ShoulderCam: Evaluating the User Experience of a Depth Camera System to Measure Shoulder Range of Motion

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ABSTRACT
Assessment of patient condition is essential for understanding physical impairment severity and treatment efficacy. It is important that measurements are objective and observer-independent so patient progress can be meaningfully assessed over time. Orthopedic shoulder surgeons typically assess range of motion with a goniometer, a manual measurement tool, which has variability between measurers and techniques. To address these limitations, we developed ShoulderCam, an objective measurement technique utilizing the Microsoft Kinect. ShoulderCam was designed with medical professionals to be integrated into the clinic. After evaluating the utility of ShoulderCam in a qualitative study with 5 medical professionals and 11 patients, we found the majority preferred ShoulderCam due to perceived accuracy, more visual information, and less mental effort. This research can inform future medical clinic assessment technologies.

CCS Concepts
• **Human computer interaction (HCI)**→Interaction paradigms→Graphical user interfaces.

Keywords
Kinect; medical clinic; shoulder; patient; doctor.

1. INTRODUCTION
Assessment of patient condition and progress is essential for understanding the extent of an impairment and the effectiveness of a treatment. To make these assessments, medical professionals need information on a patient's status and progress, which is captured via interviews, visitations, phone calls, or emails. Tracking a patient's progress objectively, especially with treatment, is important to demonstrate the performance of a treatment plan or contribute to research studies.

In evaluating the shoulder, clinicians typically assess patient outcome by taking five measurements before and after surgery using a manual tool called a goniometer (Figure 1). However, this approach has limitations due to variability between different measurers [5] [14], different methods (e.g. digital photography [12] vs. goniometer), or different positions (e.g. standing up or lying down) [6]. One way researchers have addressed variability in other domains is by developing technology to facilitate assessment, such as with physical therapy [16], knee rehabilitation [1], or detecting newborn jaundice [7]. These approaches decrease the

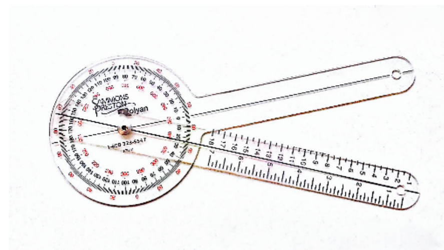

Figure 1. Goniometer, a manual tool used in clinical settings to measure shoulder range of motion.

need for a medical professional to make decisions or judgments, removes variability, and minimizes the possibility of error.

We extended these approaches in bringing objectivity to health assessment of shoulder motion in the development of a tool called ShoulderCam built with a Microsoft Kinect. ShoulderCam tracks 5 shoulder measurements: abduction, flexion, external/internal rotation, and cross body reach (Figure 2). We designed ShoulderCam with medical professionals to be used in exam rooms during pre- and post-surgery appointments.

To evaluate the utility of ShoulderCam, we conducted a qualitative pilot usability study with 5 medical professionals and 11 patients to compare their experience with using a goniometer. We found that most participants preferred ShoulderCam and perceived ShoulderCam to be more accurate than the goniometer. This work builds upon previous work from the medical field [11] that showed that ShoulderCam is comparable to a goniometer for shoulder range of motion measurements at a clinical level; how-

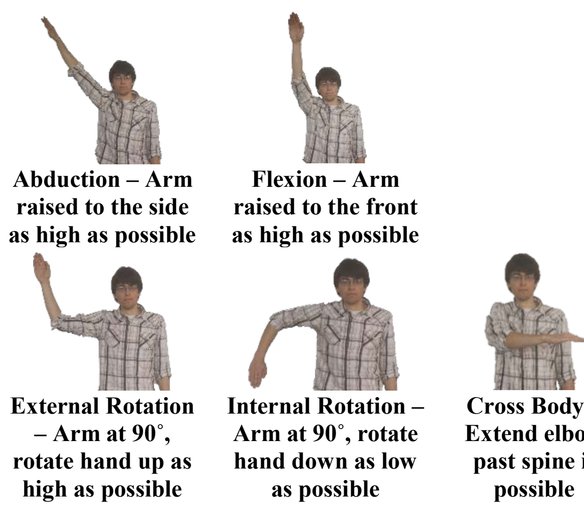

Figure 2. Measurements for assessing shoulder range of motion. Abduction & Flexion range from 0˚ - 180˚. External & Internal Rotation range from -90˚ - 90˚. Cross Body is reported in inches past spine (<0 if before spine, >0 otherwise).

ever, the prior study did not investigate aspects of the system beyond its accuracy and practicality. This paper thus demonstrates the utility and user experience with ShoulderCam for medical professionals (observers)[1] and patients in the clinic. This paper's contributions are the design and development of ShoulderCam as a tool for clinical use and a pilot usability study with both medical professionals and patients.

2. DESIGN OF SHOULDERCAM

We designed ShoulderCam to be an observer-independent depth camera system to measure shoulder range of motion in the medical clinic. Having observer independence is an advantage because it eliminates the need to have the same person conduct measurements on a patient over time, which is needed with standard goniometric measurements [14]. Further, ShoulderCam could enable staff unfamiliar with standard goniometric technique to take measurements in a clinical setting. ShoulderCam's rolling cart setup makes it compatible with the medical clinic with its ability to fit into small spaces (Figure 3). We designed the system to measure both shoulders, using the healthy shoulder as a point of comparison. The data is stored digitally to enable the observer and patient to track shoulder progress.

The design team for ShoulderCam consisted of a Computer Science Graduate Student, Orthopedic Surgeon, Resident Physician, MD Candidate, and Director of Technology. Together, the team brainstormed the physical structure and software workflow. This system was piloted in the clinic for ~6 months before the user study described in this paper.

2.1 Hardware and Software

ShoulderCam consists of a suite of hardware: rolling cart with adjustable arm, Windows laptop, Microsoft Kinect for Windows, and uninterruptable power supply (Figure 3). ShoulderCam is thus able to stay powered while moving between exam rooms. The Windows laptop had the custom software installed on the Desktop for easy access. The ShoulderCam software is a wizard-style application, which firsts asks for patient name, hospital number, shoulder with issues, diagnosis, and date. The observer then receives instructions to adjust the Kinect sensor to the patient's shoulder height. The software verifies that the Kinect is ready.

ShoulderCam was developed in C# and utilizes Microsoft's Kinect Skeleton Tracking (KST) and Microsoft Word/Excel libraries to save output data. We used the Microsoft Kinect over other single camera body tracking approaches (e.g. [15], [17]) because the Kinect is pervasive and robust. With KST output, we display the stick figure representation of a patient using OpenTK (opentk.com) (Figure 4a). To measure the shoulder angles and lengths (Figure 4d), we use a technique similar to Rector et al. [13] using the law of cosines and relative positions of body joints. For example, we determine External Rotation from three points:

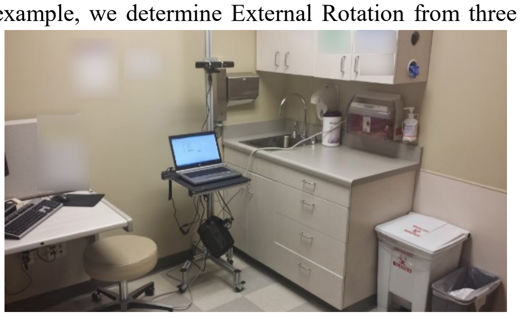

Figure 3. ShoulderCam in a medical exam room. The height of the Kinect sensor is adjustable.

[1] We use medical professional and observer interchangeably.

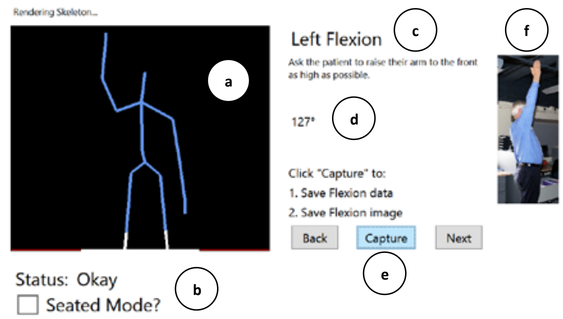

Figure 4. ShoulderCam while acquiring Flexion for the left arm. Callouts: a) stick figure, b) message about whether the patient is facing the Kinect and standing straight, plus option to choose if they are seated, c) measurement name, instructions, d) current measurement, e) Back, Capture, and Next buttons, f) example photo of position for measurement.

1) elbow Y & Z coordinates, 2) wrist Y & Z coordinates, and 3) a virtual point below the elbow by the person's hip, using the Y coordinate of the hip and the Z coordinate of the elbow.

The patient needs to be straight and square with the Kinect. We use the relative X and Z position of the hips and shoulders to determine whether a person is leaning right, left, forward, or backward and give the appropriate command (e.g. "Lean forward"). We determine if a person is facing to the right or left by calculating the relative Z position of each shoulder and give the appropriate command (e.g. "Turn Right") (Figure 4b).

When the observer is ready to take measurements, they see a screen similar to Figure 4. On the left, they see a stick figure representation of the patient (Figure 4a) and whether they are square to the Kinect Sensor. If not, an informative message appears (e.g. "Turn left", Figure 4b). On the bottom left corner, they can specify whether the patient is seated. On the right side, the observer has instructions to give to the patient (Figure 4c) and the current measurement (Figure 4d). To save the data and move forward through the measurement process, they click "Capture." Following a wizard-style design, the observer is allowed to click "Back" and "Next" to repeat or skip any measurements (Figure 4e).

Upon completion of measurements, a folder is created containing the stick figure images, a document showing each stick figure image next to the corresponding measurement as a handout for the patient, and a spreadsheet with the measurements for the observer (Figure 5). These documents are intended to be kept in the patient's file and/or given to the patient as they leave the clinic.

2.2 Accuracy of ShoulderCam vs. Goniometer

Previous research validated the measurement of ShoulderCam to that of a goniometer. Thus, ShoulderCam is a clinically valid tool [11]. In the prior study, 10 people with normal functioning shoulders completed the trial with 5 different positions of abduction, flexion, external/internal rotation, and cross body reach, resulting in 200 measurements. A medical professional acquired the goniometer measurements. The results of each measurement were compared using both techniques and were found to be highly correlated for each respective measurement (R = 0.997, 0.992, 0.982, 0.995). However, this previous work does not include the implementation details, involve a usability study, or explore whether or not medical professionals or patients would *want to use* such a tool. The study described in this paper adds to that clinical validation by assessing the user experience and viability for both observer and patient stakeholders in a medical clinic.

John Doe				
U1234567				
Sunday	February 22	2015		
Sore Shoulder				
Time	7:58:35 PM			
Right				
Abduction	Flexion	External Rotation	Internal Rotation	Cross Body
157	155	86	-73	4.98
Left				
Abduction	Flexion	External Rotation	Internal Rotation	Cross Body
159	127	54	-60	-0.1

Figure 5. Example Excel spreadsheet output of shoulder range of motion measurements. An example stick figure and measurement for patient printout is in the upper right hand corner.

3. USER STUDY

We conducted a user study at a medical clinic in two different exam rooms with two user groups: medical professional observers and patients. The lead researcher was in the room with an observer and patient. The observer first took the 5 measurements with the goniometer while being timed. The researcher asked about the observer and patient's experience with the goniometer by asking *"What are the potential benefits of the goniometer? Why?"* and *"What suggestions would make the goniometer easier or better to use? Why?*" Second, the observer took the same 5 measurements with ShoulderCam while being timed. The researcher interviewed the observer and patient by asking *"What are the potential benefits of the Kinect system? Why?"* and *"What suggestions would make the Kinect system easier or better to use? Why?*" Finally, the observer and patient gave their preference between the goniometer and ShoulderCam. Because this is a qualitative study, we did not account for order effects. All interviews were audio-recorded and transcribed following the study.

We recruited 5 observers (O1-O5: 3 females, ages: 27-44, median: 33) and 11 patients (P1-P11: 4 females, ages: 34-81, median: 57) from a medical clinic during their regular appointment. The study was designed to be ≤15 minutes to avoid interfering with the observer's and patient's schedules. There was no compensation for their time. We recruited new observers for this study that had no participation in the design of ShoulderCam and ensured that patients who helped pilot the system did not participate in the user study. Due to scheduling constraints, we had one member of the research team take measurements for 2 patients (P4 and P8). As a result, we only gathered interview data from P4 and P8 and not from the observer since he was a member of the research team.

3.1 Results and Discussion

We found that the majority of patients and observers preferred ShoulderCam (9/11 patients, 4/5 observers). Two patients did not prefer either method because they *would have to see what the difference of the measurements really are* (P5) or felt that *either one is fine* (P7). One observer preferred the goniometer since she did not *have to put out a laptop and reroute it to another room (O5)*. The authors conducted a thematic analysis of representative quotes from the transcripts with open coding [9]. Below, we discuss three themes that emerged on why the majority of patients and observers preferred ShoulderCam.

3.1.1 ShoulderCam perceived as more accurate

The majority of patients and observers listed accuracy as a benefit of ShoulderCam (6/11 patients, 4/5 observers). We did not ask the observers or patients about accuracy; this benefit was self-reported. The observers had a diverse set of reasons for accuracy: utilizing a camera (O1), more objective (O2), inter-observer reliability (O3), and correcting the patient using the camera (O4). Patients perceived accuracy for less scientific reasons; either they were not sure or felt that technology is "better," saying: *It looks more like it's more truthful because the technology [does] a better job than the do-hickey [goniometer]* (P3). Transferring patient assessments from manual measurement to technology may help with objectivity and be perceived as positive by observers and patients. Previously, Fogg and Tseng found that computers are not received as more credible than humans [10] and that computer credibility is at stake when computers report measurements [18]. Because technology is becoming more pervasive in the clinic, an interesting direction may be to empirically investigate whether observers and patients perceive measurements acquired via technology as more accurate than with manual methods.

Designers should exercise caution when designing an electronic system meant to replace manual assessment. For instance, Embi et al. found that while computerized physician documentation increased documentation availability, the system may have added mistakes and decreased physician confidence in the data [8]. Ash et al. found that IT in health care may have increased silent errors, rather than reduce errors for reasons including entering information for the wrong patient or clicking the wrong choices on the computer [3]. Because the observers used ShoulderCam once for each patient in this study, participants did not report concerns about entering errors. Further iterations with clinicians would be necessary to ensure ShoulderCam or other medical systems would integrate into the observer's workflow to mitigate potential errors.

Another reason that participants believed ShoulderCam may provide more objective measurements is that the observer is no longer directly manipulating the patient. This may remove bias that can occur with the goniometer: *You'll tend to stretch them or push them a little more if it is your patient after surgery* (O4). This also provides an advantage from the patient perspective (P1): *I had another shoulder surgery … and she was dead set on getting me up to full range of motion… At the end of that session, I got another physical therapist.* Further, Ananthanarayan et al. found that therapists pushed patients further than they were willing to move [1]. When designing patient assessment systems, it may be useful for the observer to be situated at a distance from the patient; they are able to give pointers, but are not directly manipulating the patient beyond their boundaries, which may provide a safety advantage. One caveat to consider is that not all patients will be able to demonstrate their range of motion and need help: *Some patients might push it a little more, some patients might just stop … So that is one potential disadvantage* (O4).

We recommend that designers consider the trade-off between a system that encourages direct manipulation of patients (hands on) and a system where the observer is situated at a distance from the patient (hands off). With a hands on measurement, it is possible that the observer may bias the patient, but in a hands off mode, the observer may not give enough guidance on how to perform the movement. For example, a hands on system can be helpful in the space of physical therapy, as was found in robotic therapy [4]. On the other hand, a hands off system such as ShoulderCam may be better for observers not trained with a goniometer.

3.1.2 ShoulderCam provides more visual information

ShoulderCam provided more visual information for patients during the shoulder assessment: *It certainly is easy to see where you are and where you need to get because of the stick figures telling me a lot more than what the goniometer is saying because it is just giving me some degrees* (P1). Unlike the goniometer, patients were able to play an active role in ensuring their body was square and facing ShoulderCam: *I'm actually able to reposition my body because I can tell if I am square with it* (P9). Further technology designs for the medical clinic may be enhanced when including real time visual feedback (similar to a mirror) so the patient can also participate in their assessment.

3.1.3 Less mental effort and time

ShoulderCam provided several advantages for the observers: they do not need to write things down: *you just have to take a picture with a button* (O1) and the measurements are easy to store: *I don't have to worry about losing the piece of paper* (O2). For all instances, measurements with ShoulderCam took less time than with the goniometer (ShoulderCam avg.: 116.6 seconds, goniometer avg.: 278.3 seconds, Figure 6). While it is possible that an observer may need to spend time setting up ShoulderCam, it can remain in one room so there is only one setup session, or it can be rolled between rooms to reduce setup time. In addition, the observer only needs to adjust the Kinect approximately to the patient's shoulders; no system calibration is needed. Developing technology systems for the clinic that streamline the process of recording and storing data (e.g., removing the need to write on paper and enter it to the computer) may make the observer's job easier and allow them to quickly refer to the measurements at a later time. These results are promising, but are preliminary due to the fact that our study was qualitative and not counter-balanced.

4. CONCLUSION

We built ShoulderCam, an observer-independent tool for measuring shoulder range of motion, and conducted a user study in the medical clinic with 5 observers and 11 patients. We received encouraging feedback and suggestions for improvement, including highlighting the angle currently being measured and adding a video description of the movements for patients. With more collaboration at the medical clinic, we will be able to refine ShoulderCam to improve the patient and observer experience.

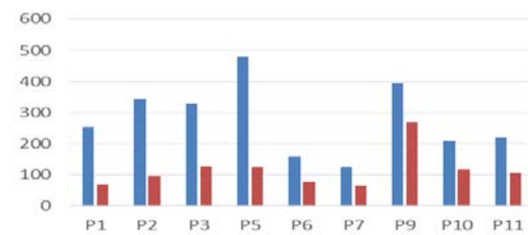

Figure 6. Average time for goniometer (blue) and ShoulderCam (red) in seconds. We omitted P4 and P8 since their measurements were taken by a member of the research team.

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