PERCRO Perceptual Robotics Laboratory
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Sensor fusion for complex articulated body tracking applied in rowing

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We present a wearable inertial tracking system for outdoor rowing training.
We introduce in the model a closed kinematic chain to further increase the tracking performance of the system.
This approach is suitable also for outdoor measurements with minimal encumbrance for the subject.

Context and Goal:

- Outdoor tracking based on inertial system
- Possibility to combine equipment and wearable sensors
- Two kinematic chains with imposed closure considering that the seat position corresponds to the rower's pelvis position and the tip of the oar handles positions and orientations match the rower's wrist poses

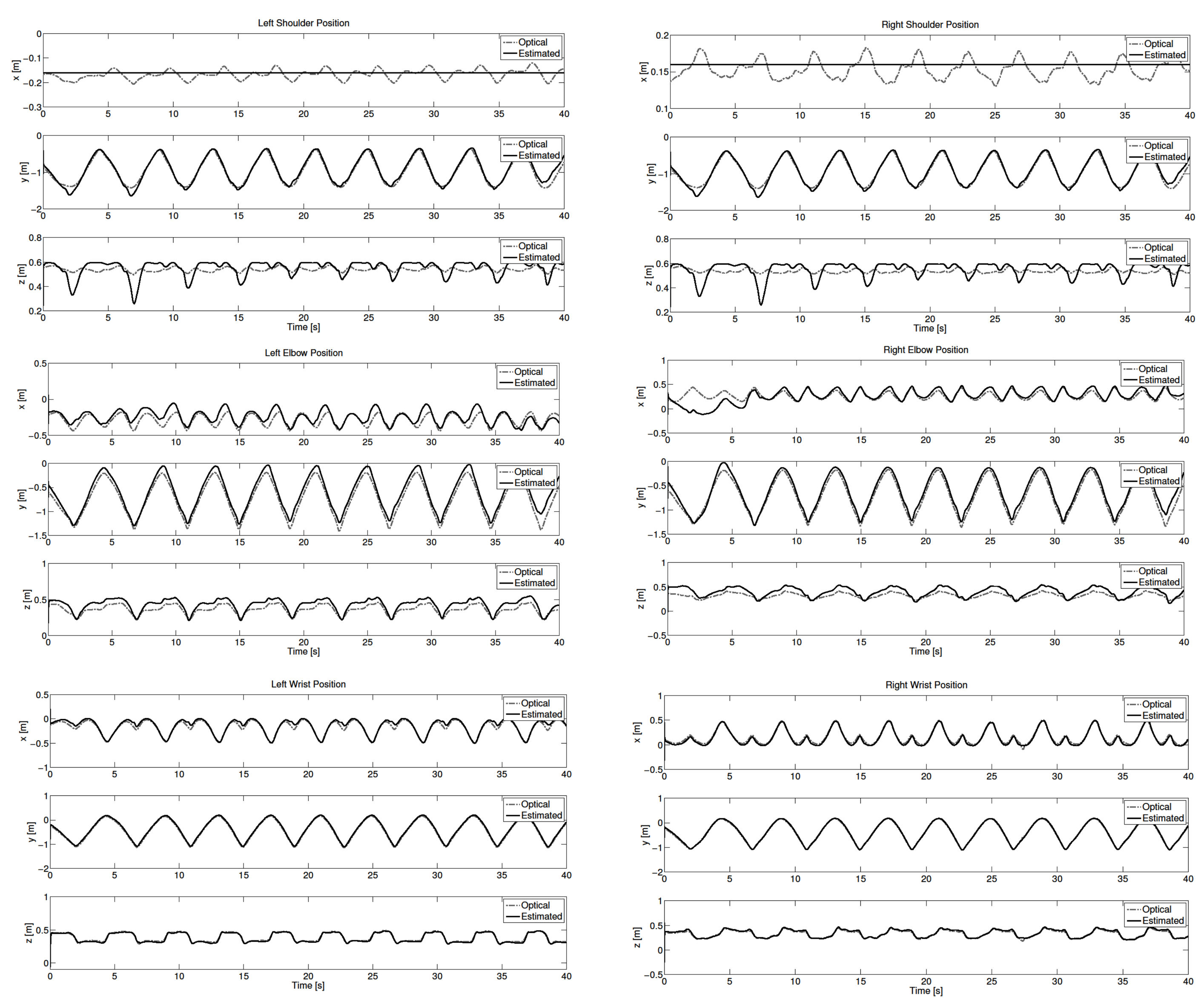
Models for the UKF:

$$\begin{cases} \dot{x}_i = f(x_i)\; i = 1, \ldots, 16 & \text{State model} \\ y_j = h(x)\; j = 1, \ldots, 52 & \text{Measurements model} \end{cases}$$

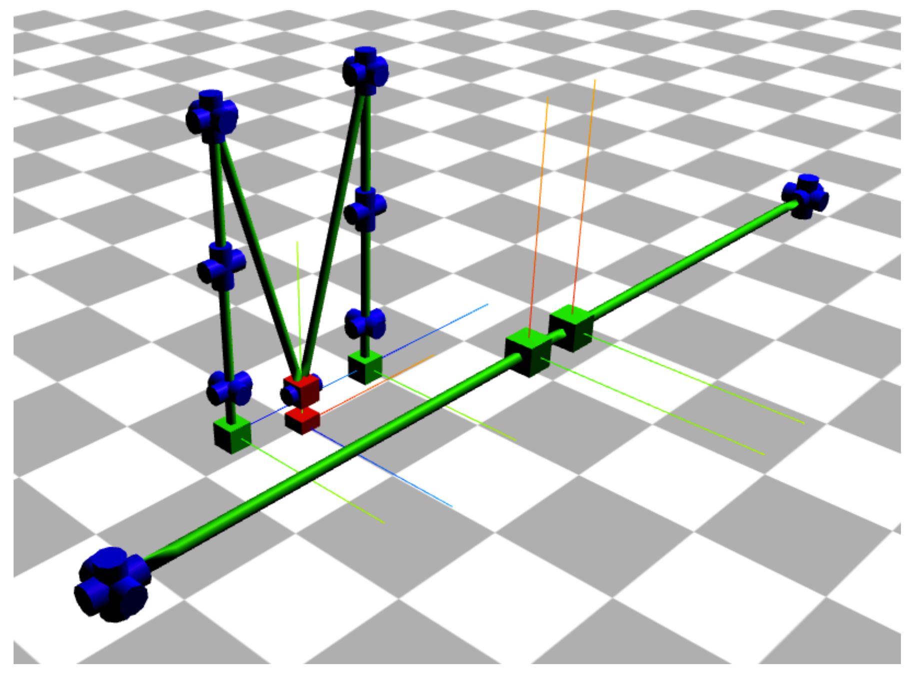
State Model

The state part related to the rower arms is composed of two sets of 7 DoF as in [2] whereas only wrist positions are included.

Results – Positions VS Optical



Two Kinematic Models



The first chain group represents the rower's upper body including:

- Pelvis: slides along the platform rail
- Back: flexion DoF with respect to the pelvis
- Shoulder: 3 DoF
- Forearm: 2 DoF with respect to the arm
- Wrist: 2 DoF with respect to the hand

The second chain group comprises:

- Two oars: each one having two rotational DoF with respect to the fixed reference frame [1]

Measurements Model (IMUs)

$$\omega_s^s = R_p^s(\omega_p^p + \dot{\vartheta}_{p+1} z_0)$$
$$\ddot{x}_s^s = R_p^s \ddot{x}_p^p + S(\dot{\omega}_s^s) r_{p,s}^s + S(\omega_s^s)^2 r_{p,s}^s + R_0^s g^0$$
$$m_s^s = R_0^s m^0$$

Measurements Model (Constraints)

- Seat position matches pelvis position

$$h_s(x) = q_1$$

- Wrists positions match oars tips positions

$$h_{rp} = r_{0,9}^0 - r_{0,21}^0$$
$$h_{lp} = r_{0,16}^0 - r_{0,25}^0$$

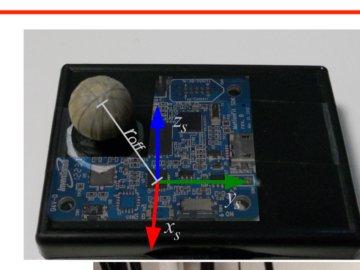
- Oars axes match wrists flexion axes

$$h_{rz} = (T_9)_x - (T_{21})_z$$
$$h_{lz} = (T_{16})_x - (T_{25})_z$$

Experimental Setup

Validation

- joint angles estimation for simulated data
- landmarks position estimation VS optical motion capture system (Vicon MX2.0)



Sensors

- Five 9-axis Invensense (Borregas Ave Sunnyvale, CA, USA) MPU9150 IMUs
- Wire potentiometer Posiwire ws31C (seat position)
- Encoders for Oars' angles

Results

RMS for Joints' Angles with simulated measures

Joints	RMS	Joints	RMS
q_1 $[m]$	0.107	q_7 $[deg]$	0.203
q_2 $[deg]$	0.326	q_8 $[deg]$	0.134
q_3 $[deg]$	0.118	q_9 $[deg]$	0.193
q_4 $[deg]$	0.220	q_{10} $[deg]$	0.306
q_5 $[deg]$	0.382	q_{11} $[deg]$	0.282
q_6 $[deg]$	0.329	q_{12} $[deg]$	0.172

RMS for landmarks positions

Position	E_p	Positions	E_p
p_{ShR} $[m]$	0.078	p_{ElL} $[m]$	0.153
p_{ShL} $[m]$	0.081	p_{WrR} $[m]$	0.034
p_{ElR} $[m]$	0.158	p_{WrL} $[m]$	0.054

Conclusions

We presented a wearable solution for motion tracking in outdoor training for rowing.

- The classical approach exploiting inertial sensors has been expanded considering the fusion between inertial sensors on the subject's body and sensors available on the sensorized boat.
- The fusion has been obtained closing the kinematic loop between the rower and the oar kinematic chains through the measurement model
- The validity of the approach has been assessed with tests both with simulated and real data

[1] A. Filippeschi and E. Ruffaldi, "Boat dynamics and force rendering models for the sprint system", Human-Machine Systems, IEEE Transactions on", vol. 43, no. 6, pp. 631–642, 2013.
[2] L. Peppoloni, A. Filippeschi, E. Ruffaldi, and C. A. Avizzano, "A novel 7 degrees of freedom model for upper limb kinematic reconstruction based on wearable sensors," in Intelligent Systems and Informatics (SISY), 2013 IEEE 11th International Symposium on., pp. 105–110.