An optimization-based approach to human body motion capture using inertial sensors

Kok, Manon, Linköping University, Sweden. Email: manko@isy.liu.se
Hol, Jeroen, Xsens, the Netherlands. Email: jeroen.hol@xsens.com
Schön, Thomas, Uppsala University, Sweden. Email: thomas.schon@it.uu.se

Introduction

Human body motion capture focuses on estimating the position and orientation of different body segments. Motion capture is often performed using either vision-based technologies or using inertial sensors. The main advantage of using inertial sensors is that they are not restricted in space and do not require line of sight visibility. In inertial human body motion capture, the human body is equipped with inertial measurement units (IMUs), consisting of 3D accelerometers, 3D gyroscopes and 3D magnetometers as shown in Figure 1. Each body segment's position and orientation (pose) can be estimated by integrating the accelerometer and gyroscope data and combining these integrated estimates with a biomechanical model. Inertial sensors are successfully used for full body motion capture in many applications.

Figure 1 Examples of inertial motion capture. Upper left: olympic and world champion speed skating Ireen Wüst wearing an inertial motion capture suit with 17 inertial sensors. Upper right: graphical representation of the estimated position and orientation of the body segments. Lower left and right: experiment showing that line of sight visibility is not necessary for inertial motion capture.

Inertial sensors inherently suffer from integration drift. When using inertial sensors for orientation estimation they are therefore often combined with magnetometers. For motion capture applications, however, magnetometer measurements are known to cause problems since the magnetic field measured at the different sensor locations is typically different. Including information from biomechanical constraints, i.e. information about the body segments being rigidly connected, can eliminate the need for using magnetometer measurements.

To allow for natural inclusion of biomechanical constraints, we introduce a new optimization-based approach for inertial motion capture. A more extensive discussion of the model and the experimental results can be found in Kok et al, (2014).

Methods

The problem of estimating the position and orientation of each body segment is formulated as a constrained estimation problem. Given N measurements $y_{1:N} = y_1, \ldots, y_N$, a point estimate of the variables z can be obtained as a constrained maximum a posteriori (MAP) estimate. This amount to solving the optimization problem

$$\min_{z=\{x_{1:N},\theta\}} \underbrace{-\log p(x_1 \mid y_1) - \log p(\theta)}_{\text{prior/initialization}} \underbrace{- \sum_{t=2}^{N} \log p(x_t \mid x_{t-1}, \theta)}_{\text{dynamic model}} \underbrace{- \sum_{t=2}^{N} \log p(y_t \mid x_t, \theta)}_{\text{biomechanical/sensor model}}$$

$$\text{s.t. } c_{\text{bio}}(z) = 0,$$

where $c_{bio}(z)$ denote the constraints based on the biomechanical model. This biomechanical model consists of three parts:

- The body segments can be assumed to be connected at the joint locations at all times.
- The position and orientation of the sensors on the different body segments can be assumed to be approximately constant.
- For some joints, it is known that their rotation is (mainly) limited to one or two axes. An example of this is the knee, which approximately is a hinge joint. Note that inclusion of this knowledge is optional in the algorithm.

Results

We validated our approach with experiments using an MVN Awinda system (Xsens Technologies B.V., 2014), which is a wireless inertial motion capture system. An optical motion capture system (Vicon, 2014) has been used as a source of reference data. The experimental setup is shown in Figure 2. This figure also depicts the body's pose estimated using our algorithm for a walking subject. Figure 3 shows that the joint angle estimates of the knee and the hip obtained using our algorithm match those obtained from the optical reference system.

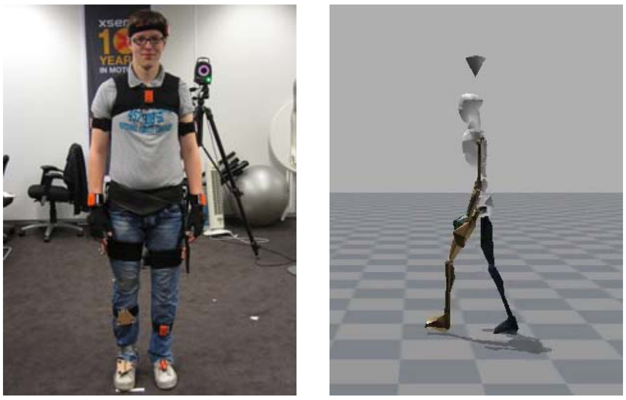

Figure 3 Left: Experimental setup where the human body is equipped with 17 inertial sensors on different body segments. Optical markers have been used as a reference. Right: estimated pose of the body while walking.

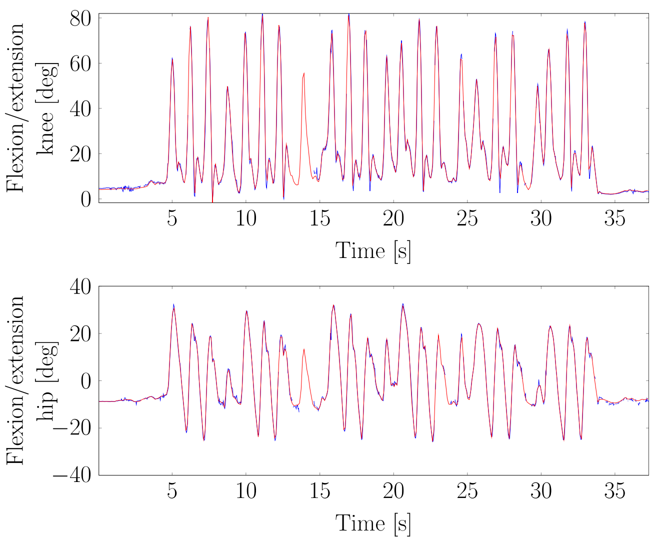

Figure 2 Flexion/extension estimates of a subject's knee and hip while walking. The optical reference data is depicted in blue. The joint angle estimated using our algorithm is depicted in red.

Conclusion

An optimization-based approach to magnetometer-free inertial human body motion capture has been developed, capable of estimating the position and orientation of the body segments. Experimental results show that the algorithm results in accurate joint angle estimates as compared to an optical reference system.

Bibliography

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