Applying Augmented Reality to Enable Automated and Low-Cost Data Capture from Medical Devices

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ABSTRACT

As an alternative to building custom electronic devices that connect to mobile phones (via Bluetooth or USB), we present a new approach using Augmented Reality (AR) and machine vision to digitally recognize a biomedical device and capture readings automatically. In the context of developing countries, this approach enables easy integration with low-cost devices, without the need for designing any electronics or obtaining new FDA regulatory approval. As an example, we illustrate the use of AR with a peak flow meter, a device used in the diagnosis and treatment of respiratory disease. In our mobile application, the AR graphic overlay is used to provide feedback to patients and doctors by displaying personalized reference values. Comparing the automated readings from this device to manual readings, our mobile application had a mean error of 5.8 L/min and a correlation of 0.99. A small user study was also conducted in an India field clinic with three health staff (two nurses and a doctor). Following one minute of instruction, the automated readings from the participants had a mean error of 5.5 L/min and a correlation of 0.99 compared to manual readings, with a median task duration of 17.5 seconds. This small case study illustrates how AR can be used to capture medical device data on a mobile phone and help automate the data recording tasks performed by health workers in developing countries. This technology can also be used in developed countries, enabling patients to automatically record readings from similar devices at home using their smart phones.

CCS Concepts

• **Human-centered computing~Mixed / augmented reality**
• **Human-centered computing~Field studies** • Human-centered computing~Empirical studies in interaction design • **Applied computing~Health informatics** • *Applied computing~Consumer health* • Applied computing~Health care information systems

Keywords

Augmented reality; consumer health; medical devices; Android; mobile health; peak flow meter; lung health; asthma

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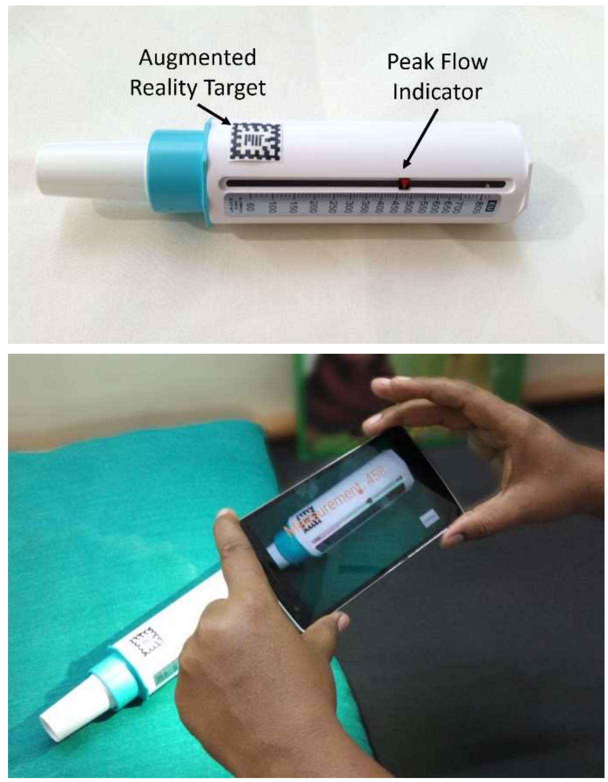

Figure 1: Peak flow meter and AR application: Peak flow meter and augmented reality target (top), AR application in use (bottom)

1. INTRODUCTION

Many biomedical devices produce analog readings that are never recorded in a digital form. As a result, analysis is difficult and hand-written measurements can be lost, prone to error, or even falsified. A typical engineering solution to this problem would be to design electronic versions of these devices that automatically record values. The problem with this approach is that it increases the complexity and cost of medical devices, in addition to requiring new manufacturing and obtaining regulatory approvals.

Given this need, we suggest the use of machine vision and Augmented Reality (AR) to automatically capture measurements from existing medical devices. Since the first AR systems were developed in the early 1980s [2], AR has been used in medicine, primarily focused either on developing training programs [5, 10]

Figure 2: Screenshots from the augmented reality application

or enabling physicians to see real-time data captured from medical sensing technologies [3, 6, 9].

By using AR to digitize measurements, we can make use of pre-existing and pre-approved medical devices without requiring any electronics. In this paper, we present the *peak flow meter* as a case study, but this approach is generally applicable to other devices, especially in contexts where data is already being collected but not aggregated or analyzed in a systematic way. While this approach requires a smartphone, such phones are being rapidly adopted in both the developing and developed world [1].

Peak flow meters are inexpensive, mechanical devices that are used to assess patient lung health. These devices measure a patient's peak expiratory flow rate (PEFR). While useful for other pulmonary diseases, one of the primary uses of a peak flow meter is to monitor the treatment of asthma in patients and evaluate changes in their lung health.

Asthma afflicts more than 300 million people around the world and the prevalence is increasing. In 2010, asthma ranked 14th for the amount of disability-adjusted life years lost to disease [7]. For young patients, asthma is a significant cause of disability. For elderly patients, asthma is a cause of premature death. The majority of the burden from asthma on low and middle income countries [4].

Tracking PEFR over time can provide information about reduced lung capacity, the effectiveness of current medications, and the effect of seasonal and environmental features on a patient' asthma. However, long-term PEFR tracking is often impeded by patient compliance. Patients are typically asked to keep a PEFR diary, in which they record daily readings. In a recent study, it was found that patients recorded values only 54% of the time and that 22% of the recorded values were fictitious [8].

Patient compliance could be improved with a device that gives immediate feedback about readings to the user and transmits data to the physician on a regular basis. This device would allow the patient to better understand changes in their lung health. It would also enable physicians to identify patients with declining lung health or contact patients if PEFR recordings stop.

In addition to digitizing device readings, a primary use of AR is to provide informative visual overlays to the user. In our case, the peak flow meter reference values are displayed on the screen in real-time, allowing the user to compare his/her reading to standard healthy and unhealthy values for the reference population.

The AR data capture for peak flow meters is useful to primary care physicians and health workers, because it reduces the likelihood of transcription errors and improves patient tracking by automatically digitizing results. Additionally, patients with a smartphone are able to track their measurements on a regular basis, allowing them to keep track of their lung health and communicate changes directly to their physician.

2. IMPLEMENTATION

2.1 Peak Flow Meter

For our analysis, we used the Cipla Breath-O Meter, a peak flow meter commonly available in India, which currently sells for 340 Indian rupees (~US$5). We modified by the peak flow meter by attaching an augmented reality target, in the form of a sticker, which was custom-printed. The AR reality target is a pattern that is readily distinguishable from the background world. A picture of the peak flow meter and attached target is shown in Figure 1.

2.2 Augmented Reality Application

The augmented reality application was developed for Android smartphones using the Vuforia™ Augmented Reality SDK. The application allows the user to enter their age, height, and gender. Using this information, the application computes the personalized reference values for comparison with the user's measured PEFR.

In order to capture a reading, the user aims the smartphone at the peak flow meter. The application automatically detects the augmented reality target and searches for the red indicator. The position of the red indicator is compared to the target and the lateral distance between them is used to determine the measurement value. The detected measurement is displayed on the screen. Underneath the peak flow meter indicator, the application displays green, yellow, and red bars that correspond to the the measurement zones defined by the American Lung Association. Although our algorithm was customized to make the specific geometry and colors of the printed scale on this device,

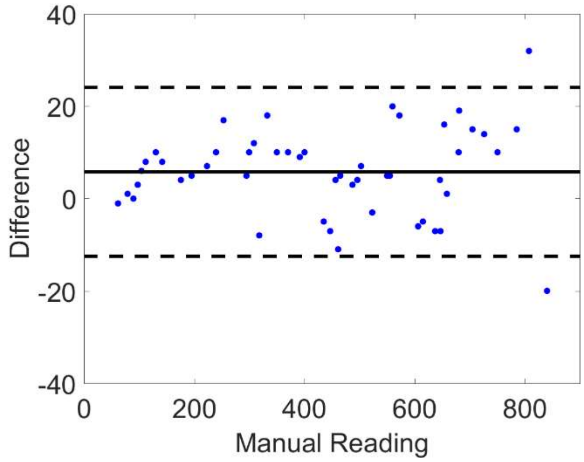

Figure 3: Technical study results: Bland-Altman plot showing the difference between the device readings and the manual readings for the technical validation task

our software can be easily customized to capture readings from any device which uses a scale and moving indicator.

Once the measurement has been detected, the user clicks continue and the reading is saved to the device. Image data is not saved, thus minimizing memory use. Each reading is saved with a timestamp and all data is saved in CSV format. The user is given the option to export all of their readings using any of the sharing options enabled on their device (text message, email, Dropbox, etc.) The user may also view a plot of their historical readings in the application. Screenshots are shown in Figure 2.

3. VALIDATION

To ensure that the device worked, we split the validation into two separate tasks. First, we tested the technical validity of the device to see if it was able to accurately measure readings across the range of possible peak flow meter values. Second, we evaluated the usability of the device by placing it in the hands of nurses in Indian hospitals and clinics and measuring the accuracy of their readings. These are described below.

3.1 Technical Validation

To test the accuracy of the device across the range of possible peak flow meter values, we selected 50 values of peak flow meter readings and randomized their ordering. For each value, a researcher moved the peak flow meter indicator to that value. Then, a different researcher used our mobile app to take a reading.

A Bland-Altman plot of the results is shown in Figure 3. The mean error between the device and the manual reading was 5.8 L/min and the root mean squared error was 10.9 L/min. The correlation between the application measurement and manual reading was 0.99.

3.2 User Testing

To evaluate the usability of the device, we provided it to doctors and nurses at clinical settings in India (Figure 5). One doctor and two nurses were each given a one minute demonstration of the device and then asked to take 10 measurements. For each measurement, one of the researchers set the indicator of the peak flow meter to a randomly selected value. Then, the nurse or doctor used the device to take a reading. The nurses and doctor were timed to determine how long it took to take a reading. The mean error between the device and the manual reading was 5.5 L/min and the root mean squared error was 10.3 L/min. The correlation between the application measurement and manual reading was 0.99. The median amount of time required to record a measurement was 17.5 seconds. A Bland-Altman plot of the errors and a histogram of the time required to record a measurement are shown in Figure 4.

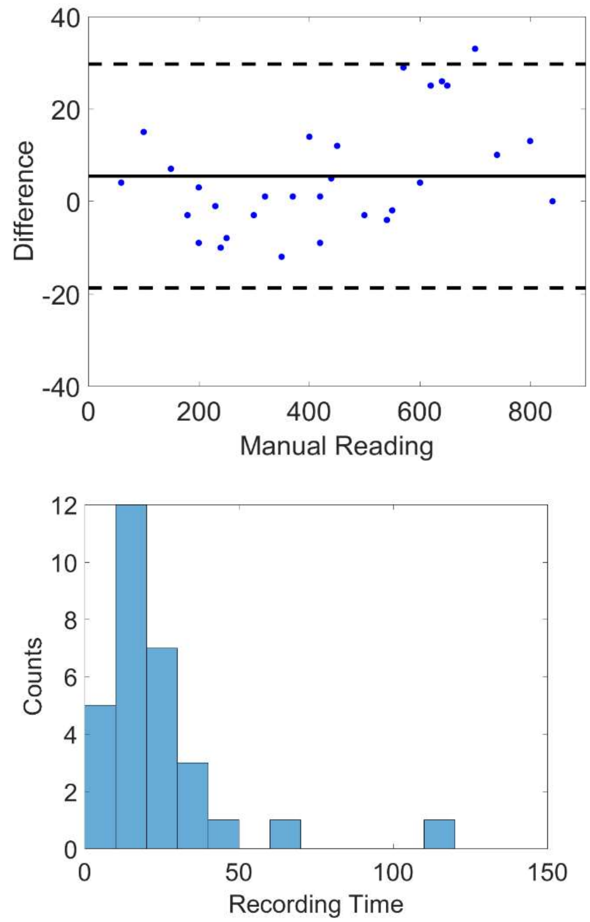

Figure 4: User study results: Bland-Altman plot showing the difference between the device readings and the manual readings for the user testing task (top), Histogram of task duration required to record a measurement (bottom)

4. DISCUSSION

The peak flow meter mobile application was able to accurately capture peak flow meter readings. In the technical validation task, after adjusting for the fixed bias, 96% of the recorded values were within 20 L/min of the actual value, a threshold defined as the lower limit of clinical significance by the collaborating pulmonologist. In addition, the two largest errors occur at PEFR readings of greater than 800. The required accuracy at these values of PEFR is less important than for low values of PEFR because all PEFR reading in this range are considered healthy.

In the user testing tasks, after adjusting for the fixed bias, 90% of the recorded values were within 20 L/min of the actual value. The median time required to take a recording was 17.5 seconds, but there were some recordings that took significantly longer. The primary delay time was the camera autofocus, which had some problem locking onto the image; but once the camera was able to focus, it was able to quickly detect the AR target and take a

Figure 5: User study test site in Mumbai, India

reading. Setting the camera focus to macro and removing the autofocus option would likely correct this issue. Additionally, providing users additional training and practice would reduce error rates and speed the recording of measurements. These users were tested after being provided only a one minute demonstration.

One source of error is that slight changes in the sticker location can affect the accuracy of the readings. Since our flow meter device has a curved surface, and the scale and AR target are not on the same plane, we noticed small variation in the reading depending on the relative angle of the phone camera. Since the PEFR uses a logarithmic scale, these small errors in the indicator reading can be more significant at the higher range of the PEFR scale (>600 L/min); however, the size of these errors were still within acceptable accuracy for clinical use (<20 L/min). If greater accuracy is needed, we are implementing a calibration routine in the settings menu of our app which can be used to calibrate the application for each individual peak flow meter. The calibration routine will ask the patient or physician to set the indicator to predetermined values and use the relative position of those values to adjust the equation used to determine a measurement from the location of the indicator on the screen. We are currently in discussion with the device manufacturer about integrating the AR target into the manufacturing quality control process at the factory in order to improve accuracy even further.

5. CONCLUSIONS

We have developed an application capable of digitizing the readings from a peak flow meter device. This application allows patients to better track changes in their lung health and allow physicians to monitor their patients and identify patients in need of additional care. The device has been tested with nurses in Indian clinics and we have demonstrated that the interface can be used successfully with minimal training. We feel that augmented reality represents a promising direction for integration of mobile technology with medical devices, eliminating the need for electronic circuitry or Bluetooth. This approach also enables mobile apps to be developed for existing medical devices that have already been certified for little additional cost.

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