A concept of medical expertise pooling by tele sensing and manipulation: emergency medicine case

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Abstract— **Physicians are not evenly distributed throughout the United States. To overcome this physical limitation, we propose a concept of medical expertise pooling, which will re-distribute the expertise throughout the nation more evenly. To establish this concept, we are proposing a system with emerging tele sensing and manipulation technologies over the network. In case of emergency, the proposed system can particularly be more important as it will provide more efficient support in the critical battle against time for diagnosis and treatment of a patient. Despite the physical constraint of long distance between the physician and the patient, the system will provide the visual, body sound and tactile feedback to ensure timely diagnosis and treatment that can contribute to increase in survival rates. While the proposed system utilizes existing technologies and resources, it is highly innovative as it implements a medical expert pooling paradigm that can lead to significant advancements in patient care.**

I. INTRODUCTION

According to the 2016 census of actively licensed physicians in the United States, the total number of physicians (953,695) in the United States represent a physician-to-population ratio of 295 actively licensed physicians per 100,000-population [1]. Also, District of Columbia represents the highest and Texas represents the lowest number of physicians per 100,000 population as mentioned in Table 1 [1]. Since the medical expertise are not evenly distributed throughout all the states and physically it is not possible to control the number of physicians in each state, we propose a concept of medical expertise pooling by utilizing and sharing the total number of physicians all over the nation.

TABLE I.   HIGHEST AND LOWEST NUMBER OF PHYSICIANS BY STATE [1]

Most Populated Physicians by State	Total No. of Physicians	Physicians per 100,000 Population
District of Columbia	12,520	1,838
Hawaii	9,464	662
Wyoming	3,775	645
Least Populated Physicians by State	**Total No. of Physicians**	**Physicians per 100,000 Population**
Texas	77,894	280
Nevada	8,861	301
Alabama	15,947	328

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We define the concept of pooling as sharing the existing medical expertise through network. Our purpose is to utilize available physicians to provide diagnosis and treatment of patients regardless of their physical location. To make our idea possible, we propose a medical support system incorporating emerging technologies which consists of a patient unit that communicates with a provider unit via high speed network.

When a physician receives a patient, he/she will read vitals, see any visual signs, and listen to heart, lung and bowel sounds using a stethoscope, also if necessary, he/she will touch the patient body to understand and detect the physical condition i.e. palpation. Careful monitoring of these vital data especially at the earlier stage is important [2]–[4]. In our system, we will incorporate a bi-directional telemedicine device that is capable of receiving and transmitting medical data such as vital signs in real time. The system will provide access to remote user controlled video camera and pointer with text advice capability. This will maximize the telemedical support capacity and minimize physical needs from the onsite medical support personnel. This facility will satisfy the need of reading and seeing the visual signs. The system will also have the unique capability of providing touch to diagnose the physical condition of the patient through palpation and for enabling listening capability, bioacoustics utility (skin-attached electronic stethoscope) will be incorporated for continuous body sound monitoring.

Several research in past have concentrated on monitoring of health status of people [5]. The commonly used vital signs are heart pulse rate, body temperature, and electrocardiography [6]. Medical transportation facilities and delivery issues have also been studied [7]–[9]. Many general and specific purpose models have been proposed [2], [7]–[13]. Most of these research on modern healthcare systems are focused on either some specific healthcare device or a system which is controlled locally or within a physically limited area. If a healthcare system is controlled locally or limited within a specific area then the system can only utilize the concentrated medical resources available in that particular area which may not have proper expertise or medical personnel needed on a particular case.

Though our proposed concept of pooling medical expertise can be applied to general medicine, this could be particularly useful in emergency medical and military casualty care. For example, Florida is the most hurricane-prone state. Of the category 4 or higher storms that have struck the United States, 83% have either hit Florida or Texas [14]. It is highly likely during such conditions that essential medical personnel may evacuate the affected place

leaving limited resources at the hand of state authorities. Moreover, the hospitals may not have the capacity to treat a large number of patients. In this emergency situation, our concept of pooling of medical experts can be utilized. Available medical experts from other states can be connected through our proposed system and provide appropriate medical assistance. Despite the physical constraint of large distance between the physician and the patient, the system will provide the visual, body sound and tactile also known as haptic feedback to ensure timely diagnosis resulting in minimum casualty rate.

II. ENABLING TECHNOLOGIES

The enabling technologies for the proposed system are found in the field of following core technologies:

Bioacoustics: audible signal acquisition. Auscultation is a valuable and common method of diagnosing cardiopulmonary conditions. Our proposed skin-attached electronic stethoscope will be connected to the bi-directional telemedicine unit for continuous body sounds monitoring. The small form factor and digital processing can allow ECG-like monitoring of body sounds, which would be particularly useful for detecting progressing changes in patient's body. Several studies, for example, have shown that certain acoustic signatures are consistent with the occurrence of pneumothorax, endotracheal tube malpositioning, or cardiac conditions [4], [15]–[17]. Electronic stethoscope technology enables sound magnification, noise canceling and data digitization. Electronic stethoscopes are often used to provide amplified and/or noise filtered body sounds where noise distracts hearing[16], [18], [19]. Moreover, digital data processing can detect acoustic characteristics that human ear cannot perceive [4],[16]. However, it has not been implemented in multiple vital sign monitoring devices as continuous monitoring of body sounds is under-utilized, partially because related equipment is not widely available.

Our proposed bioacoustics monitoring device includes a skin attached stethoscope design as shown in Fig. 1. It consists of a piezoelectric disc contact sensor that proved both sturdy and effective in acquiring body sounds for over a decade in our studies of body sounds. The disc output is amplified via an instrumentation quality amplifier. A sturdy sensor (23 mm diameter and 9 mm thick) with a mass of 20 grams is developed for detecting body sounds in the emergency department. This amplifier/disc combination has a proven successful performance during our pilot studies. Although we have established the stethoscope design based on the literature and our pilot studies, some key variables will be optimized to further maximize performance.
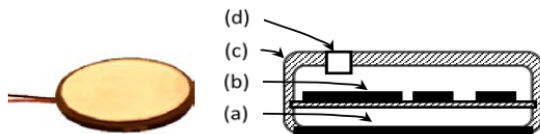

Figure 1. The sturdy acoustic contact sensor that we developed for noisy emergency rooms, design of the proposed stethoscope (a) piezoelectric disc; (b) circuit boards for amplification and filtering; (c) casing; (d) ambient noise microphone.

Haptics: tactile feedback from palpation. We propose to use haptic feedback to enable physical touch through the communication module directly to the physician and tactile imaging to see the phenomena (i.e. if any kind of nodules) to enhance diagnosis. Palpation can be helpful to detect diseases such as breast cancer and thyroid nodule [20]–[22]. It will be beneficial to have the option to feel nodules by the physician to give some preliminary decisions. A mechanical imaging device named SureTouch shown in Fig. 2 is already in the market to produce tactile imaging for breast palpation which can detect shape, size, and location [23].
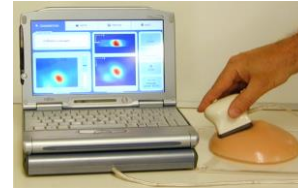

Figure 2. Palpation of breast and tactile imaging by SureTouch (Photo from Wikipedia)

Also, a thin film has been developed to produce tactile imaging of the breast [24]. Further, these tactile visual images can be used to produce pseudo haptics with the existing technology for the physician to feel the nodules or lumps with a haptics device [25], [26]. To extend this further to give the physician the actual texture, a surface can be created which will change its texture according to the input from the tactile image. This kind of technology is already under development using soft robotics, which can be integrated with the tactile imaging. Thus, when a physician sweeps his/her hand over the surface, he/she will be able to feel the lump.

Robotics: bi-directional control. The video and indicator module that can be attached to the ceiling of a transportation vehicle, will be similar to a small controllable CCTV camera or webcam. In addition, we integrate a controllable laser pointer to localize a point of interest. Control of the module can be achieved by conventional visual servoing e.g. control joystick to move the pointer. Once the video module is attached to a fixed location, the local coordinate system can be used for the control as long as the patient remains at the same location. This approach seeks synergy from image-guided robotic intervention technology from medical robotics. In our proposed system, a simple robotics technology is utilized in controlling video camera and pointer by enabling telemedical support using a bi-directional telemedicine unit device that transmits critical medical information to medical experts who can provide well-informed, life-saving decisions for the remote patient. However, once the fundamental bi-directional control is established, more complex robotics such as a robotic arm to provide physical support can easily be included.

III. SYSTEM DESIGN

We divide our proposed system into patient unit and provider unit as shown in Fig. 3. The patient unit consists of three modules i.e. video and indicator module, bioacoustics module and haptic module. The patient unit will be
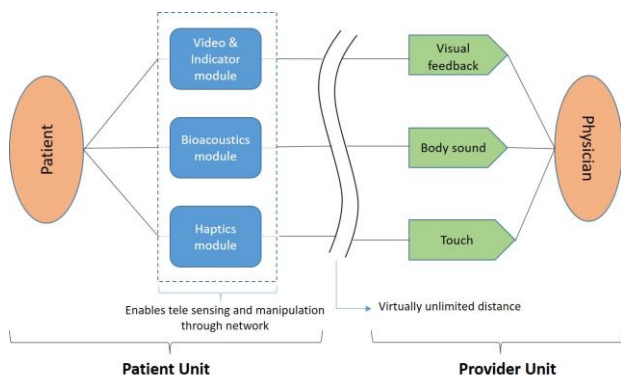
Figure 3. System Architecture

connected to the provider unit through network allowing virtual sensing capability to the physician. The provider unit will play a major role to establish the concept of pooling of medical expertise. The provider unit is responsible for collecting, managing and demonstrating the tele sensing to the physicians so that physicians can diagnose the patient and provide necessary feedback accordingly.

A. Patient unit

Patient unit will be the module that receives various medical data from portable medical data acquisition devices such as vital signs machine with plug-and-play function. The device will be similar to Tempus Pro™, a handheld or interactive monitoring device that can read and transmit medical data in real time shown in Fig. 4. Though Tempus Pro™ is mainly used as primary health monitoring device in US military [27], this kind of device can also be used for civilian purposes.

Figure 4: A handheld or interactive monitoring device, Ex: Tempus Pro™ (Photo from rdtltd.com)

We will connect portable vital signs machine that follows sharable data format. In order to design the system with realistic networking capacity, we will include a simple robotic camera and/or laser pointer indicator as a bi-directional output. Enabling the control i.e. bi-directional communication would be essentially the same when expanding to more complex telemedical system such as robotic arm to perform remote treatments. We will use the video input on-demand so that other monitoring will not be usually delayed. If needed, high-resolution video can be transmitted on-demand. Other medical data are small in size hence, we anticipate no latency issues from this system. The laser indicator is to provide means to localize point of interest by a telemedical support who can advise the medic at the site. We will also utilize the screen on the device to display simple text lines to ensure that advice from

telemedical support is clearly provided and recorded during noise ground/air transportation.

B. Provider unit

Our proposed provider unit will function as a telemedicine support system (TSS), where multiple stations can be grouped for an online healthcare team e.g. consisting of specialty physicians and nurses as shown in Fig. 5. We propose to employ a high-power workstation to accommodate necessary computing, input/output, and archiving functions. In the development stage, the station runs as a server. However, centralized servers can be established and each provider unit can access the server to utilize common operational functions and standards. From

Figure 5: Telemedicine support system. (Photo from npr.org).

telemedical support user station, physician can use various input devices such as mouse, joystick, and touch screen to control the camera and the laser pointer.

C. Network communication

A number of emergency telemedicine solutions, particularly remote monitoring, have been proposed by adopting 3G network [7], [28]–[30]. These studies are restricted to short distances and limited capabilities. In this paper, we propose a reliable and fast communication network for longer distances. The reliable and real-time delivery of medical data of patients to a distant medical facility is the key for our proposed system. In our system, the data will be sent wirelessly over long distances through our proposed advanced wireless communication system. To enable real-time delivery of signals and possibly videos, we propose to use 3G/4G cellular technology. The patient's vital signals are collected and recorded on a sub-system, which we refer to as the patient unit. The data is then processed. The processed data will be transmitted to a cellular base station through a 3G/4G modem. The data is then sent to the medical facility through the Internet.

An important aspect of our system is its efficiency. In other words, we would like to transmit as little information as possible without losing the accuracy of data. Besides reliability, the timely delivery of the information of patients is of vital importance. Unfortunately, wireless networks are prone to packet losses. Therefore, we need to use a form of error-correction mechanism which recovers the lost data. Possible techniques are automatic repeat request (ARQ) and forward error correction (FEC) coding. To ensure a fast and reliable communication over wireless networks, we propose to use rateless coding [31]–[33], a modern FEC technique, in the application layer, over UDP.

IV. Discussion

In this paper, we proposed the concept of medical expertise pooling with an efficient medical support system that could enhance patient's quality of life. In particular, in case of emergency situation, the system will support the critical diagnosis and treatment. Our vision is to diagnose the patient early, before hospital arrival, so that he/she does not have to undergo typical examinations that need to be performed in the hospital. Once diagnosed using our proposed bi-directional patient unit and provider unit, medical experts can provide assistance whether the patient needs to be admitted to a hospital or simple treatment can be done by local providers. Therefore, the proposed system could save time and resources at hospital, which could be critical, especially in mass casualty events.

Since early diagnostics is particularly essential before any physician can start a treatment, the system we have proposed, for now, is diagnostics focused. However, once the concept of medical experts pooling is effectively developed, the current system can be extended by incorporating additional technologies and devices to make the diagnostic and treatment procedure more efficient.

The effort is highly innovative because the proposed system and the medical expert pooling paradigm utilize existing technologies and resources yet creating significant advancements. The proposed development is also vastly transformative since the proposed medical support paradigm can revolutionize the emergency medical support system using available physician resources all over the nation. This paradigm could well be implemented for combat causality care in military medicine and rural medical support in civilian healthcare.

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