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A Marker Free Visual-based Home Rehabilitation Framework

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Abstract – Adhesive capsulitis or more commonly known as frozen shoulder, is a familiar occurrence for adults aged above 40 caused by the inflammation of the connective tissues surrounding the shoulder joint. There are different severity of adhesive capsulitis but patients afflicted with frozen shoulder typically will experience stiffness, severe pain, and reduced range of motion (ROM) for the shoulder. No matter the course of treatment being non-steroidal anti-inflammatory drugs (NSAIDs) or steroid injections, which can help reduce the inflammation and reduce pain, in order to restore ROM for the afflicted shoulder joint, rehabilitation exercises need to be performed. Even without the current climate where medical workers are severely overworked, physical therapists are in short order especially for developing countries like Malaysia. A remedy for this situation would be to deploy home rehabilitation instead. This would be a way for patients to get proper rehabilitation exercises in between visits to the clinic to meet the physical therapist. This can also reduce the frequency of in-clinic visits while still allowing the patient to progress in the rehabilitation of their afflicted shoulder joint. Though home rehabilitation seems like a clear solution, it does come with its own set of challenges. How open will the patients themselves be to utilizing a home rehabilitation system? In light of that, this paper proposes a home rehabilitation framework focusing on a marker free visual-based implementation using the Microsoft Kinect camera. The framework will measure the impact of variables such as capability, motivation and opportunity on the adoption rate of the home rehabilitation. Cronbach's Alpha tests were conducted to ascertain the reliability of the variables used in the framework.

Keywords— kinect, frozen shoulder, home rehabilitation, framework, pilot study

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I. INTRODUCTION

Adhesive capsulitis or more commonly known as frozen shoulder is a condition that is reported to be 2 – 5% in the general population [1] and can begin without any obvious reason. This means there is a possibility for this to afflict anyone at any given time without significant or catastrophic events causing it, but it does have higher tendencies to occur in adults over the age group of 40. Symptoms of frozen shoulder can be gradual at the beginning; thus, it could be mistakenly self-diagnosed by patients as simply being stiff or being a passing malady. Symptoms could worsen over time if no corrective measures are taken and if left untreated frozen shoulder could naturally go away but could take a year or even more. In other cases, patients never fully recover their afflicted shoulder's full range of motion. Physical therapy exercises can be used as a first line of treatment for frozen shoulder and when used with non-steroidal anti-inflammatory drugs (NSAIDs) it has proven to be even more effective [2]. As in most common cases, home

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exercises targeting mobilization and strength are conducted without the constant supervision of a physical therapist because of limitations to time and finance [3]. Patients would have to make a trip to the clinic for the initial consultation with the physical therapist. The patients would be taught rehabilitation exercises to perform to rehabilitate their afflicted shoulder. But patients performing physical therapy exercises by themselves at home often forget the steps or movements taught by the physical therapist. Even if that is not the issue, there are patients who also may not feel obligated to perform those exercises in the first place. Although the prescribed treatment can help alleviate their frozen shoulder symptoms, patients' non-compliance rates can be up to 70% as reported in [4]. In [5] the research found that less than 25% of patients performed the exercises taught correctly after two weeks of unsupervised home-based exercises. Home-based therapy may seem like the obvious solution to the lack of availability and access to physical therapist in developing countries but it does come with its own unique challenges. A marker free visual-based home rehabilitation has to be properly designed to not only be cost effective but also not require any technical or medical expertise to set up, as it would not be practical for the majority of the population. Although rehabilitation can be done using a myriad of ways such as physical therapist, robotic arms, sensor based markers, and visual based, for a home deployment, this paper focuses on a visual based system. In the vein of visual based systems, it could go the way of marker or marker free. With marker-based solutions, things get a little tricky because improper setup of markers on the human soft tissue will garner inaccurate results and may also require another party to assist in the placement of the marker on the patient itself. Due to these difficulties, a visual-based marker free implementation is more desirable as it does have a simpler setup that does not affect the accuracy of the tracking.

The Microsoft Kinect camera with its software development kit (SDK) can be a package used to implement such a marker free visual-based home rehabilitation system. Kinect, although initially intended as a gaming apparatus to be used with the XBOX 360, has been a curious tool to be used in research involving human motion tracking and it has even been deployed in the context of disabled students such as in [6]. Kinect combines a depth sensor with two dimensional RGB camera to create a three-dimensional spatial analysis of scenes. It is able to track and display the position of 25 individual joints for the user up to 30 frames per second. This information can be accessed directly through the Kinect SDK which will allow the programmer to perform skeletal tracking of up to six users simultaneously. This ability should suffice for tracking the patient's movement whilst performing rehabilitation exercises since the Kinect has a tracking range of 0.5m to 4.5m [7] which would provide ample space for the patient to perform rehabilitation exercises. The set up of Kinect is plug and play and the proposed implementation would merely require the patient to run the program and it will begin tracking the patient's movement. At the same time the home rehabilitation system would also keep records of the patient's exercises performed for the physical therapist to review when an in-clinic consultation is done. Also, the home rehabilitation system could access a patient specific rehabilitation exercise regime which means exercises could be specifically set by the physical therapist to cater to the specific patient to optimize their rehabilitation.

The main aim of rehabilitation exercises when it comes to rehabbing frozen shoulder is to improve the impaired range of motion of the afflicted shoulder. Patients will be prescribed tailored rehabilitation exercises and progress made can be measured by their increased range of motion. The current method of measurement for the range of motion (ROM) in most rehabilitation clinics in Malaysia, like the Unit Perubatan Rehabilitasi in Melaka General Hospital, is by using the goniometer. Goniometer has two so called arms, one of it should be stationary and the other moveable, which are hinged together. Goniometer will mimic the movement of the patient's shoulder and the center of the goniometer should be aligned to the afflicted shoulder. For better accuracy when getting the reading for the range of motion, it would be advisable for this to be done by medical experts, such as nurses. Since it would not be possible for the patient themselves to perform measurement using the goniometer, another party would be required to assist. Alas, in the standard home setting, the chances of a medical expert being present cannot be depended upon. So, if the goniometer is employed in a home rehabilitation setting, odds are inaccurate measurement of the range of motion will happen then the progress of the patient cannot be reliably ascertained. The proposed replacement of the goniometer would be the Microsoft Kinect camera and if Kinect is to be a viable replacement of the goniometer in measuring ROM, Kinect must have a good agreement of measure with the goniometer. A study conducted by [8] has shown Kinect has excellent relative reliability for the measurement of ROM. The 95% Limits of Agreement indicated there is no clinically significant difference between Kinect and the goniometer. Studies in [8] and [9] are consistent in finding Kinect as a viable replacement for the goniometer in measuring ROM.

II. FRAMEWORK

The proposed home rehabilitation framework focusing on a marker free visual-based implementation using Microsoft Kinect is shown in Figure 1. This framework has components adapted from Health Action Process Approach (HAPA) – Schwarzer, 1992, Technology Acceptance Model (TAM) – Davis, 1986, Behavior Change Wheel (BCW) – Michie, 2011, and Fear Avoidance Beliefs Questionnaire (FABQ) – Waddel, 1993. This framework attempts to investigate how variables such as capability, motivation and opportunity would affect the adoption rate of a marker free visual-based home rehabilitation framework. The capability variable is informed by self-efficacy, knowledge, memory, self-monitoring and physical ability. The motivation variable is informed by belief and attitude which in turn is informed by the variables; perceived usefulness and perceived ease of use. The opportunity variable is informed by social support, barriers and resources. This research also believes the capability and opportunity variables will affect the motivation of the patient as well.

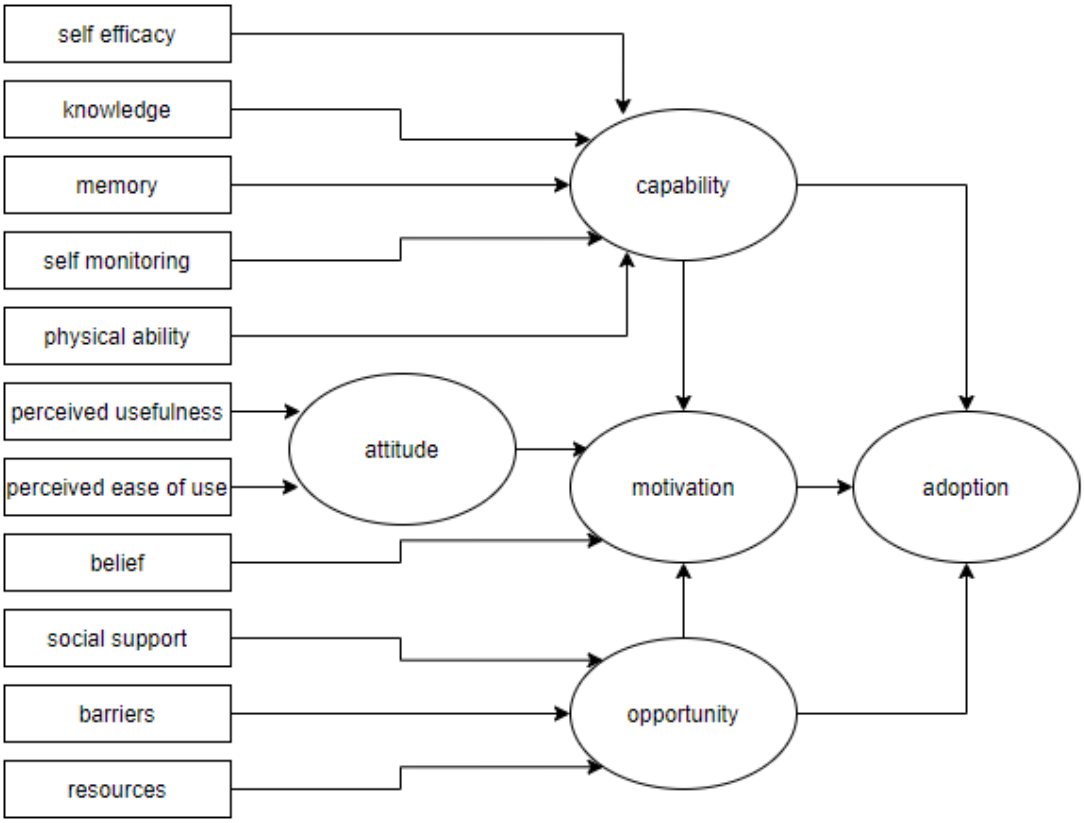

Figure 1. A Marker Free Visual-based Home Rehabilitation Framework

HAPA is a social cognition model and can identify the belief-based determinants of intentions and behavior, and the processes involved [10]. There are two phases; motivation and volition, which the HAPA model states are required in order to achieve health behavior change. In the motivation phase it studies how factors such as self-efficacy, outcome expectations and risk awareness lead to the formation of intention. Then in the volition phase it studies how action planning bridges between intention and behavior [11]. Just having the intention to change is insufficient, it must be coupled with proper planning in order to affect sustainable health behavior change. Since the proposed home rehabilitation system does incorporate a novel component in the Microsoft Kinect camera that is not familiar to most rehabilitation patients, it would serve this framework well to have a measurement to predict user's acceptance. By using the Technology Acceptance Model which utilizes the PU and PEU factors; PU being perceived usefulness and

PEU being perceived ease of use, this model is able to predict behavior of patients as well as their acceptance and intended use of technologies [12]. Perceived usefulness is the perception that is held by the patient, to what extent using a particular system will improve their rehabilitation performance. And perceived ease of use is the perception that is held by the patient, to what extent using a visual-based home rehabilitation system will be effortless or easy. Studies such as [13] and [14], have shown that the variables perceived usefulness (PU) and perceived ease of use (PEU) have a significant relationship with the quality of the information system. Next, the BCW is added into this framework to study how the sources of behavior such as capability, opportunity and motivation affect behavior. In this paper, the change in behavior is focused on the adoption of the proposed marker free visual-based home rehabilitation framework. By using the BCW model, a better understanding of what variables under capability, opportunity and motivation can help improve the adoption rate of the system. In general, "Is the patient capable of the behavior", "Does the patient have the opportunity to enact the behavior", and "Is the patient motivated to enact the behavior" [15]. Another consideration taken was how the patients fear of activities causing pain will affect their adoption of the proposed home rehabilitation system. FABQ is a questionnaire approach that was initially developed to assess patients with lower back pain disorder but has also been adapted for research in the context of shoulder disorders as detailed in [16].

Self-efficacy variable in the proposed framework from Figure 1 is used to measure the patient's belief in their own capacity to perform the rehabilitation exercises using the proposed home rehabilitation system, for example "I am able to return to my regular Kinect home rehabilitation program even if I happen to give up for a couple of days". The knowledge variable in the framework is used to measure the patient's awareness regarding the utilization of the proposed system, for example "With regard to the Kinect home rehabilitation program, I know what my responsibilities are". The memory variable is the patient's mental capacity to recall rehabilitation exercises whilst using the proposed system, for example "Performing the exercises following the Kinect home rehabilitation program's instructions is something I seldom forget". Self-monitoring in turn measures how well the patient self-assess their behavior and progress using the proposed system, for example "Using the Kinect home rehabilitation program, I will constantly monitor myself whether I exercise frequently enough". Physical ability is used to measure how well the patient can perform rehabilitation exercises using the proposed system, for example "I have been trained to perform the home rehabilitation exercises following the Kinect program guidelines". Capability measures the patient's psychological and physical capacity to perform rehabilitation exercises using the proposed system, for example "I have my own plan regarding when to start the Kinect home rehabilitation program". Perceived usefulness measures the patient's belief that using the proposed system can help their rehabilitation progress, for example "The Kinect home rehabilitation program would improve my exercise performance". Perceived ease of use in turn measures the patient's belief that using the proposed system is effortless, for example "I find the Kinect home rehabilitation program easy to use". Attitude measures the patient's view on using the proposed system, for example "I generally have a positive attitude towards using the Kinect home rehabilitation program". Belief measures the patient's fear avoidance belief on how performing general activities or rehabilitation exercises can impact their afflicted shoulder, for example "I should not do rehabilitation exercises which (might) make my pain worse". Motivation, be it reflective or automatic, measures the process of stimulating the patient to perform rehabilitation exercises using the proposed system, for example "I am confident that I can perform my rehabilitation exercises using the Kinect home rehabilitation program on my own, at home, with proper guidance". Social support measures the assistance or comfort afforded to the patient using the proposed system, for example "My physical therapist is willing to listen to my problems about performing the home rehabilitation exercises following the Kinect program guidelines". Barriers measures the patient's obstacles to obtain rehabilitation, for example "It is easy to get transport to rehabilitation". Resources measures the available means for the patient to obtain rehabilitation, for example "There is a rehabilitation center in my area". Opportunity is the social and physical factors that are external to the patient that makes it possible for the patient to perform rehabilitation exercises using the proposed system, for example "I have easy access to the Kinect home rehabilitation program and guidance from the hospital to perform rehabilitation exercises on my own". Adoption measures the degree to which the patient will implement the marker free visual-based home rehabilitation system in their rehabilitation journey, for example "I would use the Kinect home rehabilitation program in the future".

III. METHODOLOGY

A pilot study was done using a questionnaire as its instrument. And for the questionnaire to be able to measure what it was intended to measure, first it must be ascertained to have the ability to measure consistently. For this purpose, Cronbach's Alpha was used in this research. The Alpha variable can be used to measure internal consistency, or in

other words the extent to which all items in a test measures the same concept [17]. With the proposed visual-based home rehabilitation framework, there are 16 variables namely self-efficacy, knowledge, memory, self-monitoring, physical ability, planning, perceived usefulness, perceived ease of use, attitude, belief, motivation, social support, barriers, resources, opportunity and adoption. Although these variables are adapted from established models such as HAPA, TAM, BCW and FABQ, modifications have been done to either clarify the question to this research's context or to reduce the number of questions for the variables. To that end, it was necessary to use Cronbach's Alpha to measure the internal consistency. The questionnaire consists of 59 questions with two of the questions for gathering demographic data such as age and technology savvy, which was self-assigned. As stated before, the questions were modified to clarify this research's context, for example the self-efficacy variable was measured using four questions, which were modified to "I am able to perform my Kinect home rehabilitation program even if there is no one to guide me", "I am able to maintain my Kinect home rehabilitation program even if I am tired", "I am able to return to my regular Kinect home rehabilitation program even if I happen to give up for a couple of days", and "I am able to return to my regular Kinect home rehabilitation program even if I feel weak after an illness" for better clarity of the context at hand. The questionnaire had 4 items used to represent the self-efficacy variable, 3 items to represent knowledge, 2 items to represent memory, 4 items to represent self-monitoring, 3 items for physical ability, 3 items for capability, 3 items for perceived usefulness, 3 items for perceived ease of use, 2 items for attitude, 11 items for belief, 3 items for motivation, 4 items for social support, 2 items for barriers, 2 items for resources, 4 items for opportunity, and 4 items for adoption. All the items were rated on a 7-point Likert scale, providing a neutral opinion, 2 moderates, 2 intermediates and 2 extremes, ranging from 1=strongly disagree to 7=strongly agree.

A. Experiment Setup

The questionnaire was distributed to voluntary and random patients attending physical rehabilitation at Melaka General Hospital. The pilot study was conducted with 20 patients with age ranging from 36 to 58 and self-rated technology savvy of beginner to advanced. Patients were given time to try out the Kinect-based home rehabilitation system before the questionnaire was administered to them. First, the patients were given explanation about the home rehabilitation system and further explanation were given regarding the usage of data gathered. After that a consent form is given to the patient. The patients then performed a few rehabilitation exercises such as shoulder flexion along the coronal and sagittal planes, and shoulder extension along the sagittal plane. Patients were asked to perform ten repetitions per exercise type. Then a final repetition is performed, and the afflicted shoulder's ROM angle is measured using the Kinect rehabilitation system and by two nurses using the goniometer. Once all exercises are completed, the patient is asked if there are any queries regarding the system. Lastly, the questionnaire is administered to the patient.

B. System Setup

Although the proposed system was intended to be a home rehabilitation system, for convenience and the lack of equipment to distribute to each respondent, the patient was asked to try the proposed system in the Melaka General Hospital rehabilitation clinic. A section of the clinic was cordoned off for the patient to try the system in private. The setup of the system is as shown in Figure 2. The system consists of a standard 41" LED TV, an Intel Compute Stick, the Microsoft Kinect camera, and a clip to hold the Kinect camera in place. The home rehabilitation program was executed, then the patient would step in front of the Kinect camera. Distance of the patient would be approximately 1.2 to 3 meters away, depending on the height of the patient. As long as the full body of the patient was visible to the Kinect camera, the system would be able to capture the patient's exercise movements. Since this system is a live system, the patient can visually see their body image and skeletal view on the TV. Once the patient has visually confirmed that the full body is visible on the TV, the patient can start performing their exercises. For the purpose of this research, 3 types of exercises were required of the patient. For each type, 10 repetitions are required. The home rehabilitation system will measure and record each repetition's ROM angle. Then a final repetition is performed, and nurses will use the goniometer to record the ROM angle as well. Once all repetitions are done, the program will proceed to the next type of exercise. The proposed system would provide live feedback to the patient, and the patient can view the angle achieved on the range of motion for the afflicted shoulder. Statistics regarding the patient's exercises performed were gathered by the system.

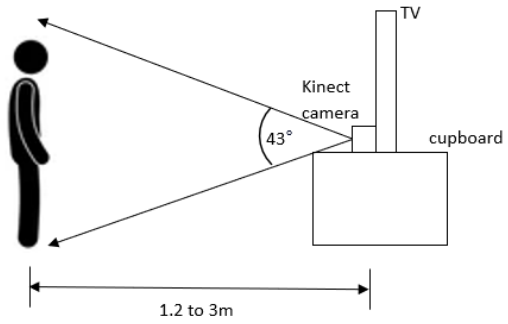

Figure 2. Setup Of Home Rehabilitation System Using Microsoft Kinect.

IV. RESULTS AND DISCUSSIONS

Since the variables in the questionnaire have been adapted from various sources, conducting Cronbach's Alpha was necessary to show that the questionnaire was fit for purpose. Cronbach's Alpha showed that the variables of the questionnaire had acceptable reliability, all α values were larger than 0.7. Because of that, no item was considered to be removed at this stage as there is no indication that the questionnaire cannot generate trustworthy results. There is slight concern about the α value of items adapted from the FABQ, as it is on the high side of 0.948. A high α may suggest redundancies [17] but the adapted items from FABQ have already been trimmed down from 16 items to 11 items, only focusing on FABQ-W (to measure the degree to which the patient believes work activities impact the patient's frozen shoulder) and FABQ-PA (to measure the degree to which the patient believes rehabilitation exercises impact the patient's frozen shoulder) items. Table 1 details the variables and their corresponding Cronbach's Alpha values.

Table 1. Variable Reliability Statistics

Variables	**Cronbach's Alpha**
Self-efficacy	0.738
Knowledge	0.819
Memory	0.749
Self-monitoring	0.739
Physical ability	0.868
Planning	0.705
Perceived usefulness	0.836
Perceived ease of use	0.857
Attitude	0.734
Belief	0.948
Motivation	0.728
Social support	0.894
Barriers	0.760
Resources	0.765
Opportunity	0.754
Adoption	0.773

V. CONCLUSION

A marker free visual-based home rehabilitation framework is important for patients afflicted by frozen shoulder to have a steady progress in their rehabilitation journey. Since its marker free, this allows the setup of the system to be

done easily by non-medical experts. The Microsoft Kinect camera with its accompanying SDK is an attractive package to implement the visual-based home rehabilitation system and it does have excellent relative reliability for the measurement of ROM. With the outcome of the test showing that the instrument is reliable, further research can be done to explore the effectiveness of the proposed marker free visual-based home rehabilitation framework.

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