A Preliminary Study on Smartphone Applications for
Upper-arm Rehabilitation in Korea

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Abstract. This paper proposes the mobile assessment system for shoulder joint
rehabilitation. To monitor the patient’s condition during the rehabilitation
process, it is necessary to assess the initial condition and monitor the progress
before and after the treatment. For the assessment, the shoulder joint angle in
certain positions needs to be measured. The proposed system measures and
assesses the patient’s joint angles in four different positions using smart sensors
embedded in the smartphones such as the accelerometer and the gyroscope. The
performance of the proposed system is evaluated by comparing the assessment
results with measurements using the goniometer.

Keywords: Smartphone, Shoulder joints , Measurement, Mobile, Sensor

1 Introduction

The medical industry comprising of medical devices and services is expanding due to
the rapid progress of information technology. Information technology is being applied
to all kinds of medical devices, ranging from expensive surgical robots to less
expensive small medical devices. In addition, the convergence of IT and medicine has
enabled the digitization of medical data, enhancing the credibility of diagnoses and
tests prescribed by doctors. The primary function of medical devices is to measure
biological data using sensors, which makes sensor technology a major factor in
medical devices merged with IT. Various sensors are being used in the medical
system for diagnosis and examination and more recently, the research and
development of various smart sensor-based medical systems for diagnosis and
examination are underway. Smartphones carry smart inertial sensors that can measure
angular acceleration, which are evolving into motion sensors and IMU sensors by
combining the three-axis acceleration sensor with the three-axis gyro sensor.[1]

Meanwhile, safety accidents and extreme exercises have been contributing to a
steady increase in the number of patients with functional disorders. Continuous
rehabilitation is required for such patients. Doctors record the initial state of the
patient and monitor any changes prior to and following the treatment by measuring
the joint angle.

This paper proposes the measurement and evaluation system for shoulder joint
rehabilitation using smartphones. In order to check for any changes in a patient’s
condition over the course of rehabilitation, joint angles in specific positions needs to
be measured. The proposed system measures and evaluates the patient’s shoulder
joint angles in 4 different positions using the smart sensors (accelerometer and
gyroscope) embedded in smartphones. The performance of the proposed system is
evaluated by comparing the assessment results with measurements using the
goniometer.

2 The angle measurement for the evaluation of shoulder joint
rehabilitation using smartphones

The proposed system measures the shoulder joint angle to evaluate the rehabilitation
using accelerometer and gyroscope embedded in the smartphones. The measurement
order of the proposed system proceeds as follows: 1) Initialize the smartphone to
offset the coordinate in the accelerometer with the radius bone. 2) Make shoulder
joint rehabilitation motion with the smartphone attached. 3) Measure the shoulder
joint angle holding the the final motion.

In order to measure the shoulder joint angle, the accelerometer has to be aligned
with the coordinate system of the shoulder joint. Fig. 1 (a) shows the three-
dimensional coordinates of the accelerometer embedded in the smartphone; the x-axis
plots horizontal movements with the device facing the front, the y-axis plots vertical
movements, and the z-axis plots back and forth movements of the device itself.
Therefore, the initialization is performed to register the accelerometer and coordinates
of the radius bone as shown in Fig. 1 (b-c).

![Fig. 1. The location initialization of Smartphone.](image)

The accelerometer in the smartphone estimates the rotation displacement using the
gravity acceleration [2]. Because rotation displacement estimation using gravity
acceleration carries intrinsic measurement errors due to the gravity factor, the
The proposed system separates the gravity component using the low pass filter as shown in Equation (1) [3].

\[
g_i(k) = ag_i(k-1) + (1-a)a_i(k)
\]  

(1)

Where, \(g_i(k)\) is gravity component, \(a_i(k)\) is the acceleration of axis-I, I is axis x, y, z value respectively.

The acceleration of the smartphone is obtained by deducting the gravity component of three axis found in the equation (1) from the acceleration found in the equation (2).

\[
a_i(k) = a_i(k) - g_i(k)
\]  

(2)

Based on the equation (1) and (2), the smartphone application is implemented for the measurement of the shoulder joint angle. Android provides API creating the event if the current sensor value changes in the comparison with the previous sensor value measured periodically according to a set schedule. The implemented application measures the angle by applying then low pass filter to the accelerometer and gyroscope sensor data obtained from API.

### 3 The preliminary study and Discussion

As a preliminary experiment for the clinical study, this section deals with the evaluation of proposed shoulder joint rehabilitation system by comparing the measurement result using goniometer with the proposed system. The performance is evaluated in a way that the measurement error of the system is calculated based on the measured result using goniometer. During the experiment, the measurement of the shoulder joints is carried out in four motions used for the rehabilitation evaluation; abduction, forward flexion, internal rotation, external rotation [4]. The abduction movement refers to the arm being lifted as high as possible sideways; forward flexion is the movement raising an arm towards the front; internal rotation and external rotation is when elbows are rotated to their fullest extent both inwards and outwards while being fixed to the sides. The experiment was conducted on five subjects.

The measurement result are as follows: Abduction showed the angular displacement from 142° to 167°; Forward flexion showed the angular displacement from 87° to 101°; Internal rotation and External rotation showed the angular displacements of 27-82° and 29-51° respectively. The error ranged from 0° to 6° and the mean error was 2.9375°.
4 Conclusion

In this paper, the angle measurement system for the rehabilitation evaluation using the smartphone has been discussed. Based on the accelerometer and gyroscope embedded in the smartphone, the proposed system measured the patient’s shoulder joint angle in four different positions. The performance of the system was reviewed by comparing the measurement results of the method using goniometer with the proposed one which was conducted on five subjects. The experiment result verified that the measurement result of the system, unlike its counterpart using goniometer, was within the allowable range of error (The mean error was approximately 2.9375), which validated the viability of the proposed system. While the proposed system must remain parallel with the radius bone at all times for measurement accuracy, the wristband provides relatively accurate measurements of the shoulder joint angle from simple movements by securing the device. The shoulder joint rehabilitation assessment system presented in this paper is expected to be implemented in blind tests for patients with various shoulder joints disorders in the future.

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References