INTERACTION: AN INTERACTIVE KNEE ANGLE MEASUREMENT SYSTEM FOR AT HOME PHYSICAL THERAPY

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INTRODUCTION

In the United States alone, 600,000 total knee replacements are performed each year [4]. Rehabilitation from this type of procedure is often prescribed to be performed by the patients at their own home [1]. The main problem with at home physical therapy is that it is hard for the therapists to monitor how their patients are performing the prescribed exercises. The patients could perform the exercises incorrectly, not perform the exercises, or overdo the exercises, all of which could result in improper healing or even injury of the joint.

In order to help physical therapists monitor the progress of their patients, Inertial Measurement Units (IMUs) can be used to measure the anatomical knee angles of the patients while they are performing their prescribed exercises. IMUs are small devices that contain accelerometers, gyroscopes, and magnetometers. They output their orientation in space as transformation matrices based on gravity and magnetic north, which are sensed by the accelerometers and magnetometers, respectively. These transformation matrices can then be converted into Euler angles around three distinct axes. For the purpose of this project, two different sensor types were considered: VectorNav and InertiaCube BT.

In order for these sensors to measure the true anatomical knee angles, one sensor must be strapped on to the femur, while the other is attached to the tibia. The sensors therefore track the motion of their respective segments. However, in order to obtain accurate knee angles in the anatomical planes, a calibration procedure is required to align the sensors to the knee joint [3]. Previous literature [1][2][3] has explored the best way to perform this alignment, but there is no gold standard. These sources have also not tried to make the sensors wireless, and have not connected the practice specifically to physical therapy.

OBJECTIVE

Overall, the objective of this project is to develop and test a system that will allow physical therapists to monitor their patients’ anatomical knee angles with IMU sensors as they perform their prescribed exercises at home for knee rehabilitation.

SUCCESS CRITERIA

In order for this objective to be achieved, three success criterion must be met: the results must be accurate within 3 degrees as compared to VICON; the results must be repeatable, indicating that the sensors did not drift from each other; and the entire system must be comfortable, in that the knee sleeve or and sensor attachments are not restrictive and the user interface is helpful and visually pleasing.

METHODS

To begin this project, different types of IMU sensors were compared by many different parameters. In the end, VectorNav and InertiaCube BT were the sensors chosen because they were relatively small and were compatible with the software packages that were to be used for the duration of the project.

Next, a calibration procedure was developed. Each time a subject begins the exercises, first they need to turn on the sensors and place them on a flat surface against a wall. A computer program through Matlab records this initial position of the sensors (Position 1). Next, the sensors are attached to their respective positions on the subject’s leg, and the subject stands against the same wall against which the sensors were placed, defining this as the anatomical plane. The position of the sensors is recorded again (Position 2), and the orientation relationship between Position 1 and Position 2 is calculated for each sensor (T1 and T2). Throughout the exercises, the transformation matrix (Tf) between the two sensors is calculated and modified by T1 and T2, aligning the angles to the anatomical plane. Any changes in Tf are therefore recorded as anatomical angles about three different axes (flexion/extension, varus/valgus, and internal/external rotation).

In order to test the repeatability of the sensors, two methods were used. The first method was to have a subject perform squats for one minute in a controlled environment, with physical stops (a chair and wall) to ensure the consistency of the subject’s movements. The second method was to use a Gimbal system, which ensures ideal movement about one of the three axes. This means that no off-axis movement should have been recorded. The angles recorded between the built-in physical stops on the Gimbal system were 40 to -35 degrees. Measuring these angles before testing allowed for approximate accuracy testing. For each of these methods, the average and standard deviations of the peaks and valleys around the flexion axis were calculated for each system. After this, the repeatability of the two systems were compared to each other.

To test the accuracy and comfort of the system, 25 healthy subjects will be asked to perform exercises in the lab. During these exercises, their anatomical knee angle data will be recorded by both InterAction and VICON, and the results will be compared. The results from InterAction should be accurate within 3 angular degrees of what VICON has recorded. To test comfort, these same subjects will fill out surveys including various questions about the knee sleeve, attachments, and the user interface. These questions will ask them to rate the system on a scale of 0-4, so it will be easy to quantify what still needs to be modified. Only preliminary testing of this part of the project has been completed due to time constraints. For this preliminary test, three exercises were recorded (knee extensions, squats, and gait) for one subject. Both the peaks of
the data and the total range of motion were used for accuracy comparison. The remainder of testing will be completed in the upcoming months.

RESULTS

This means that the standard deviations of all of the peaks and valleys were less than 3 for both sets of sensors. During the squats, the standard deviations for the peaks and valleys were: Inertiacube: 2.574 and 1.930, and VectorNav:1.200 and 1.725, respectively. Using the Gimbal system, the peaks and valleys were: InertiaCube: 0.390 and 0.378; and VectorNav: 2.092 and 0.975, respectively (Figure 1).

![Figure 1: Repeatability](image)

From this test, a general knowledge of the system’s accuracy was also measured. The VectorNav sensors recorded an average peak on the Gimbal system of 40.710 degrees, and an average valley of -36.692 degrees. The InertiaCube sensors recorded an average peak of 39.345 degrees and an average valley of -38.683 degrees.

The preliminary results for accuracy testing are shown in Table 1 below. Because VICON is currently the gold standard, ideally InterAction should have matched the values shown for VICON below.

<table>
<thead>
<tr>
<th></th>
<th>Avg. ROM (Flexion)</th>
<th>Avg. Peak (Flexion)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VICON</td>
<td>InterACTION</td>
</tr>
<tr>
<td>Knee Ext:</td>
<td>77.925</td>
<td>69.990</td>
</tr>
<tr>
<td>Squat:</td>
<td>49.691</td>
<td>47.158</td>
</tr>
<tr>
<td>Gait:</td>
<td>56.950</td>
<td>56.057</td>
</tr>
</tbody>
</table>

To summarize the table, there was a difference in average range of motion of 7.935, 2.533, and 0.893, for knee extension, squat, and gait, respectively. There was a difference in average peak of 6.793, 9.222, and 9.221 for knee extension, squat, and gait, respectively.

DISCUSSION

The results from the repeatability testing showed that both sets of sensors were repeatable within 3 degrees for all trials.

The results from the squats were expected to be much higher values than those of the Gimbal system because it allowed for much more error of movement. The relatively large standard deviation seen in the VectorNav peaks for the Gimbal system was a single peak that was an outlier in actual movement. From the average peaks recorded by both systems, it can be seen that they are somewhat accurate, as the average peaks and valleys are relatively close to the measured values of approximately 40 and -35 degrees.

The results from preliminary testing of accuracy indicated good accuracy in range of motion for the squats and gait exercises. However, the constant offset of the peaks of approximately 10 degrees indicates that there was a disparity in initial position of the subject. In further testing, this disparity will be minimized, and any other issues that contributed to poor accuracy during the knee extension exercise will be looked into and modified.

This project was limited mostly by time. It took a long time to get all of the sensors and equipment necessary to complete all of the development, which needed to happen before any testing could take place. There is also no guarantee that VICON gives completely accurate results, so it is impossible to know exactly how accurate InterAction is.

CONCLUSION

At home rehabilitation, while a useful tool for physical therapists, is often hard to monitor. InterAction has proven to be a repeatable system to measure the anatomical movements of the knee, and therefore can help physical therapists prescribe corrections to the exercises. This system could be a great asset to physical therapists around the world, and could aid in the rehabilitation of various knee injuries, primarily those who have undergone a total knee replacement surgery.

ACKNOWLEDGEMENTS

I would like to acknowledge Dr. Richard Debski for being my mentor and helping me to work through this project. I would also like to thank Kevin Bell, Rob Hartman, and Shawn Farrokhi for teaching me the skills necessary to complete this project. Lastly, I want to thank the department of bioengineering for funding, and Dr. Almarza and Avinash for helping me with my presentations and abstract.

REFERENCES