerCC using WebRTC
3 Oct 2017	• Develop Signaling Server for Video Call system
20 Oct 2017	• Integrate Video Call system with the main application
10 Nov 2017	• Add Vital Signs display on the main application
15 Nov 2017	• Categorize users as doctor or nurse
19 Nov 2017	• Add the Speech Recognition system
14 Dec 2017	• Separate the vital signs display to another application
18 Dec 2017	• Change all of the Scrolling and menu buttons on UIs
22 Dec 2017	• Add passwords on Signaling Server
26 Dec 2017	• Reorganize user access authorities
9 Apr 2018	• Adjust the application to improve usability
Date	**Details**
7 May 2018	• Adjust the Signaling Server
7 May 2018	• Swap the display on the nurse side of Video Call

The adoption of the HoloLens in the treatment and care of ICU patients clearly increases the help available to the medical and nursing staff and provides a high level of security for the patients. In the current project, we used the HoloLens system in the Cardiovascularthoracic (CVT) ICU, Emergency Trauma ICU, and Surgical ICU Buddhachinaraj Hospital, and in the ICU unit of Bangkok Phitsanulok Hospital. The details of how the HoloLens was used in these environments are shown in Table I. The system update lists are shown in Table II.

The installation and demonstration of use at Buddhachinaraj Hospital are shown in the photos of the event held in the conference room in Buddhachinaraj Hospital, Phitsanulok (March 30, 2018), at which 50 participants attended (see Figure 12).

D. CONSULTATION USING THE HOLOLENS

The researchers conducted consultations using the HoloLens technology to help care for critically ill patients in the ICU. The doctors and nurses in the ICU are the requestors and the specialist medical practitioner is the consultant. The procedures are as follows:

1) The requestors choose a suitable patient, whose medical condition is too complex for them to handle, to present for consultation to the critical care doctor.

TABLE 2. The operational problems of the consulting system via HoloLens as reported by the users, with the solution report from the researchers.

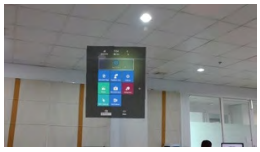
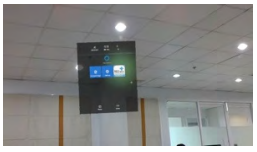
Problems found	Solutions
1. A request to have incoming videos displayed on the big screen and the videos transmitted to the consultants displayed on the small one.	The developers modified the displays to achieve the requested processing.
2. Remove unused icons and bring the icons from the HoloLens Consult back to the Start Menu 	Unpin other applications and pin the HoloLens Consult on to the Start Menu. 

FIGURE 12. Activity and demonstration photos.

2) The critical care doctor assesses the condition of the patient and decides if an E-consultation through a phone call is appropriate.
3) If the condition is too complex for an E-consultation through a phone call, the HoloLens is used for the consultation.
4) The local junior doctor and ICU nurse complete the information and questionnaire after the consultation with the doctor, using the HoloLens

The E-Consultant system of the HoloLens was used with the selected patients, nurses and medical professionals during procedures carried out in the CVT ICU, Emergency Trauma ICU, and Surgical ICU of Buddhachinaraj Hospital, and in the ICU unit of Bangkok Phitsanulok Hospital. During these procedures, there were two specialist physicians and a group of ICU nurses. The project ran from 1st April 2018 to 1st May 2018, during which period 17 patients participated in the treatment during which the HoloLens was used. This included 7 cases of Cardiovascularthoracic Surgery, 4 surgery cases, 3 emergency trauma cases, and 3 cases in the ICU unit

TABLE 3. Patients' information in consulting with HoloLens.

#	Date	Service Unit	Starting Time	Ending Time	LOS in ICU	SOS Score (While consulting)	Surgery
1	26/04/2018	ICU CVT	20.00	20.02	58	14	NO
2	26/04/2018	ICU CVT	20.02	20.04	1	3	YES
3	26/04/2018	ICU CVT	20.04	20.06	1	0	YES
4	26/04/2018	ICU CVT	20.06	20.08	40	7	YES
5	27/04/2018	ICU CVT	09.15	09.30	-	-	-
6	28/04/2018	ICU CVT	22.20	22.30	60	8	YES
7	11/05/2018	ICU CVT	22.00	22.05	15	7	YES
8	14/04/2018	ICU Surg.	10.00	10.30	17	10	YES
9	18/04/2018	ICU Surg.	20.00	20.40	-	-	-
10	21/04/2018	ICU Surg.	19.00	19.30	-	6	YES
11	30/04/2018	ICU Surg.	21.30	22.05	3	-	YES
12	4/05/2018	ICU TRAUMA	11.30	11.40	-	4	YES
13	4/05/2018	ICU TRAUMA	12.30	12.45	8	3	YES
14	5/05/2018	ICU TRAUMA	10.00	10.15	-	5	YES
15	15/04/2018	ICU Bangkok Hospital	13.00	13.30	12	5	YES
16	15/04/2018	ICU Bangkok Hospital	13.30	13.45	30	5-8	NO
17	29/04/2018	ICU Bangkok Hospital	9.30	10.00	7	5	NO

TABLE 4. The present Status of HoloLens.

#	Date	Service Unit	HoloLens Equipment	WIFI Equipment	Image& Sound Signal	Satisfaction
1	26/04/2018	ICU CVT	Available	Available	Available	3
2	26/04/2018	ICU CVT	Available	Available	Available	3
3	26/04/2018	ICU CVT	Available	Available	Available	3
4	26/04/2018	ICU CVT	Available	Available	Available	3
5	27/04/2018	ICU CVT	Available	Available	Available	3
6	28/04/2018	ICU CVT	Available	Available	Available	3
7	11/05/2018	ICU CVT	Available	Available	Available	3
8	14/04/2018	ICU Surg.	Available	Available	Available	4
9	18/04/2018	ICU Surg.	-	-	-	-
10	21/04/2018	ICU Surg.	Available	Available	Available	4
11	30/04/2018	ICU Surg.	Available	Available	Available	4
12	4/05/2018	ICU TRAUMA	Available	Available	Available	4
13	4/05/2018	ICU TRAUMA	Available	Available	Available	-
14	5/05/2018	ICU TRAUMA	Available	Available	Available	3
15	15/04/2018	ICU Bangkok Hospital	Available	Available	Available	3
16	15/04/2018	ICU Bangkok Hospital	Available	Available	Available	3
17	29/04/2018	ICU Bangkok Hospital	Available	Available	Available	3

from Bangkok Phitsanulok Hospital (see Tables III-IV and Figure 13).

E. ANALYSIS

Between 19th April 2018 and 19th May 2018, the researchers conducted developmental testing of the E-Consultant system through 3D Hologram at Buddhachinaraj Hospital and Bangkok Phitsanulok Hospital. The process included the critical care physicians advising the nurses, and data was collected regarding the participating patients.

FIGURE 13. HoloLens testing held on 10th November at Buddhachinaraj Hospital, Phitsanulok.

TABLE 5. Users' satisfaction.

Topic	Satisfaction 5	4	3	2	1	Total	Mean	SD
1. HoloLens								
1.1 HoloLens is interesting.	7	8	1	-	-	70	4.37	0.62
1.2 The consultation system of HoloLens is easy and simple.	-	6	8	1	1	51	3.19	0.83
1.3 The resolution is high.	2	8	5	1	-	59	3.69	0.79
1.4 The sound is clear.	2	8	4	2	-	58	3.62	0.88
1.5 HoloLens has the right view of the image	1	6	7	2	-	54	3.37	0.81
1.6 Internet Stability	-	-	7	7	2	37	2.31	0.70
2. The Usefulness of HoloLens								
2.1 The integration of technology is useful and practical for solving medical problems.	2	10	4	-	-	62	3.87	0.62
2.2 The convenience of consultation compared to the old way.	-	5	8	3	-	50	3.12	0.72
2.3 Users get full usage of HoloLens.	2	9	5	-	-	61	3.81	0.65
2.4 It is the case study for users as an effective medical consultation.	2	10	4	-	-	62	3.87	0.62
2.5 Further development is needed for the most effective and covered benefits for medical personnel	9	6	1	-	-	72	4.50	0.63
3. Development Team								
3.1 Speed of solving problems	1	9	6	-	-	59	3.69	0.60
3.2 The satisfaction of the team	1	12	3	-	-	62	3.87	0.50
3.3 The attention of the team	1	11	4	-	-	61	3.81	0.54
3.4 The team delivered messages clearly and understandingly.	1	10	5	-	-	60	3.75	0.58

Overall, 2 physicians and 15 nurses collaborated in the use of the E-Consultant system through 3D Hologram. At the end of

the test period, the physicians and the nurses were requested to evaluate the project, based on their experience in using the HoloLens.

Analysis of the results of a satisfaction survey of the collaboration amongst the medical practitioners (doctors and nurses) and the development team showed that the average satisfaction was 4.37 for system usability and 4.5 for the benefits identified, and average satisfaction with the development team was 3.87, both out of a maximum score of 5 points. This evaluation demonstrates the reliability and efficiency of deploying HoloLens and Hologram devices, and justifies their use in E-Consulting systems in ICU centers (see Table V).

V. CONCLUSION AND FUTURE WORK

The use of the HoloLens in critical care was demonstrated to be highly beneficial in the provision of care and preventing or reducing the rate of morbidity and mortality. However, we found that HoloLens technology that sufficient training must be provided to users before it can be implemented; users are entirely unused to such technology, and may well continue in their reliance on telephones for consultation and using video calls through various applications, such as Skype and LINE.

Most problems with using HoloLens were related to the hardware and to the stability of the connection. The hardware problems were the size of the HoloLens lens, the weight, and the heat generated when using it, particularly if worn for more than 30 minutes when the wearer can become fatigued as well. The problem of signal and connection stability is directly related to the quality of the Internet; availability and speed, and to the speed of the wireless signal used in the connection. We can hope for, and expect, further developments in both the hardware and the system in the near future, and guaranteed connectivity, all of which will contribute to improving the efficiency, effectiveness and usability of the HoloLens system.

Even though the HoloLens devices are rather costly in monetary terms, the benefits of using such a device and system to provide ICU consultations are incalculable. Prompt consultation with a specialist is an imperative, and is well worth the cost. Further study of, and development of, such technology in the future seems essential to improving medical services, especially in the situation envisaged, that of remote and under-serviced areas and small medical centers.

Further development is needed to attain greater convenience by including smartphones, tablets and LED screen in the information display and interaction. One important aspect would be the convenience to the consulting physician of using his smartphone rather than being required to wear a HoloLens device. Displays on an LED screen would enable patients to be more directly involved in the consultation, seeing and directly communicating with the physician.

Furthermore, using this technology for developing personnel resources, and as an education and training tool, would greatly assist in overcoming the shortages of personnel currently being experienced. It can also be used to increase the efficacy of patient bedside teaching for physician-funded teams and nurses in ICUs, who have little experience and opportunity to study with specialists in Critical Care Medicine.

ACKNOWLEDGMENTS

The authors would like to thank Mr Roy I. Morien of the Naresuan University Graduate School for his assistance in editing the English grammar and expression.

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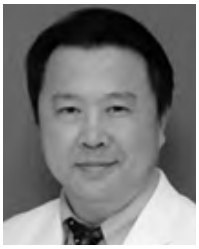

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