Motion Tracking for portable biomechanic measures

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I. MOTIVATION

Human motion tracking has been vastly studied for performance assessment. Traditional motion tracking techniques are based on optical capture systems that, despite being accurate, suffer from occlusions, changes in lighting conditions, and, in some cases, small workspaces. These issues are overtaken by wearable motion tracking systems, in particular those based on inertial motion units (IMUs).

Motion tracking based on direct integration of IMU's data is unsuitable because of drift. In this study we fuse IMUs data using Unscented Kalman filter (UKF) to compensate drift and to reconstruct human upper limb pose. Results will be exploited in a new system aimed at the wireless monitoring of workers for the detection of unhealthy activities based on both EMG sensors and motion tracking by IMUs.

II. METHODS

a) Upper limb model: we use a 5 degrees of freedom (DoFs) model of the human arm having the chest as root and two links for upper arm and forearm. The shoulder is modeled as a 3 DoFs spherical joint, two revolute joints allows for elbow flexion and forearm pronosupination. The Denavit-Hartenberg (DH) convention is used to model the kinemaitc chain. Shoulder joint is broken down in three revolute joints as a spherical wrist. Six frames are hence used in the chain. An homogeneous matrix A^i_{i-1} dependent on i^{th} link parameters and the joint angle ϑ_i represents the relationship between two consecutive $i-1^{th}$ and i^{th} frames. The set of joints' angles $\Theta = [\vartheta_1, \ldots, \vartheta_5]$ suffices for motion reconstruction. A UKF is used to estimate Θ, prediction and update models are then described.

b) Prediction step State-Space Model: We choose as the state of the system $x = [\vartheta_i, \dot{\vartheta}_i, \ddot{\vartheta}_i]^T$ with $i = 1, \ldots, 5$. Defined T_s the system's sample time, and $\nu_{\ddot{\vartheta}_i(k)}$ the white gaussian process noise, the state model equations are:

$$
\begin{aligned}
&\vartheta_i(k+1) = \vartheta_i(k) + T_s\dot{\vartheta}_i(k) + \tfrac{1}{2}T_s^2(\ddot{\vartheta}_i(k) + \nu_{\ddot{\vartheta}_i(k)}) \\
&\dot{\vartheta}_i(k+1) = \dot{\vartheta}_i(k) + T_s(\ddot{\vartheta}_i(k) + \nu_{\ddot{\vartheta}_i(k)}) \\
&\ddot{\vartheta}_i(k+1) = \ddot{\vartheta}_i(k) + \nu_{\ddot{\vartheta}_i(k)}
\end{aligned}
$$

c) Update step Measurement Model: We measure the subject motion through two 9-axis IMUs (Invensense 9150 using BT 2.0) worn on the arm and the forearm. The s^{th}'s IMU measurements, i.e. angular velocity (ω^s_s), linear acceleration ($\ddot{x}^s_s$) and magnetic field (m^s_s), attached to p^{th} (parent) frame:

$$
\begin{aligned}
&\omega^s_s = R^s_p(\omega^p_p + \dot{\vartheta}_{p+1}z_0) \\
&\ddot{x}^s_s = R^s_p\ddot{x}^p_p + S(\dot{\omega}^s_s)r^s_{p,s} + S(\omega^s_s)^2 r^s_{p,s} + R^s_0 g^0 \\
&m^s_s = R^s_0 m^0
\end{aligned}
$$

where $S(v)$ is the skew-symmetric matrix from vector v, g^0 and m^0 are gravity and Earth magnetic field in the chest root frame, z_0 is the $(0,0,1)^T$ vector, and $r^s_{p,s}$ provides the position of sensor frame relative to parent in sensor frame.

A. Filter design

As the measurements model is nolinear, a nonlinear state estimator is required. UKF was preferred to EKF because of its better performance with larger nonlinearity. Moreover, as algorithm performance is important given the embedded nature of the final system, UKF does not requires to compute a heavy Jacobian matrix. The variances of the measurement noise are derived from static tests performed with the sensors, while for the process noise we use $GI_{15}G^T$, where G is the 15×15 matrix defining the relationship among the state and the process noise, derived from the state model expression.

III. RESULTS AND DISCUSSION

We gathered optical marker-based motion data from the Vicon system to validate IMU based motion reconstruction. After standing still in neutral pose and T-pose a subject performed elbow flexion and pronosupination, shoulder abduction, flexion and rotation for a total of $140s$. Each movement comprises a slow and a fast trial with a maximum speed of 280 deg/s, while the average speed of slow sections is 17 deg/s. Marker placed on anatomical landmarks allowed to reconstruct joint angles according to the upper limb model. The results of the comparison are reported in Figure 1. Errors average in deg for the 5 joints are: $7.03, 6.03, 4.95, 9.93, 11.29$ while cross-covariance with the optical system are: $0.95, 0.87, 0.99, 0.98, 0.85$. We are currently developing a 7 DoFs version, comprising also the 2 scapular joints, with three 9-axis IMUs.

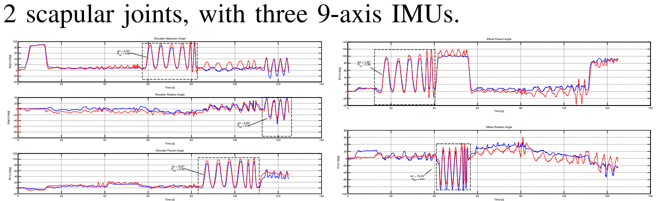

Fig. 1. Optical tracking (blue) against Kalman estimation for shoulder angles (left) and elbow angles (right), with mean error and cross-correlation for every joint local trial

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