A Wearable System for Elbow Joint Angle Measurement
Institute of Biomedical Engineering, University of New Brunswick

INTRODUCTION:
There are presently about 300,000 Canadians living with the debilitating effects of stroke\(^1\) with annual costs exceeding $2.7 billion. A common functional deficit experienced by many stroke survivors is severe arm paresis with loss of elbow and shoulder mobility. Recent evidence suggests that arm motor function at 1 month post-stroke is one of the biggest predictors of stroke recovery.\(^2\) It is imperative that close monitoring of arm function in the weeks following stroke be clinically viable.

This project seeks to address this problem by developing, testing and implementing a wireless, wearable motion sensor device for capturing arm (elbow and shoulder) motion at any desired temporal resolution, and with accuracy and reliability exceeding that of commonly used clinical instruments.

The purpose of this study was to evaluate the accuracy, precision and repeatability of a wearable sensor system.

QUANTIFYING ELBOW KINEMATICS:
Sensor-to-segment transformations for the upper arm can be computed.

The relative rotation matrix:
\[
\begin{align*}
\theta_{S1}^{B1} &= \begin{bmatrix}
\phi_{S11} \\ \phi_{S12} \\ \phi_{S13}
\end{bmatrix}
\end{align*}
\]

Shoulder position:
\[
J_1 = S_1 + P_{S1}^{B1} \phi_{S1}
\]

Elbow position:
\[
J_2^{(1)} = S_1 + P_{S1}^{B1} \phi_{S1}
\]

METHOD:
A Prototype Arm with elbow flexion/extension joint and a shoulder abduction joint was constructed to simulate and measure human arm movement.

• Prototype Arm instrumented with potentiometers, 3-DOF and 6-DOF sensors and arrays of reflective markers.

• Validation by comparing synchronized sensor readings to potentiometers and captured Vicon M-Cam marker positions.

• Measured elbow joint angle at various known configurations: shoulder abduction angles 0, 30 and 60 deg., and elbow flexion angles 0, 45 and 90 deg.

• All positions repeated 3 times randomly and also repeated on a second day for 54 trials total.

• Calculate elbow joint angles from sensor-to-segment transforms.

RESULTS:
Accuracy: Absolute mean error (± 1 standard deviation) across all trials and test days (N=54) for the sensor system was 4.4 ± 1.4 deg, and 3.0 ± 1.2 deg for the Vicon.

Precision: Overall precision as measured by standard deviation of samples over the 1 second data collection period across all trials and test days (N=54) was .07 ± .02 deg for the sensor system, and .07 ± .06 deg for the Vicon system.

Repeatability: Within-test repeatability, for trials having identical configurations (N=9 per test day), was very high, with the intraclass correlation coefficient (ICC) = .99 for both test days. Within-test repeatability, for trials having the same elbow angle but different shoulder positions (0, 30 and 60 deg), across both test days (N=18), was also very high, with ICC = .99. Finally, test-retest repeatability between days was also very high, with ICC = .99, with no differences in elbow angle measurements between days after removing and replacing the entire sensor system from the mechanical arm.

These preliminary validation experiments show that the sensor system for measuring elbow angle exceeded both the target precision (<.1 deg) and the target repeatability (ICC>.90) performance criteria. However, the overall accuracy of the device, primarily due to increasing error at larger elbow flexion angles, did not reach the target of <3 deg.

DISCUSSION AND FUTURE WORK:
The results are very promising at this stage of development. The accuracy is comparable to the Vicon system when the limb is extended. The error increases with angle and becomes considerably different than the Vicon angle when the elbow flexion angle goes beyond 45°. It is expected that this error at larger angles can be reduced through a combination of revised mounting schemes for the sensors and optimizations of the calibration protocols and algorithms. Further work in this area also needs to be performed to investigate the impact of different mounting strategies using actual limbs of a variety of shapes and sizes. A study measuring elbow angle of stroke patients is planned for the near future.

REFERENCES

ACKNOWLEDGEMENTS
Atlantic Innovation Fund and Atlantic Canada Opportunities Agency.