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A Non-Contact System for Measuring Wrist and Carpal Kinematics

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BIOMEDICAL

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CAPSTONE DESIGN EXPO 2015

Introduction

Motion of the wrist relies on the complex articulations of the distal arm and the many small carpal bones located at the radiocarpal joint. Ligamentous injuries of the wrist are often sustained by athletes, individuals who experience trauma due to falling, or other sources of high impact on the delicate bones and ligaments. These injuries can result in instability and possible dislocations of the bones within the joint.

Treatment for injured wrists ranges from simple splinting to surgical intervention. Both therapies involve limiting the motion of the wrist for a period of time in order to minimize the stresses on the recovering soft tissues. Research into the minute kinematics of the carpal bones, namely the scaphoid and lunate, would help gain an understanding of the small, but significant effects that ligamentous injuries can cause. It can also be used to simulate and improve surgical techniques. Additionally, the insight gained from this type of research could aid in developing more advanced and effective physical therapy techniques.

Figure 1: Dorsal radiograph of a right wrist including radius (R), ulna (U), lunate (L), and scaphoid (S)

There are some devices that can measure the kinematics of a cadaveric wrist, however, they either use relatively expensive technology, or require physical contact with the specimen that can impede bone movement.

We proposed a non-contact system for measuring wrist kinematics that could measure the movement of the scaphoid and lunate (Figure 1).

The main deliverables of the project were a project design, a program and algorithm that could identify and measure movement on an image both accurately and precisely, and a final working prototype.

Imaging Selection

First, a method of measurement was selected. CT, radiography, ultrasound, and magnetic tracking methods (Figure 2) were considered. The main constraints of the selection were maintaining no contact to permit natural movement, allowing three dimensional measurement in six degrees of freedom (translation and rotation about three axes), and a relatively low cost to allow implementation in a basic research environment.

After exploring the aforementioned options as well as others, video motion capture was selected as most qualified for the requirements. By using two cameras placed at 90° with respect to one another, two individual recordings of two dimensional motion could be used to render and calculate all the degrees of freedom. Additionally, this method would cost only a fraction of the other methods and would not require extensive tethering to the bones.

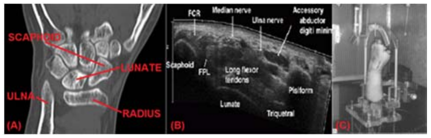

Figure 2: (A) CT of wrist, (B) Ultrasound of wrist, (C) Magnetic Tracking of Wrist

Design and Specifications

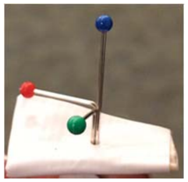

Figure 3: Single set of markers

Next, marker specifications needed to be chosen. Markers serve as optical reference points for the imaging technique and move in direct relation to the bone into which they are rigidly attached. Therefore, tracking the marker motion would equate to tracking the bone motion. The options considered were active markers and passive markers. Active markers provided the benefit of additional contrast within the videos and would allow for easier detection. Also, ambient light sources would have a hindered effect on the marker clarity. Passive markers, however, could be much smaller and would stand alone. As opposed to active markers, passive markers do not require a power source, and therefore, there would not need additional wiring to add forces to the small bones; conversely, they require closer control on the ambient interferences.

Orthogonally shaped passive markers were selected for use (Figure 3). Each distinctive head within a single set was used as a reference for the x, y, and z axes, respectively.

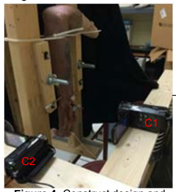

Figure 4: Construct design and setup of Camera 1 (C1) and Camera 2 (C2)

Figure 5: Front facing view of cadaver wrist and setup

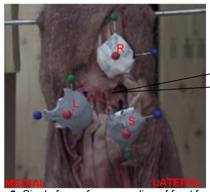

Figure 6: Single frame from recording of front facing camera (C1-Figure 4) with markers identified for radius (R), scaphoid (S), and lunate (L)

Three orthogonal markers were glued into drilled holes in the scaphoid, lunate, and radius, respectively. Two cameras were placed at a position normal to the height of the bones at 90° with respect to each other (Figure 4 - C1 and C2). Both cameras were used to record motion of the markers in during wrist motion (Figure 5 and Figure 6).

Software and Processing

Video recordings were made of the wrist during both flexion and extension. Matlab was chosen as the appropriate software for programming because of its figure processing ability, built in functions, and ease of use, and it was used for image processing and data collection. Recordings were separated into individual frames, and every successive fifth frame was analyzed. Markers and their respective centers within each frame were then identified using the software (Figure 7).

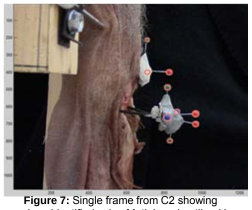

Figure 7: Single frame from C2 showing markers identified using Matlab and outlined in red

Analysis and Application

The images were washed of excess data, and the pixel position of each marker was determined (Figure 8). The distance change was calculated throughout the frames in pixels. Calibration of the pixels allowed measurements in millimeters.

By using two dimensional analysis of the center of the marker position from both views, translation along all three of the axes for each respective bone was able to be determined.

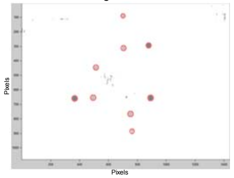

Figure 8: Conversion, isolation, and identification of markers in Figure 6 by Matlab

```
RadiusTotalTranslationMM =

   -0.0022   -0.0986    0.1648

ScaphoidTotalTranslationMM =

   -1.2884  -20.6961    2.1366

LunateTotalTranslationMM =

   -1.9015  -15.6479   -1.8704
```

Figure 9: Matlab output for translation during extension; x y and z axes represented by column 1, 2, and 3, respectively

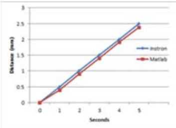

Figure 10: Accuracy diagram of Matlab code vs. standardized MTS translation

The total translation of the bones during translation were (Figure 9):

- Radius - 0.0022mm medially, 0.0986mm superiorly, and 0.1648mm posteriorly
- Scaphoid - 1.2884mm medially, 20.6961mm superiorly, and 2.1366mm posteriorly
- Lunate - 1.9015mm medially, 15.6479mm superiorly, and 1.8704mm anteriorly

By comparing the measurements made by the Matlab code with a MTS standardized translation, the accuracy was found to be ±0.1mm (Figure 10).

This method of motion analysis has the potential of further application throughout additional joints and bony structures throughout the body. By mimicking injuries as well as surgical procedures and analyze their effects on the kinematics of a joint, researchers will be able to implement more effective treatments in a more cost effective manner than before.