HUMAN JOINT ANGLES TRACKING WITH INERTIAL SENSORS

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INTRODUCTION

Wearable inertial systems have recently been used to track human movement in and outside of the laboratory. Traditionally, orientation has been calculated by integrating the angular velocity from gyroscopes. However, a small drift in the measured velocity leads to large integration errors. To compensate that drift, complementary data from accelerometers are normally fused into the tracking systems using the Kalman or extended Kalman filter (EKF). In this study, we combine kinematic models designed for control of robotic arms with state space methods to continuously estimate human joint angles using a minimal number of inertial sensors. The tracker utilizes an improvement to the EKF; the unscented Kalman filter which removes the need for linearization that introduces tracking errors.

METHODS

The human body can be represented as a system of rigid segments connected in kinematic chains by joints. The configuration between consecutive segments is characterized by a transformation matrix [1]. Orientation, velocity and acceleration are recursively tracked and propagated from one segment in the chain to another using a set of forward recursive equations known as Newton-Euler (N-E) equations. To track joint angles using state space methods, two models are required; a model describing the evolution of the system states with time and a model that relates the measurements to these states.

For illustration purposes, we present a model for elbow and forearm movement. This algorithm could be generalized to model any full limb movement. The elbow and forearm are modeled with two degrees of freedom, where Z_1 is the axis of rotation for elbow flexion/extension and Z_2 is for the forearm pronation/supination. Frame $\{X_0, Y_0, Z_0\}$ is a fixed reference frame, see Fig. 1. An inertial measurement unit with a triaxial gyroscope and accelerometer is attached to the wrist.

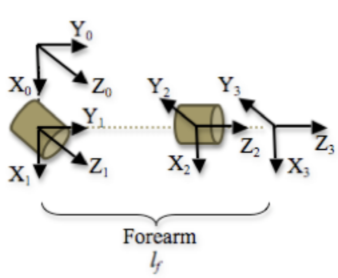

Fig. 1. Kinematics diagram of the biomechanical model of the elbow and forearm.

The process model is given by

$$\begin{aligned}
\theta_i(n+1) &= \theta_i(n) + T_\text{s}\dot{\theta}_i(n) + \frac{1}{2}{T_\text{s}}^2\ddot{\theta}_i(n)\\
\dot{\theta}_i(n+1) &= \dot{\theta}_i(n) + T_\text{s}\ddot{\theta}_i(n)\\
\ddot{\theta}_i(n+1) &= \alpha\ddot{\theta}_i(n) + u_{\ddot{\theta}_i}(n)
\end{aligned}$$

where θ_i is the angle, $\dot{\theta}_i$ is angular velocity, $\ddot{\theta}_i$ is acceleration, $i = \{1, 2\}$ for the two angles of rotation and $T_\text{s} = f_\text{s}^{-1}$ is the sampling interval. The observation model is given by

$$\begin{aligned}
\omega_x(n) &= \sin\theta_2(n)\dot{\theta}_1(n) + v_x(n)\\
\omega_y(n) &= \cos\theta_2(n)\dot{\theta}_1(n) + v_y(n)\\
\omega_z(n) &= \dot{\theta}_2 + v_z(n)\\
\dot{v}_x(n) &= \cos\theta_2(n)[l_\text{f}\ddot{\theta}_1(n) + g\cos\theta_1(n)] + v_x(n)\\
\dot{v}_y(n) &= -\sin\theta_2(n)[l_\text{f}\ddot{\theta}_1(n) + g\cos\theta_1(n)] + v_y(n)\\
\dot{v}_z(n) &= -l_\text{f}\dot{\theta}_1^2(n) + g\sin\theta_1(n) + v_z(n)
\end{aligned}$$

where l_f is length of the forearm and g is gravity.

RESULTS

Fig. 2 shows the performance of the tracker with synthetic data. The solid lines represent true angles and the dashed lines represent the corresponding angles estimated by the unscented Kalman filter. The difference between the true and estimated angles of the elbow and forearm was calculated and the RMSE for the elbow flexion/extension angles was 2.1° and 3.1° for the forearm supination/pronation angles.

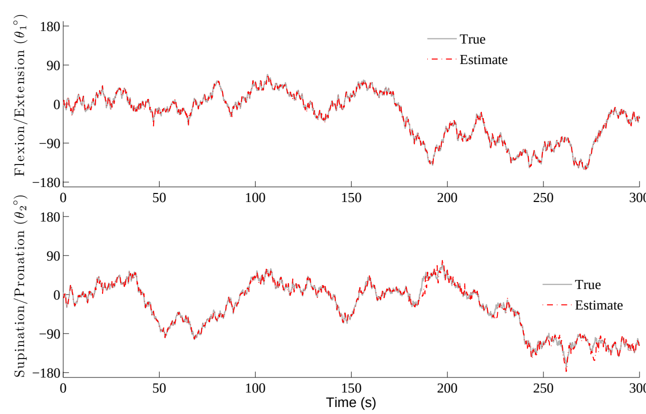

Fig. 2. Five minute segment of synthetic data; the solid lines represent real angles and the dashed lines represent the estimated angles.

REFERENCES

[1] J. J. Craig, *Introduction to Robotics, Mechanics and Control*, ser. Electrical and Computer Engineering: Control Engineering. Addison-Wesley, 1989.