FROM TRADITIONAL TO INTERDISCIPLINARY APPROACHES FOR INERTIAL BODY MOTION CAPTURE

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Inertial motion capture (mocap) is a widespread technology for capturing human motion outside the lab, e.g. for applications in sports, ergonomics, rehabilitation and personal fitness. Even though mature systems are commercially available, inertial mocap is still a subject of research due to a number of limitations: besides measurement errors and sparsity, also simplified body models and calibration routines, soft tissue artefacts and varying body shapes lead to limited precision and robustness compared to optical gold standard systems. The goal of the research group wearHEALTH at the TU Kaiserslautern is to tackle these challenges by bringing together ideas and approaches from different disciplines including biomechanics, sensor fusion, computer vision and (optimal control) simulation. In this talk, we will present an overview of our approaches and applications, starting from the more traditional ones.

KEY WORDS: inertial motion capture, model-based sensor fusion, egocentric vision, optimal control simulation, human kinetics.

PHYSICAL ACTIVITY MONITORING AND BODY MOTION CAPTURE USING INTERTIAL SENSORS: There are two typical ways of deducing information from body worn inertial measurement units (IMUs) for health and sports applications: 1) Using one or few IMUs in combination with machine learning approaches, with the goal to derive coarse information, such as type, intensity, frequency and duration of different activities. This is mostly based on accelerometer information. 2) Using many IMUs with a dedicated placement on the body, a kinematic body model and (recursive) filtering techniques, with the goal to derive more detailed information, such as the motion of each body segment. This typically exploits accelerometer, gyroscope and magnetometer information. The book chapter (Bleser et al. 2015) presents respective methods that we have developed within the European project PAMAP (Physical Activity Monitoring for Aging People, http://www.pamap.org) for the purpose of home based rehabilitation.

The majority of approaches to inertial mocap relies on simple stick figure models to approximate the human skeleton with only a few rigid segments and connecting joints. Especially the spine is often extremely simplified. This results in significant kinematic estimation errors. In (Miezal, Taetz, Schmitz, & Bleser, 2014), we presents an approach, where a recursive filter with integrated constraints enables more detailed and efficient estimation of the spine kinematics in real-time.

Our talk will start with presenting the above mentioned, more traditional approaches to human mocap and then focus on different interdisciplinary methods in order to tackle some of their limitations as summarized below.

INERTIAL MOCAP SUPPORTED BY EGOCENTRIC VISION: Another relevant application of ambulatory mocap is the ergonomic assessment of manual tasks in industrial environments. When using ergonomic tools, such as RULA (Rapid Upper Limb Assessment), the joint angles of the upper body need to be precisely tracked. However, since most industrial settings are heavily contaminated by magnetic disturbances, body tracking systems based on IMUs are difficult to use. Within the European project COGNITO (Cognitive Workflow Capturing and Rendering with On-Body Sensor Networks, http://www.ict-cognito.org), a fully wearable solution based on IMUs and a chest-mounted camera has been developed to enable accurate tracking of the upper limbs also under magnetic disturbances (Bleser, Hendeby, & Miezal, 2011). The method was then used as basis for a real-time ergonomic feedback system, which, in a user study, significantly decreased the outcome of both globally as well as locally hazardous RULA values that are associated with increased risk for musculoskeletal disorders (Vignais et al, 2013).

Figure 1 shows the on-body sensor network used for the visual-inertial tracking method. Both the tracking method and the ergonomic feedback system will be shortly presented in this talk.

TOWARDS BRIDGING THE GAP BETWEEN MOTION CAPTURING AND BIOMECHANICAL OPTIMAL CONTROL SIMULATION: Inertial and also optical mocap systems often heavily rely on sensor measurements, which inevitably contain noise, systematic errors and sometimes lacks. Moreover, model assumptions, e.g., concerning the human body, the sensor positioning with respect to it and its motions are often simplified. Even if advanced sensor fusion techniques are available, these problems in combination with simplified sensor-body calibration techniques can lead to gross errors in the estimated body movements, whereas the latter are often not even physically plausible.

Instead of heavily relying on the measurements with only simplified assumptions, another promising approach is to embed more intelligence into the digital models and consider the tracking problem as a problem of realistic (physics-based and biomechanical) human motion simulation guided through measurements. This also includes moving from pure human kinematics to human kinetics, making even more useful data available for the above described application areas.

In a recent work (Gail, Hoffmann, Miezal, Bleser, & Leyendecker, 2015), we made a first step towards this direction by combining mocap measurements and physics-based/biomechanical simulation. In particular, we integrated mocap measurements into optimal control simulations based on a constrained optimization framework, investigating the following aspects: (I) How should the measurements best be incorporated into the optimization? (II) In how far does a combination with physiologically motivated cost functions reduce the dependence on measurements and provide more accurate, realistic and natural results? In a sequence of simulation experiments with different cost functions, constraints and gradual reduction of the measurement update rate, we found that the fusion of physical laws (i.e., the equations of motion), biomechanical simulation (in this study, minimal torque and minimal torque change) and real mocap data within an optimal control simulation framework indeed has the potential to improve mocap with respect to some of its above mentioned inherent problems. The experimental setup and selected results are illustrated in Figure 2 and Figure 3, respectively. While we started with measurements of a human steering motion obtained from a stationary optical system, i.e., optical marker positions, the next step consists in transferring the method to inertial measurements, which have already been captured. The method as well as preliminary results and future directions will be presented in this talk.

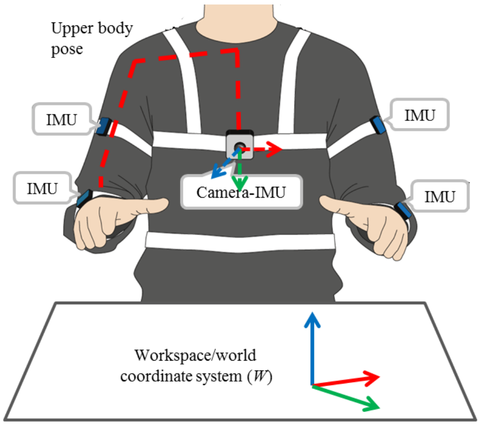


Figure 1: Wearable sensor network for visual-inertial upper body tracking.

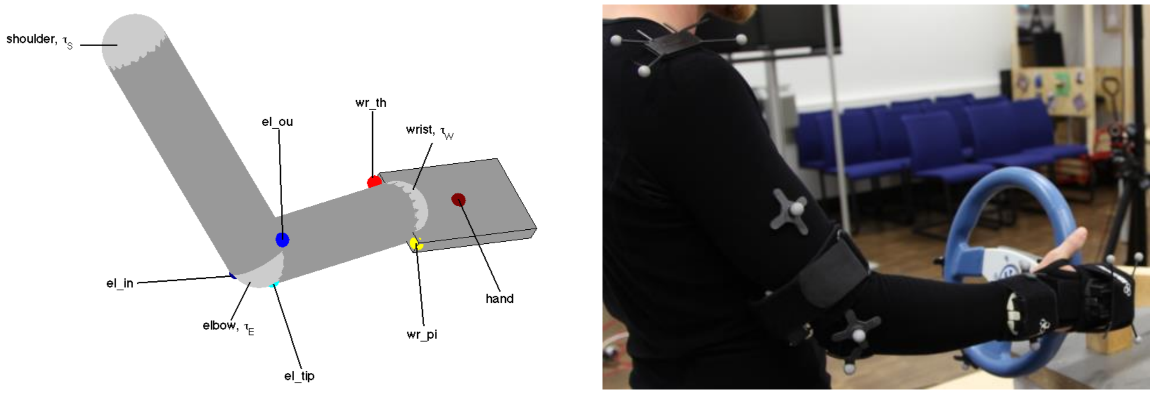
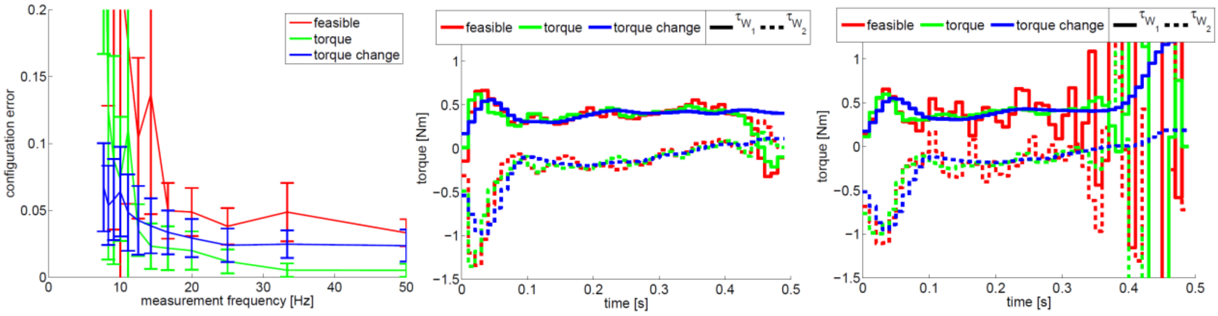


Figure 2: Left: human arm model used for optimal control simulations. Right: Measurement setup showing the optical targets and IMUs for obtaining mocap measurements from a steering motion.



Mean errors and standard deviations

Estimated torques in the wrist at 100 (left) and 8.33 Hz (right) measurement update rate.

Figure 3: Combining mocap measurements and optimal control simulation: The left plot shows mean errors and standard deviations when gradually reducing the measurement update rate for different simulation experiments. Here, feasible refers to using only measurements without biomechanical simulation. While the torque minimizing solution provides the most accurate results down to a measurement rate of about 12.5 Hz, the torque change minimizing solution provides acceptable accuracy for extremely low measurement update rates down to 8.33 Hz. As shown on the middle and right plot, for the torque change solution, also the evolution of the estimated joint torques remains smooth and nearly unaffected by the measurement reduction, which indicates a natural and physically plausible motion. In combination, it can be concluded that the torque change minimizing solution adds further stability and makes the whole system less dependent on the measurements.

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