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An augmented reality-supported mobile application for diagnosis of heart diseases

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Abstract

Nowadays, it is important to design and develop effective applications for improving solution experiences in the fields associated with studies of biomedical and health informatics. Along with rapid developments in computer and electronics technologies, that has become more important in especially twenty-first century. Moving from that, main objective of this study is to deal with the problem of heart sound analysis and disease diagnosis by using a mobile application that can perform the mentioned tasks by having also support from both virtual reality- and augmented reality-oriented components. Thanks to the using features and functions provided over the application, it is possible to analyze signals instantly and have rapid feedback over the interface supported with virtual or mixed reality objects as combining both real and virtual worlds in a common ground. The paper briefly focuses on technical background and essentials of the developed mobile system and then evaluates its performance in the context of different perspectives.

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1 Introduction

Technological improvements in computer- and software-oriented technologies make it better to experience real-world-based tasks easier in every field of the modern life. It has become always important for the humankind to deal with the real-world problems with effective tools, and the expressed technologies have taken that many steps away, as a result of rapid developments. Today, we can use just our mobile devices to perform some tasks or reach to the desired information over the communication network like Internet. At this point, it is also important that there are many different software-oriented components aiming to improve our using experiences. The approaches for high interaction have an important place here because of their mechanism to combine different elements in a common area to trigger different points leading to improvement in experiences. When we discuss about especially mobile devices and improved interaction, both virtual reality (VR) and augmented reality (AR) have a popular place today.

Reality is shaped differently in software environments thanks to VR and AR. With its role to ensure interaction between the software environment and the user, VR has a remarkable place and an important historical background [1–5]. Not for only recent years, but also for certain, remarkable time period in the twentieth century, VR had popularity in especially entertainment [6–8]. But in time, it has been figured out that there is much more need for VR in different fields, which are associated with real-world tasks—problems [9–16]. After a while, the concept of the mixed reality has raised and as one of popular application type in this manner: augmented reality (AR) has taken its place in the related literature [17–20]. With its role on placing virtual components to the view of real-world [21, 22], AR has gained popularity in a very short time because that has been a revolutionary step in improving experience for applied tasks, which means better training and understanding of the facts in addition to already improved entertainment sides [23–26].

Main objective of this study is to deal with the problem of heart sound analysis and disease diagnosis by using a mobile application that can perform the mentioned tasks by having also support from both virtual reality- and augmented reality-oriented components. Considering this objective, the study also tries to find answers to the following research questions:

- Is it possible to develop a successful and usable enough mobile application for heart sound analysis and performing disease diagnosis?
- How can an effective processing flow for heart sound analysis and disease diagnosis approach be designed?
- Is it possible to diagnose vital diseases like murmur and extra-systole by using such a mobile application?
- Can such a mobile application improve doctors' working efficiency at the end?

- How can AR and VR be used in that application in order to improve interaction and usability?

Thanks to the using features and functions provided over the application, it is possible to analyze signals instantly and have rapid feedback over the interface supported with virtual or mixed reality objects as combining both real and virtual worlds in a common ground. With the advantages of mobile devices [27–29] and the scientific approach regarding analysis and diagnosis of heart sounds [30, 31], the application is believed to be an effective tool for doctors and experts working in especially cardiology. As mobile devices became effective assistances for supporting our daily tasks, the solution approach provided here is an alternative work for improving working experience and interaction in the field of medicine.

As associated with the research followed here, the remaining content is organized as follows: the next section focuses on some examples of medical and heart disease-oriented applications of both VR and AR, as reported in the literature. Following that, the third section gives information about the solution approach and used technologies in the context of the mobile application. Next, some explanations on using the mobile application are provided under the fourth section. After that, the fifth section focuses on some evaluation works done for understanding especially success, effectiveness and efficiency of the mobile application (solution approach considered). Following that, the sixth section provides a general discussion and the paper is ended with conclusions and future works discussed in the last section.

2 Brief literature review

The literature of medical focusing on using VR and AR has a long past in a historical manner. In this context, some remarkable studies can be explained briefly as follows:

- You et al. [32] used VR to realize a supportive approach for cortical reorganization and associated locomotor recovery in chronic stroke.
- For stroke rehabilitation, Saposnik et al. [33] employed VR to perform a general meta-analysis and application for clinicians.
- Weidenbach et al. [34] used AR for achieving a training approach for examining better two-dimensional echocardiography.
- Marescaux and Diana [35] explained the hybrid image-guided surgery approach as an effective tool. In detail, they have used an AR-based system for their model.
- Regarding the use of AR for surgery tasks, Nicolau et al. [36] focused on laparoscopic surgical oncology. On the other hand, Bernhardt et al. [37] used AR for achieving automatic localization of endoscope in intraoperative CT image, as associated with laparoscopic surgery.
- General views on improving surgery experiences have also been a popular subject because of using AR to make interactions better. In this context, Tang et al. [38] provided a good view on AR and its medical applications.
- Birkfellner et al. [39] designed and developed a head-mounted device (binocular) for improving medical experiences with AR.

- De Buck et al. [40] had support from AR to develop a patient-specific system for treatment of cardiac arrhythmias by catheter ablation.
- Post-stroke hand opening rehabilitation is an important phase for patients. In order to improve that rehabilitation experience, Luo et al. [41] developed a device supported with AR.
- Khademi et al. [42] improved rehabilitation for human arm's stiffness, thanks to an AR-based solution as they reported in their study.
- In the context of medical education, AR has become a powerful tool. In the associated literature, there are different examples of studies examining potential of AR in medical training—education [43–46].
- For some more examples of VR- and AR-supported medical studies, readers are referred to [47–57].

As it can be seen from a brief view on the literature, there is a remarkable increasing interest in using interactive solutions like VR and AR, in order to achieve better applications over especially medical tasks. As reported in the related research studies, positive findings—results have been obtained with the use of such supportive technologies over mobile-based solution ideas. That has been a motivation for the study here and both main objective and research questions were shaped by moving from the idea of developing an alternative, mobile solution for analyzing heart sounds and even detect diseases, which are vital for well-being. As it is known, design and development of such mobile application are not enough to be sure about an effective analysis—diagnosis solution and further evaluation works should be done. Because of that, evaluations from different perspectives were also performed by also considering the research questions and main objective of the study.

3 Materials and methods

Doctors listen to heart sounds first to diagnose heart diseases. Listening to heart sounds is called auscultation and is a noninvasive practical method. Heart sounds give information about the pathological state of the heart. Conditions such as arrhythmia, murmur, extra-systole, heart valve disorders can be understood from heart sounds. It is known that diseases like murmur and extra-systole are vital diseases that require accurate analysis and because of that more consideration was given to them in this study. While considering diagnosis, it is important to understand more about characteristics of heart sounds and how to analyze them. Furthermore, the research question of "how can an effective processing flow for heart sound analysis and disease diagnosis approach be designed?" should be answered here, by designing a simple but fast running approach for especially mobile devices.

3.1 Characteristics of heart sounds

In diagnosing heart diseases, the graphics of the heart sounds are more important than the heart sounds. The graphs of the heart sounds produced by the mechanical movements around the heart pumping the body of blood also show symptoms of many

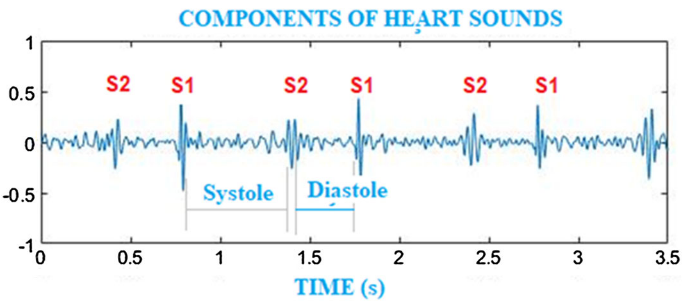

Fig. 1 General form and components of heart sounds [58]

heart problems. The general form and components of heart sounds are shown in Fig. 1 [58].

The heart sounds are mainly produced by opening and closing the heart valves between the upper and lower regions of the heart. The first sound is called S1 and is usually in the 30–100 Hz frequency range. The second sound is called S2 and the frequencies are usually more than 100 Hz. The interval between S1 and S2 sounds is called systole and the interval between S2 and S1 is called diastole [58]. In fact, heart sounds include S3 and S4 sounds, but normal adults are not heard during auscultation. Maybe it can be heard in some children [59].

3.2 Steps of for diagnosis within a mobile application

The signal analysis of the heart sounds is generally based on the time-dependent segmentation of S1 and S2 sounds. From these sounds, which describe heart cycles, the S1 sound indicates the systolic onset and the S2 systole is the last. The changes in the durations and intensities of the sounds in S1 and S2 are explained as definitive symptoms of heart diseases [60]. In this study, a mobile application that responds in normal, murmur and extra-systole by considering the time intervals and periodicity of S1 and S2 sounds were developed. In detail, the application is able to use graphs of online recorded heart sounds. The details of this application lie over an implemented by using a sensitive microphone with a suction cup and also a mobile phone with the Android operating system. General application flow regarding heart sound operations and displaying the results is shown briefly in Fig. 2. Details are explained under the next subtitles.

3.2.1 Heart sounds records

Heart sounds are recorded three times at 10-s intervals. In practice, the application waits for 5 s to be fully located the microphone and then records for 10 s. Then, 10 s is expected and 10 s recording is done again. For this reason, the user of the application must hold the microphone for about 1 min without moving properly.

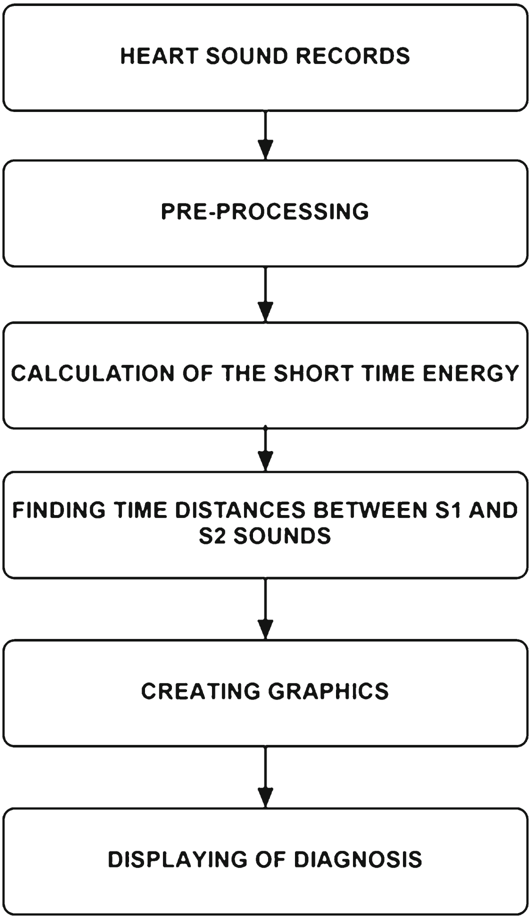

Fig. 2 General application flow

3.2.2 Preprocessing

When heart sounds are recorded, noises are recorded due to internal and external sounds. In addition, changes in the contact area between the microphone and the body also affect the recordings. For this reason, heart sounds are firstly normalized and followed by filtration. This process is called preprocessing. In this practice, heart sounds were normalized to the [− 1 1] scale. Then, filtering was performed with Elliptic filter by taking advantage of previous experiences [61].

3.2.3 Calculation of the short time energy

To determine the beginning and ending points of the sounds, it should be determined from the short time sound energy from the 1970s. Calculation of the short time energy of the sound signal is a very simple process when compared to other processes. There are two basic parameters in processing the sound signal, such as zero crossing speed

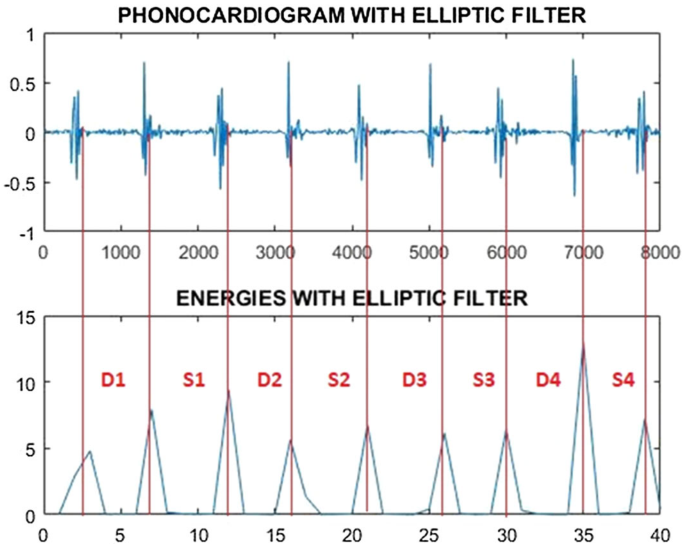

Fig. 3 The short time energy graph of heart sound

and short time energy. In general, these two parameters are calculated before others. A short time energy calculation is used to calculate the energy that the sound signal has at a given time. The short time energy calculation has three different definitions [62, 63]. In this study, a sum of square energy function in Eq. 3 was used with resampling of the filtered signal

$$\text{Logarithm energy: } E = \sum_{i=1}^{N} \log x(i)^2 \tag{1}$$

$$\text{Sum of square energy: } E = \sum_{i=1}^{N} x(i)^2 \tag{2}$$

$$\text{Sum of absolute energy: } E = \sum_{i=1}^{N} |x(i)|. \tag{3}$$

3.2.4 Finding time distances between $S1$ and $S2$ sounds

As shown in Fig. 3, the energy graphs of the heart sound signals consist of triangles corresponding to sounds $S1$ and $S2$. By choosing the maximum value of these triangles, time intervals between $S1$ and $S2$ sounds can be found easily. As mentioned before, these intervals are the times of systole ($S1$, $S2$, $S3$, …, Sn) and diastole ($D1$, $D2$, $D3$, …, Dn).

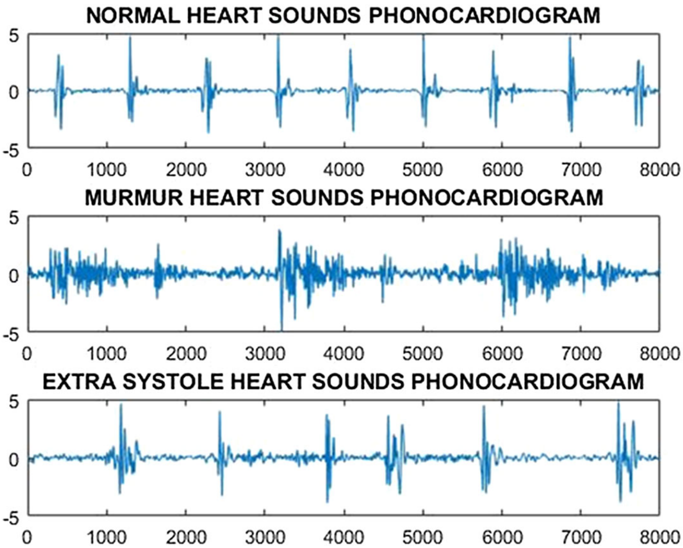

Fig. 4 The short time energy graph of heart sound

3.2.5 Creating graphics

In practice, because the heart sounds recorded in 10 s length have too much noise especially at the beginning and end of the file, the graphics are drawn by subtracting 1 s from the beginning and end of the sound files. Thus, 8-s graphs are obtained for each record.

3.2.6 Displaying diagnosis results

In Fig. 4, sound graphics were given for normal, murmur and extra-systolic sounds used in this study. As seen from the figure, in normal sounds, the intervals S and D are generally equal to each other and continue periodically. The intervals do not continue periodically in the murmur sounds. The values of S and D vary depending on the murmur condition. Extra-systolic sounds usually go on periodically, but there is an extra pulse in between S and D. Utilizing these features, we tried to distinguish sounds after many repetitions.

After finding the time intervals between sounds $S1$ and $S2$, the mean systolic time (S) and diastolic time (D) are calculated in each of the three records. After a lot of experimentation, we created quarks for each type of sound. These rules are given below:

- For normal sounds, this heart sound is normal if the average of the obtained S and D values are equal to each other with $\pm 10\%$ tolerance compared to the current S and D values and the intervals are periodically maintained.
- For murmur sounds, these heart sounds are murmur if the averages of the obtained S and D values are not balanced enough to be compared with the existing S and D values, and the intervals do not continue periodically.

- For extra-systolic sounds, these heart sounds are extra-systole if the average of the obtained S and D values is mostly equal to 70% when compared to the current S and D values, and there is an extra sound with a period corresponding to 50% of D or S.

With these rules, the application is recovered from the heavy classification process of the backplane and thus it is able to operate faster. At the end, the whole processing flow explained in detail here has been an effective way for achieving heart diagnosis in a mobile device (phone, tablet). It was thought that the designed process is fast and resource friendly enough if we consider limited hardware and software resources of mobile devices. Thus, the question of “how can an effective processing flow for heart sound analysis and disease diagnosis approach be designed?” has been answered with the approach explained here. Its effect on usability and fast process have been evaluated within further evaluation works as explained under the next sections—subsections.

4 Heart disease diagnosis with a mobile application employing virtual and augmented reality support

One remarkable research question within this study has been: “how can AR and VR be used in that application in order to improve interaction and usability?”. In order to meet with this question and include both AR and VR to improve interaction over the application, more consideration was given for AR- and VR-based using features. As it is known, both virtual reality (VR) and augmented reality (AR) are today’s important technological components for improving people’s experiences with software systems and achieve better interaction in the context of application framework. VR can use virtual elements to enable users for understanding concepts and events in a virtual environment, while AR is a workspace that combines the details that users get with computer support, in a real-world environment. The latest developments in technology have enabled VR and AR applications to run on small mobile devices. In this study, VR and AR support was used for a better using experience by combining both real and virtual world in a common ground. That is important for especially doctors, whose job requires always active interaction with patients and medical data generally. Because mobile applications widely used today require less complex interfaces with optimum interaction approaches, AR and VR were chosen as supportive components in the diagnosis application developed in this study.

The application here was implemented with a sensitive microphone with a suction cup and a mobile phone with the Android operating system. Both AR- and VR-based features have been developed by using essential libraries of Android programming and also Google AR library, which specifically aims use of AR technology in mobile applications. The application was called briefly as “MY HEART,” which is thought as an intimate name. In practice, a “General Mobile GM5 Plus” smart mobile phone was used with a sensitive microphone with a suction cup along the experiments—applications considered for this study. The phone has an optimum hardware resource so if the mobile application is effective and efficient enough to run over it, it can be easily used in many similar smartphones with Android operating system. The related tools

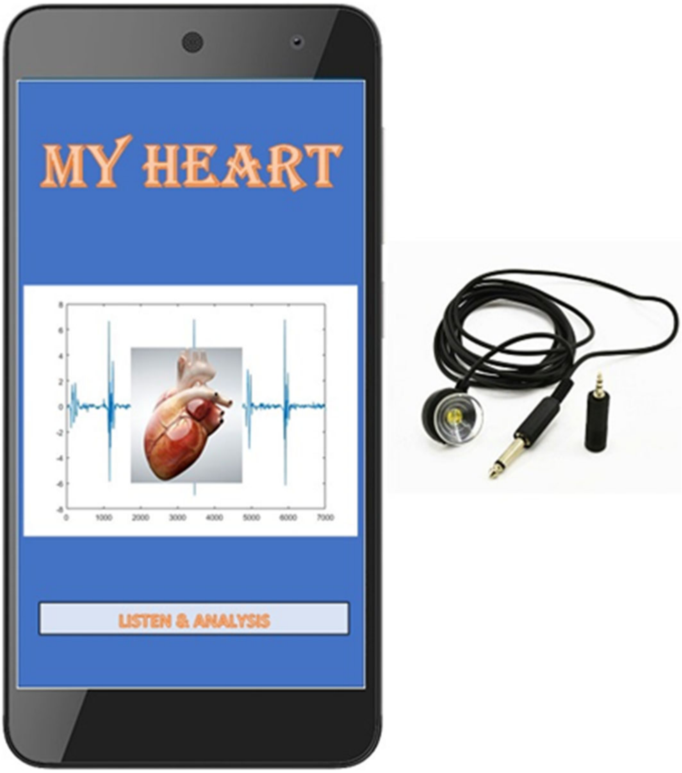

Fig. 5 MY HEART system for diagnosis over heart sounds

(Fig. 5) benefit from VR visualization and test results of heart sound data by listening to heart sounds. Thus, a VR system was created in which users could listen to their heart sounds, control themselves, and physicians can use it as an auxiliary tool for diagnosis with an easy-to-use interface.

4.1 Virtual analysis and diagnosis process

MY HEART records heart sound three times at 10-s intervals. In practice, the application waits for 5 s to be fully located the microphone, and then records for 10 s. Then, 10 s is expected and 10 s recording is done again. For this reason, the user of the application must hold the microphone for about 1 min without moving properly. After recording process, MY HEART analyzes the heart sound and shows its phonocardiogram and state. After recording process, MY HEART analyzes the heart sound and shows its phonocardiogram and the state at the final. MY HEART gives three types of result such as normal, murmur and extra-systole. As some examples for these results, some screenshots are provided in Figs. 6, 7, and 8, respectively.

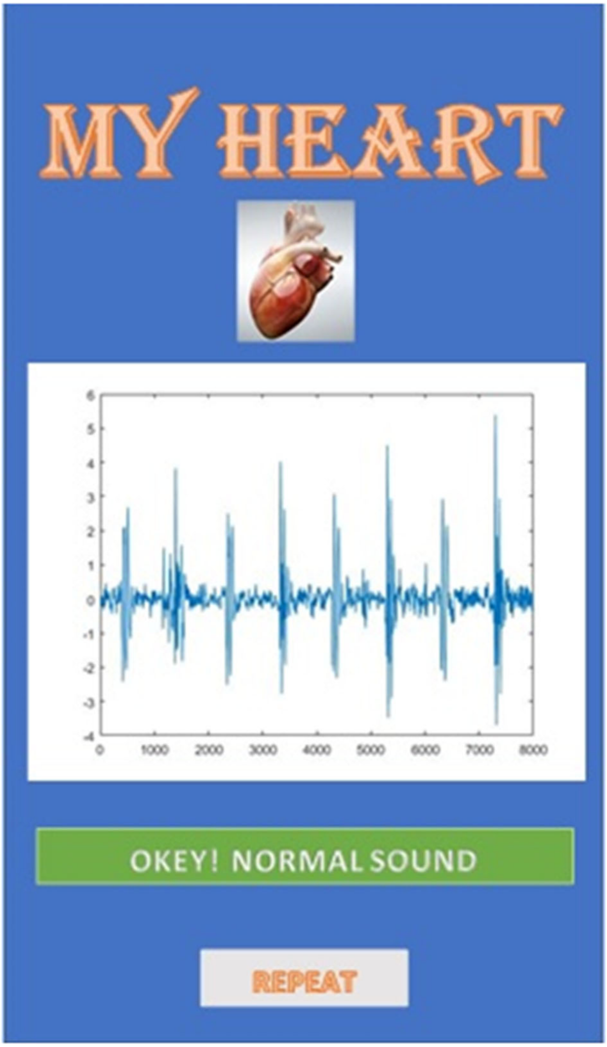

Fig. 6 MY HEART result for normal heart sounds

4.2 Augmented reality-based use

VR used in the application is effective to improve user experience and give good reading of medical data of heart. But more interaction to achieve better using experience was given with also AR. AR can give advantages of reading real-world signs and making connections with the data, by making a connection between real and digital world. In the application, that was used to call back saved heart disease analysis by viewing QR or special sign stickers over patients' personal files. Figure 9 presents some examples of QR codes and special signs that the application can read and also Fig. 10 represents a view from the application interface while reading a personal file.

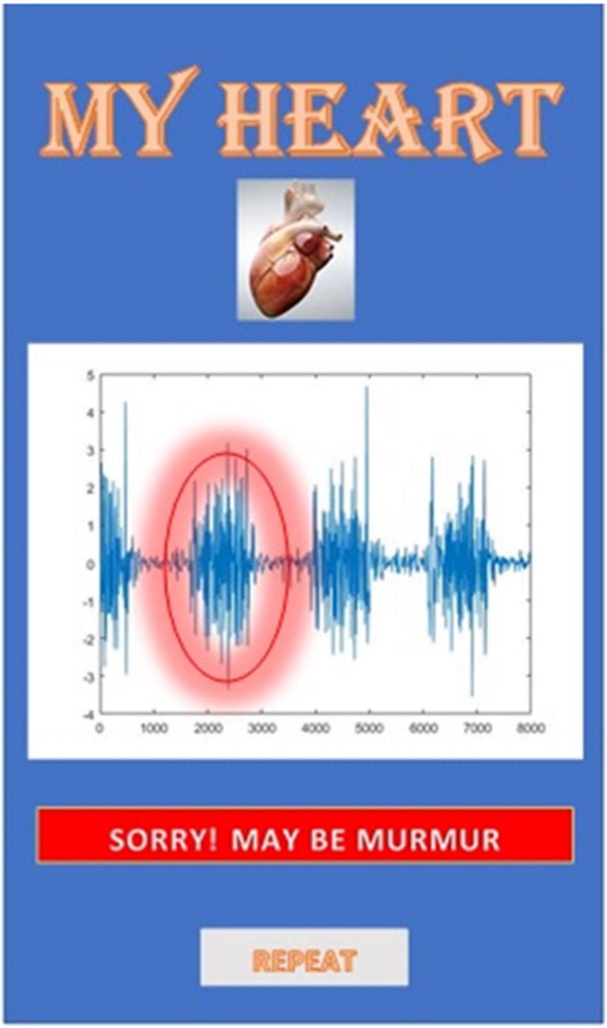

Fig. 7 MY HEART result for heart sounds with murmur

Except the related mechanism of reaching to patients' data, the application can also be used to gather some examples of heart signals as saved in the database. It can be achieved by just reading again QR codes or special signs provided by other doctors or experts working on the same field and want to share their data with their colleagues accordingly (Fig. 11).

5 Evaluation

So far, technical background on heart sound analysis and diagnosis approach and the developed mobile application-oriented system has been explained in detail. At this

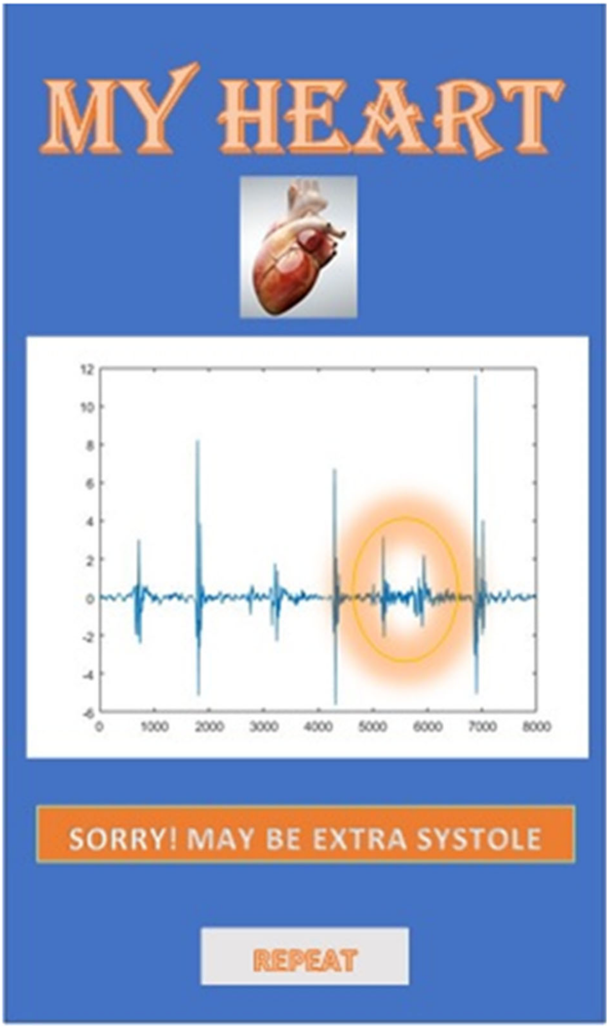

Fig. 8 MY HEART result for heart sounds with extra-systole

point, in order to see if the application is successful enough to meet with the main objective and research questions of this study, some evaluation works should be done. In this context, the following subsections are devoted to the performed evaluations.

5.1 Findings regarding effectiveness and efficiency of the application

In order to test the effectiveness and efficiency of the "MY HEART" AR system, it was tested with sounds in a public database. For this test, PASCAL Btraining heart sounds data set was used. That data set is an essential ones used widely for evaluation purposes in research studies. Sound files in this data set are wave format, and they were obtained

Fig. 9 Some examples QR codes and special signs MY HEART can read

from a clinical trial in hospitals using the digital stethoscope DigiScope® [64]. Forty normal, 40 murmur and 40 extra-systolic heart sounds were selected from the data set and played on the system. MY HEART recorded these voices and analyzed them thirty times, in order to see the results. The average accuracy ratios obtained from the analysis are given in Table 1 and Fig. 12.

As seen in Table 1 and Fig. 12, MY HEART provided accuracy ratios of ~87.5% for normal sound samples, ~92.5% for murmured sound samples and ~80% in extra-systolic sound samples. In addition to these results, Table 2 also shows average working time regarding analysis and diagnosis of the MY HEART on the related diagnosis evaluation. Considering both findings within Tables 1, 2, it can be said that the MY HEART works effectively and efficiently.

Heart sounds analysis and diagnosis, which are achieved without using artificial intelligence method for especially classification task, are very good, and they show that MY HEART has a very high performance. In this study, high accuracy ratios were obtained according to many classification studies done over the same database. In terms of time, MY HEART seems to perform the necessary tasks within a half minute.

5.2 Findings regarding real use cases

The application was also used by 10 hospital staff including doctors and supportive staff working at the hospital of Suleyman Demirel University, Turkey. By realizing interviews with the doctors, it was figured out that the MY HEART is effective enough to diagnose heart disease and improve doctors' working experiences by reducing time period on diagnosis and making it practical. Some remarkable expressions received from the doctors are as follows:

- "That application made by work more practical in all busy time period needing concentration."
- "That application is very easy-to-use."
- "The application is even good at diagnosing the diseases."

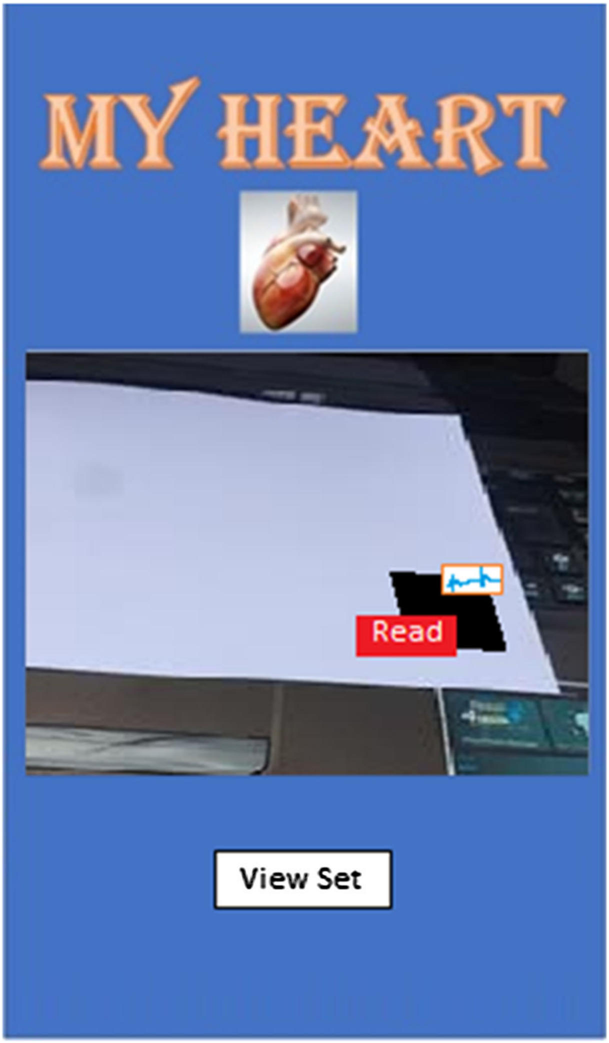

Fig. 10 Reading patient's personal file to call back saved analysis

- "I started to compare results of the application with my diagnosis."
- "It is more effective to share analyze results with my colleagues. It is also a secure way because of using special signs."
- "As some doctors, we have started to use the application for medical training."
- "It would be better if the application can also be associated with a medical social media environment for sharing experiences, data…etc."

In addition to the feedback received, the doctors were also asked to save findings regarding diagnosis tasks done at the related hospital by using the MY HEART. After about three and half month of use, a remarkable amount of data has been gathered about that. Considering last 50 diagnosis processes done for heart sounds by real patients,

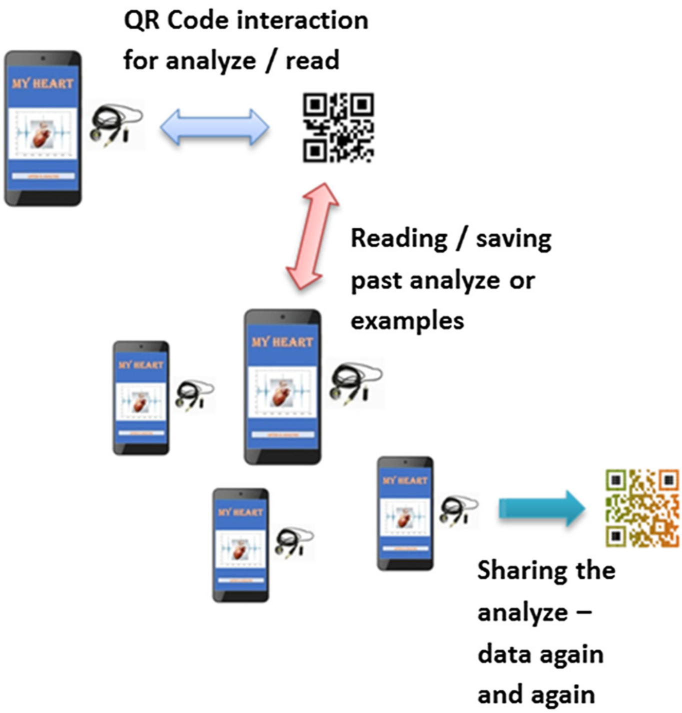

Fig. 11 Reading QR codes—special signs to gather heart signal data

Table 1 Average findings from the performed heart disease diagnosis done over the PASCAL data set

Type of the heart sound	Total number of sound files	Total average number of true diagnosis	Total average number of false diagnosis	Average accuracy (%)
Normal	40	~35	~5	~87.5
Murmur	40	~37	~3	~92.5
Extra-systole	40	~32	~8	~80

The whole analysis—diagnosis process has been done thirty times by the application

Table 3 and Fig. 13 show findings on disease diagnosis (the findings are based on one time analysis and diagnosis with the application, for each heart sound).

Considering both evaluations done over objective PASCAL data set and the real cases, the research question of "Is it possible to diagnose vital diseases like murmur and extra-systole by using such a mobile application?" was answered well-enough. Furthermore, the answer for that question points also an efficient application in terms of analysis and diagnosis time. Furthermore, findings also show a remarkable performance state indicating that the application can be successful for diagnosing also other hearts diseases, which are not included in this study.

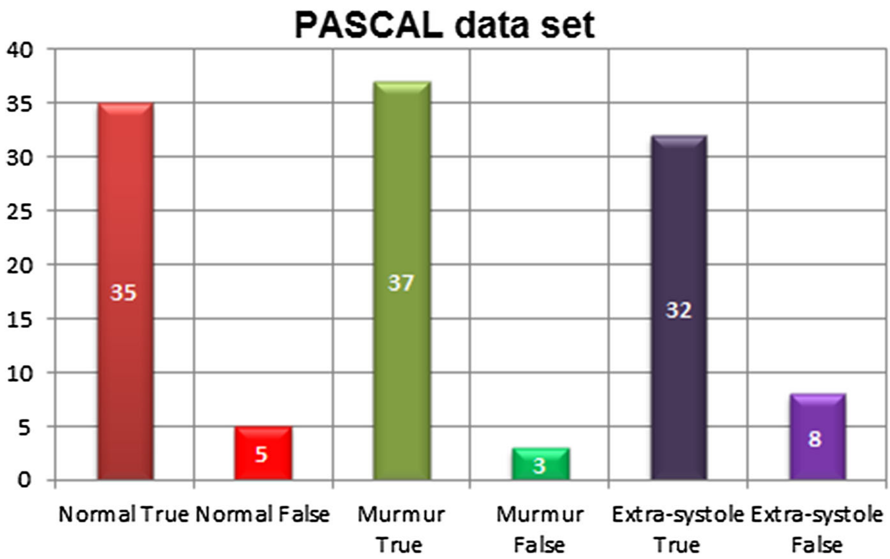

Fig. 12 Visualization of the average diagnosis performance over the PASCAL data set

Table 2 Average analysis and diagnosis time of the mobile application over the PASCAL data set

Type of the heart sound	Average sound analysis time (s)	Average diagnosis time (s)
Normal	~22.4	~5.2
Murmur	~26.2	~7.3
Extra-systole	~28.1	~8.2

Table 3 Findings from the performed heart disease diagnosis within real cases

Type of the heart sound	Total number of sounds considered	Total number of true diagnosis	Total number of false diagnosis	Accuracy (%)
Normal	50	46	4	92
Murmur	50	40	10	80
Extra-systole	50	41	9	82

The whole analysis—diagnosis process has been done one time by the application

5.3 Findings regarding usability evaluation

In order to have an idea about how usable the mobile application (MY HEART) is, a usability evaluation process has been done with 10 participants (doctors and medical staff) from the hospital of Suleyman Demirel University, Turkey. In detail, a total of 8 different tasks ($T1, \ldots, T8$) done by the 10 participants by considering task completion time (in seconds) and their feedback (1: very easy; 2: easy; 3: normal; 4: difficult; 5: very difficult) on how each task is easy—difficult to do. Each task was designed in order to achieve optimum conditions for performing the exact task by not losing additional

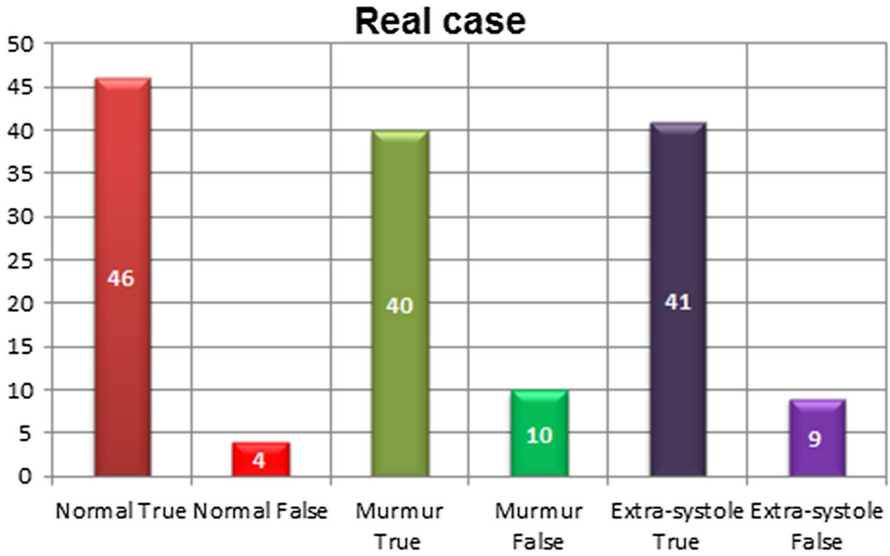

Fig. 13 Visualization of the diagnosis performance in the context of real cases

time as caused by alternative factors. Table 4 provides findings regarding each task, completion time for each task and feedback, considering 10 different participants ($P1$, …, $P10$) enrolled within this evaluation process.

As shown in Table 4, MY HEART can be used fast and efficiently by users and also feedback obtained for each task show that the application is seen as a usable one in the context of the study objective and research questions. That result also indicates that the analysis and diagnosis done by the application is a usable approach that can be employed at hospitals. In detail, there is not any task found "very difficult" by participants. On the other hand, there are a few feedbacks given as "difficult" to some certain tasks. In particular, important tasks on analysis and diagnosis are generally found "easy" or "very easy" by the participants. In terms of time, it seems that the analysis and diagnosis times meet with optimum time periods seen within PASCAL data set. If the average time considered, it seems that performance of all tasks correspond to less than 10 s if optimum conditions are stable enough.

5.4 Findings regarding working efficiency

It is important for medical staff to have enough working efficiency after using the MY HEART (in other words, the solution approach running with it). In order to have some ideas about that, 10 participants were wanted to fill a survey in which 5 different statements (S1, …, S5) tries to have feedback (with the Likert Scale: 1: totally disagree; 2: disagree; 3: no opinion; 4: agree; 5: totally agree) in terms of working efficiency achieved is better or worse. Table 5 presents the related survey statements and the feedback by the related participants.

Table 4 Findings obtained with the performed usability evaluation

Task	P1		P2		P3		P4		P5		P6		P7		P8		P9		P10	
	CT*	D**	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D
T1: Run the application	1.6	1	1.4	1	1.8	1	1.9	2	1.6	1	1.4	1	2	2	1.8	1	2.1	2	1.7	1
T2: Record a heart sound	13.4	2	12.4	2	16	3	12.2	1	14.5	2	11.4	1	20.1	3	17.6	3	18.3	4	15.3	2
T3: Perform an analysis on a heart sound	23.5	1	22.8	1	26.7	2	21.8	1	25.3	3	26.2	3	23.8	2	21.9	1	24	2	23.4	3
T4: Perform a diagnosis on a heart sound	6.3	3	5.9	1	6.2	2	7.8	4	8.2	2	8.4	1	7.3	1	6.4	2	6.1	1	7.2	1
T5: Save a diagnosis result	2.2	2	2.1	1	1.8	1	1.9	1	1.7	1	2.3	2	1.4	1	2.5	2	3	2	2.2	1

Table 4 continued

Task	P1		P2		P3		P4		P5		P6		P7		P8		P9		P10	
	CT*	D**	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D	CT	D
T6: Create QR code for sharing data	4.3	1	4.7	1	5.2	2	6.4	4	5.3	3	4.2	1	4.1	2	4.4	1	3.9	1	4.1	1
T7: Read a data from QR code	4.3	2	4.7	2	3.9	1	4.7	1	5.6	4	5.8	4	4.5	3	3.8	2	4.1	1	4.6	1
T8: Read a past analysis—diagnosis	3.4	2	2.7	1	3.5	2	4.6	3	3.2	2	2.8	1	2.6	1	3.2	2	4.1	2	3.4	1
Total	59	14	56.7	10	65.1	14	61.3	17	65.4	18	62.5	14	65.8	15	61.6	14	65.6	15	61.9	11
Average	7.4	1.8	7.1	1.3	8.1	1.8	7.7	2.1	8.2	2.3	7.8	1.8	8.2	1.9	7.7	1.8	8.2	1.9	7.7	1.4

*Completion time of the task (in seconds)

**Difficulty on doing the task (1: very easy; 2: easy; 3: normal; 4: difficult; 5: very difficult)

Table 5 Findings obtained with the survey for evaluating working efficiency

Statement	Feedback on Likert Scale*					Average
	1	2	3	4	5	
S1: "While using MY HEART, I saved time"	0	0	1	3	6	4.5
S2: "It was better to analyze and diagnose without MY HEART"	7	2	1	0	0	1.4
S3: "MY HEART allows collaboration in diagnosis as saving time"	0	0	1	1	8	4.7
S4: "VR and AR allow me to work better on my tasks"	0	1	0	1	8	4.6
S5: "I have increased my diagnosis performance with this solution"	0	0	0	2	8	4.8

*Likert Scale: 1: totally disagree; 2: disagree; 3: no opinion; 4: agree; 5: totally agree

Findings shown in Table 5 reveal that the mobile application has been good for improving working efficiency. That is important for especially achieving a collaborative working among doctors and supportive staff. Also, ensuring interactive features—functions to improve using experience seem to have positive effect on working efficiency in a general perspective. At the final, findings obtained here show that the research question of "can such a mobile application improve doctors' working efficiency at the end?" is answered—met successfully enough.

5.5 Brief cost evaluation

It is important to know a little about how much money does it cost to employ such mobile application developed within this study. It is remarkable that Android Google Play allows providing mobile applications for free of charge to download—use, so it is thought to provide the MY HEART free over the Web. On the other hand, it may be possible to calculate sum of the used mobile smartphone and other components considered with the system. Table 6 provides some costs (considering average prices in June 2018) according to different options to be employed at a hospital.

As shown in Table 6, it is possible to have a cost of around $150 for using an optimum system structure of mobile device and sensitive microphone in order to achieve the

Table 6 A brief cost evaluation with different options

Mobile device	Sensitive microphone (with a suction cup)	Total cost per system
General Mobile GM5 Plus: ~ $140 (in this study)	Low quality: ~ $8	$148–$170
Samsung Galaxy Tab S T800 (10.5″): ~ $120	Normal quality: ~ $15	$128–$150
Lenovo k320t Smartphone: ~ $110	High quality: ~ $23	$118–$140
Sony Xperia Xa1 Smartphone: ~ $210	Very high quality: ~ $30	$218–$240

According to average prices in June 2018

solution approach considered in this study. Lower quality mobile devices can even reduce the cost toward $100 at total.

6 Discussion

By taking the evaluation works into consideration, it is possible to express the following remarkable points regarding the developed mobile application and its solution approach provided for heart sounds analysis and disease diagnosis done eventually:

- By considering the whole findings obtained along the study and evaluation works, it is possible to mention that the research question of “” has been met enough by also meeting with other questions. From a general perspective, the main objective of the study on dealing with the problem of heart sound analysis and disease diagnosis by using a mobile application has been achieved in this study.
- As it can be seen from the findings obtained from different perspectives, MY HEART is successful enough at analysis and diagnosis over heart sounds. In detail, efficiency, effectiveness and usability of the system have been also seen well-enough by the objective staff of the hospital of Suleyman Demirel University, Turkey.
- Use of such mobile application developed in this study is essential to ensure necessary speed and efficiency in places like hospitals. Because of that, it is important to ensure more interactive features allowing users to reduce their task times by also providing an advanced framework on the background. MY HEART is able to deal with the heart sound analysis and diagnosis by using resources of a mobile device accurately.
- The diagnosis made with the MY HEART included some remarkable diseases like murmur and extra-systole. But findings show that the system is capable of dealing with alternative diseases.
- By considering current prices of mobile devices and sensitive microphones, general cost of the system is around $150. But although that amount is affordable by hospitals, choosing cheaper mobile device with a normal quality sensitive microphone can make the cost very low.

- Using QR approach over the system allows medical staff to store and share heart sounds and diagnosis results data in order to ensure a collaborative environment among all workloads. That is an important aspect to use mobile devices for medical purposes and for enabling medical staff to improve their working efficiency.
- Except the performed diagnosis over PASCAL data set, real-world experiences regarding a long enough use of MY HEART shows positive feedback at all. All these positive feedback are essential to open more doors of using such diagnosis systems for different diseases and achieving an interactive environment thanks to use of trendy technologies like VR and AR.

7 Conclusions and future work

In this study, the problem of heart sound analysis and an effective disease diagnosis over a mobile application was tried to be solved by using an alternative mobile application. In detail, the application developed within this study employs advantages of both virtual reality (VR) and augmented reality (AR) to ensure a desired level of interaction for better experiences. Called as MY HEART, the application is able to listen—record and analyze heart sounds for determining status of the heart health and because of its portability; it is a useful tool for doctors and experts working in the associated fields. VR used here makes it possible to analyze medical conditions with graphics and improve using experience. Additionally, AR enables the user to interact with the real-world over QR codes or special signs to reach any saved records of patients or examine data sets provided by other doctors—experts to be seen over the application environment.

Evaluations done for understanding better about success of the MY HEART have resulted in positive findings mostly. Considering different evaluation works done for having an idea about the performance of the mobile application, it is possible to express that heart sound analysis and disease diagnosis can be done effectively and efficiently thanks to the developed application. Findings on heart diseases diagnosis done over PASCAL data set and also feedback that was received from doctors in their real use cases point that the application has a remarkable value in terms of medical tasks. Additionally, usability of the application seems well-enough and even doctors' working efficiency is improved with it, according to received feedback. At the final, it was also shown that employment of such system can be low-cost according to chosen components.

There are also some future works thought over the application. In the future, it is aimed to add some artificial intelligence-based techniques on the background to give some additional "smart" using features to the application, by not affecting the general performance in a negative way. Server side of the application will be also optimized in order to deal with more data for a collaborative approach among hospitals—departments. Diagnosis for additional heart disease will be done and also, more different interaction ways associated with the use of AR will also be included in future versions of the application.

References

1. Steuer J (1992) Defining virtual reality: dimensions determining telepresence. J Commun 42(4):73–93
2. Burdea Grigore C, Coiffet P (1994) Virtual reality technology. Wiley-Interscience, London
3. Rheingold H (1991) Virtual reality: exploring the brave new technologies. Simon & Schuster Adult Publishing Group, New York
4. Biocca F, Levy MR (eds) (2013) Communication in the age of virtual reality. Routledge, London
5. Lévy P, Bononno R (1998) Becoming virtual: reality in the digital age. Da Capo Press, Incorporated, Cambridge
6. Zyda M (2005) From visual simulation to virtual reality to games. Computer 38(9):25–32
7. Bates J (1992) Virtual reality, art, and entertainment. Presence Teleoperators Virtual Environ 1(1):133–138
8. Sherman WR, Craig AB (2002) Understanding virtual reality: interface, application, and design. Elsevier, Amsterdam
9. Hughes CE, Stapleton CB, Hughes DE, Smith EM (2005) Mixed reality in education, entertainment, and training. IEEE Comput Graph Appl 25(6):24–30
10. Ong SK, Nee AYC (2013) Virtual and augmented reality applications in manufacturing. Springer Science & Business Media, Berlin
11. Roussou M, Oliver M, Slater M (2006) The virtual playground: an educational virtual reality environment for evaluating interactivity and conceptual learning. Virtual Real 10(3–4):227–240
12. Weiss PL, Rand D, Katz N, Kizony R (2004) Video capture virtual reality as a flexible and effective rehabilitation tool. J Neuroeng Rehabil 1(1):12
13. Merchant Z, Goetz ET, Cifuentes L, Keeney-Kennicutt W, Davis TJ (2014) Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: a meta-analysis. Comput Educ 70:29–40
14. Loeffler CE (1993) Distributed virtual reality: applications for education, entertainment and industry. Telektronikk 89:83
15. Guttentag DA (2010) Virtual reality: applications and implications for tourism. Tour Manag 31(5):637–651
16. Oliveira JM, Fernandes RCG, Pinheiro PR, Ribeiro STG, de Albuquerque VHC (2016) Novel virtual environment for alternative treatment of children with cerebral palsy. Comput Intell Neurosci 2016:1–10
17. Ohta Y, Tamura H (2014) Mixed reality: merging real and virtual worlds. Springer Publishing Company, Incorporated, Berlin
18. Van Krevelen DWF, Poelman R (2010) A survey of augmented reality technologies, applications and limitations. Int J Virtual Real 9(2):1
19. Cawood S, Fiala M, Steinberg DH (2007) Augmented reality: a practical guide. Pragmatic Bookshelf, Raleigh
20. Silva RDDC, Albuquerque SGC, Muniz ADV, Filho PPR, Ribeiro S, Pinheiro PR, Albuquerque VHC (2017) Reducing the schizophrenia stigma: a new approach based on augmented reality. Comput Intell Neurosci 2017:1–10
21. Billinghurst M, Clark A, Lee G (2015) A survey of augmented reality. Found Trends® Hum Comput Interact 8(2–3):73–272
22. Azuma R, Baillot Y, Behringer R, Feiner S, Julier S, MacIntyre B (2001) Recent advances in augmented reality. IEEE Comput Graph Appl 21(6):34–47
23. Höllerer T, Feiner S (2004) Mobile augmented reality. Telegeoinformatics: location-based computing and services. Taylor and Francis Books Ltd, London, p 21
24. Köse U (2017) An augmented-reality-based intelligent mobile application for open computer education. In: Kurubacak G, Altinpulluk H (eds) Mobile technologies and augmented reality in open education. IGI Global, Hershey, PA, pp 154–174. https://doi.org/10.4018/978-1-5225-2110-5.ch008
25. Dunleavy M, Dede C (2014) Augmented reality teaching and learning. In: Michael Spector J, David Merrill M, Elen J, Bishop J (eds) Handbook of research on educational communications and technology. Springer, New York, pp 735–745. https://doi.org/10.1007/978-1-4614-3185-5
26. Nee AY, Ong SK, Chryssolouris G, Mourtzis D (2012) Augmented reality applications in design and manufacturing. CIRP Ann Manuf Technol 61(2):657–679

27. Rodrigues JJPC, Segundo DBDR, Junqueira HA, Sabino MH, Prince RM, Al-Muhtadi J, De Albuquerque VHC (2018) Enabling technologies for the internet of health things. IEEE Access 6:13129–13141
28. Da Cruz MAA, Rodrigues JJPC, Al-Muhtadi J, Korotaev VV, De Albuquerque VHC (2018) A reference model for internet of things middleware. IEEE Internet Things J 5:871–883
29. Hussein AF, Kumar A, Burbano-Fernandez M, Ramirez-Gonzalez G, Abdulhay E, de Albuquerque VHC (2018) An automated remote cloud-based heart rate variability monitoring system. IEEE Access. https://doi.org/10.1109/access.2018.2831209
30. De Albuquerque VHC, Nunes TM, Pereira DR, Luz EJDS, Menotti D, Papa JP, Tavares JMRS (2016) Robust automated cardiac arrhythmia detection in ECG beat signals. Neural Comput Appl 29:1
31. Luz EJS, Nunes TM, de Albuquerque VHC, Papa JP, Menotti D (2013) ECG arrhythmia classification based on optimum-path forest. Expert Syst Appl 40:3561–3573
32. You SH, Jang SH, Kim YH, Hallett M, Ahn SH, Kwon YH, Lee MY (2005) Virtual reality–induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. Stroke 36(6):1166–1171
33. Saposnik G, Levin M, Stroke Outcome Research Canada (SORCan) Working Group (2011) Virtual reality in stroke rehabilitation: a meta-analysis and implications for clinicians. Stroke 42(5):1380–1386
34. Weidenbach M, Wick C, Pieper S, Quast KJ, Fox T, Grunst G, Redel DA (2000) Augmented reality simulator for training in two-dimensional echocardiography. Comput Biomed Res 33(1):11–22
35. Marescaux J, Diana M (2015) Next step in minimally invasive surgery: hybrid image-guided surgery. J Pediatr Surg 50(1):30–36
36. Nicolau S, Soler L, Mutter D, Marescaux J (2011) Augmented reality in laparoscopic surgical oncology. Surg Oncol 20(3):189–201
37. Bernhardt S, Nicolau SA, Agnus V, Soler L, Doignon C, Marescaux J (2016) Automatic localization of endoscope in intraoperative CT image: a simple approach to augmented reality guidance in laparoscopic surgery. Med Image Anal 30:130–143
38. Tang SL, Kwoh CK, Teo MY, Sing NW, Ling KV (1998) Augmented reality systems for medical applications. IEEE Eng Med Biol Mag 17(3):49–58
39. Birkfellner W, Figl M, Huber K, Watzinger F, Wanschitz F, Hummel J, Bergmann H (2002) A head-mounted operating binocular for augmented reality visualization in medicine-design and initial evaluation. IEEE Trans Med Imaging 21(8):991–997
40. De Buck S, Maes F, Ector J, Bogaert J, Dymarkowski S, Heidbuchel H, Suetens P (2005) An augmented reality system for patient-specific guidance of cardiac catheter ablation procedures. IEEE Trans Med Imaging 24(11):1512–1524
41. Luo X, Kline T, Fischer HC, Stubblefield KA, Kenyon RV, Kamper DG (2005) Integration of augmented reality and assistive devices for post-stroke hand opening rehabilitation. In: 27th Annual International Conference of the Engineering in Medicine and Biology Society, 2005. IEEE-EMBS 2005. IEEE, pp 6855–6858
42. Khademi M, Hondori HM, Lopes CV, Dodakian L, Cramer SC (2012) Haptic augmented reality to monitor human arm's stiffness in rehabilitation. In: 2012 IEEE EMBS Conference on Biomedical Engineering and Sciences (IECBES). IEEE, pp 892–895
43. Kamphuis C, Barsom E, Schijven M, Christoph N (2014) Augmented reality in medical education? Perspect Med Educ 3(4):300–311
44. Herron J (2016) Augmented reality in medical education and training. J Electron Resour Med Libr 13(2):51–55
45. Kiourexidou M, Natsis K, Bamidis P, Antonopoulos N, Papathanasiou E, Sgantzos M, Veglis A (2015) Augmented reality for the study of human heart anatomy. Int J Electron Commun Comput Eng 6(6):658
46. Zhu E, Hadadgar A, Masiello I, Zary N (2014) Augmented reality in healthcare education: an integrative review. PeerJ 2:e469
47. Hsieh MC, Lee JJ (2018) Preliminary study of VR and AR applications in medical and healthcare education. J Nurs Health Stud 3(1):1
48. Smith M, Gabbard JL, Burnett G, Doutcheva N (2017) The effects of augmented reality head-up displays on drivers' eye scan patterns, performance, and perceptions. Int J Mob Hum Comput Interact (IJMHCI) 9(2):1–17
49. McGrath JL, Taekman JM, Dev P, Danforth DR, Mohan D, Kman N, Bond WF (2018) Using virtual reality simulation environments to assess competence for emergency medicine learners. Acad Emerg Med 25(2):186–195

50. Mostafa AE, Ryu WHA, Chan S, Takashima K, Kopp G, Costa Sousa M, Sharlin E (2017) Designing NeuroSimVR: a stereoscopic virtual reality spine surgery simulator. Science 1:1–20
51. Wiederhold BK, Miller I, Wiederhold MD (2018) Augmenting behavioral healthcare: mobilizing services with virtual reality and augmented reality. In: Rivas H, Wac K (eds) Digital health. Springer, Cham, pp 123–137
52. Moro C, Štromberga Z, Raikos A, Stirling A (2017) The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anat Sci Educ 10(6):549–559
53. Douglas DB, Wilke CA, Gibson D, Petricoin EF, Liotta L (2017) Virtual reality and augmented reality: advances in surgery. Biology 2(5):1–8
54. Freeman D, Reeve S, Robinson A, Ehlers A, Clark D, Spanlang B, Slater M (2017) Virtual reality in the assessment, understanding, and treatment of mental health disorders. Psychol Med 47(14):2393–2400
55. McCloy R, Stone R (2001) Science, medicine, and the future: virtual reality in surgery. BMJ Br Med J 323(7318):912
56. Riva G (2002) Virtual reality for health care: the status of research. Cyberpsychol Behav 5(3):219–225
57. Ma M, Jain LC, Anderson P (eds) (2014) Virtual, augmented reality and serious games for healthcare 1, vol 1. Springer, Berlin
58. Deperlioglu O (2018) Segmentation of heart sounds by re-sampled signal energy method. BRAIN Broad Res Artif Intell Neurosci 9(1):17–28
59. Ahlström C (2006) Processing of the phonocardiographic signal-methods for the intelligent stethoscope, Disseration, Linköping University, Institute of Technology, Linköping, Sweden
60. Zabihi M, Rad AB, Kiranyaz S, Gabbouj M, Katsaggelos AK (2016) Heart sound anomaly and quality detection using ensemble of neural networks without segmentation. Comput Cardiol 43:613–616
61. Deperlioglu O (2018) Classification of phonocardiograms with convolutional neural networks. BRAIN Broad Res Artif Intell Neurosci 9(2):22–23
62. Bulbul HI, Karaci A (2007) Speech command recognition in computer: pattern recognition method. Kastamonu Educ J 15(1):45–62
63. Qiang H, Youwei Z (1998) On prefiltering and endpoint detection of speech signal. In: 1998 Fourth International Conference on Signal Processing Proceedings ICSP'98, vol 1, pp 749–753
64. Bentley P, Nordehn G, Coimbra M, Mannor S (2011) The PASCAL classifying heart sounds challenge 2011 (CHSC2011) results. http://www.peterjbentley.com/heartchallenge/index.html. Accessed 05 Feb 2018