Inertial Human Motion Estimation for Physical Human-Robot Interaction Using an Interaction Velocity Update to Reduce Drift

Late-breaking Report

Erik Kyrkjebø
Western Norway Univ. of Applied Sciences
Sogndal, Norway
Erik.Kyrkjebo@hvl.no

ABSTRACT

Robots used for physical human-robot interaction (pHRI) are currently advancing from being simple stand-alone manipulators passing tools or parts to human collaborators to becoming autonomous co-workers that continuously share operational control with their human partners. One of the major challenges in this transition is to extend robot capabilities in sensing human motions and behaviour, thereby allowing for more seamless cooperation and ensuring the safety of human partners. Currently, there is a gap between the desire for humans and robots to work closely together and share control of operations, and how robustly we can measure and predict human motions and intentions in pHRI operations. In this paper, we propose to use a set of wireless inertial motion sensors fixed to the body of the human partner to track and estimate human motions, and to use the interaction contact between the robot and the human, as detected by a force/torque (FT) sensor, as an interaction velocity update (IVU) to estimate and reduce drift in the position/orientation estimates. Our hypothesis is that human motion estimates from inertial sensors with an IVU will give sufficiently accurate and robust motion information for safe cooperative pHRI operations.

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1 INTRODUCTION

"Robotics is currently undergoing a fundamental paradigm shift" [3] from dangerous position-controlled rigid robots to safer more lightweight compliant robot designs. This shift is opening up the possibility of true human-robot *cooperation* where the robot is more than just a passive assistant where interactions largely occur serially through turn-taking. Instead, the robot can share control of the task and have continuous interactions with the human partner. Recent developments in industrial robotics have put forward a range of robot manipulators designed for working in the same work environment as humans [4], and that are purposely designed to minimise injury and equipped with force-sensing and force-limiting features. These collaborative robots have the potential to become cooperative robots and true co-workers, but are today mostly used as standard industrial robots that can be installed without expensive safety measures. One of the major challenges in enabling true cooperation between the human and the robot and in ensuring the safety of the human partner is to keep track of the human motions and to predict human intentions during the co-operation.

In an increasing number of installations, humans and robots occupy the same challenging workspace [1] without dividing physical safety measures such as fences, and the human may physically lead the robot by hand-guiding it to teach it new positions and operations. For the rest of the time, the robot is unaware of the human's location if no additional sensors are used to monitor human motions. Most strategies for non-contact human motion monitoring in pHRI today are vision based using either markers or markerless solutions [3], but vision-based strategies are prone to disturbances because of occlusion, changing light conditions, and dust/dirt issues, and are often expensive and require a careful setup for each work area. More cost-effective and robust real-time human motion estimation is thus desirable.

Inertial motion sensors use triaxial accelerometers and gyros to measure acceleration and angular rates that are integrated into position and orientation data through either complementary filters or Kalman filters [2]. Inertial motion sensors do not suffer from range limitations or many of the other interference problems of other external motion sensors, and have excellent real-time capabilities, but suffer from unbounded drift due to the integration of biases and noises. Many inertial motion sensors are therefore equipped with additional sensors (e.g., magnetometers) to reduce drift in orientation measurements. Fillipeschi et al. [2] thoroughly review different methods to reduce this drift, including fusing the dynamic estimate with a quasi-static one, estimating and removing the gyroscope bias, or exploiting the constraints of the kinematic chain of connected limbs. A method used previously for lower limbs tracking is to exploit contact with the ground, and to reset the speed (zero-velocity update, ZVU) and the height of the foot upon contact with the ground [5, 6].

In this paper, we propose to use the interaction between the robot and the human partner to perform an *interaction velocity update (IVU)* to estimate and reduce the drift of inertial human motion estimates for pHRI operations. The proposed method is inspired by the ZVU used for lower limbs tracking [5].

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2 RESULTS

There is currently a gap between the desire for pHRI and shared control of operations, and how robustly we can measure and predict human motions and intentions. In this paper, we propose to use wireless inertial motion sensors to estimate human motions during a human-robot interaction, and to use the physical interaction between the robot and the human as a velocity update to estimate and reduce drift in the position/orientation estimates.

Motion estimation systems relying on accelerometers and gyros are subject to drift, and require a form of sensor fusion with other data to give useful information on the position and orientation of limbs over time. The orientation of a motion sensor is estimated by integrating the rate gyro measurements and combining this estimate with the orientation estimate derived from accelerometers and magnetometers. This combination of two different orientation estimates gives near drift-free estimates of the orientation [5]. The translation is estimated by a double-integration of the dynamic acceleration, and where the drift comes from any residual orientation estimation errors when removing static acceleration due to gravity.

To reduce drift in motion estimates, we propose to use the contact between the human and the robot as detected by a FT sensor to reset the velocity of the inertial sensors in contact with the robot as shown in Fig. 1. The internal sensors of the robot manipulator give accurate position/orientation and velocity information of the end-effector, and the relative position and velocity of the human wrists to the end-effector can be calculated. Thus, assuming a constant fixed grip and little relative angular motion between the wrist and the rigid and known object of manipulation, the angular velocity of the inertial sensors on the human wrists can be reset to the calculated velocity derived from the robot sensors through an IVU. The IVU will allow estimation of bias and drift using an extended Kalman filter (EKF) and to reset the drift during physical interaction with the robot. Additionally, the fact that – different from the ground contact for ZVU in [5, 6] – the position and orientation of the end-effector are known can be used to correct the estimates in the EKF to give drift-free motion estimates of the wrist sensors during a physical interaction. The robot is an external drift-free motion reference for the inertial motion estimation during pHRI. The position and orientation of the other inertial sensors in Fig. 1 can then be estimated using the kinematic chain of the human body as a biomechanical process model in the EKF.

When the human and the robot are not in physical contact, the main objective of the human motion estimation scheme is to provide sufficiently accurate motion estimates to ensure the safety of the human partner, and for the robot to be able to coordinate its motions with those of the human hands when approaching or picking up objects. For shorter time periods, the position and orientation estimates of the inertial motion sensors aided by internal magnetometers and the drift estimates in the EKF should reduce drift significantly, and extend the reliability of motion estimates. When the belief in the estimates drops below a certain threshold, the velocity of the robot should be reduced to a safe speed within the open-loop operating speed of the collaborative robot as recommended by the manufacturer.

To initiate a new interaction phase between the human and the robot, the user may touch the robot end-effector to reset the velocity and position estimates, and to start the shared-control phase of the human-robot interaction. The physical interaction will provide the inertial human motion estimation filter with a set of reliable initial conditions, and will reset the drift of inertial motion estimates through the IVU. Frequent contact and interaction between the human partner and the robot is thus beneficial to improve human motion estimation using inertial sensors.

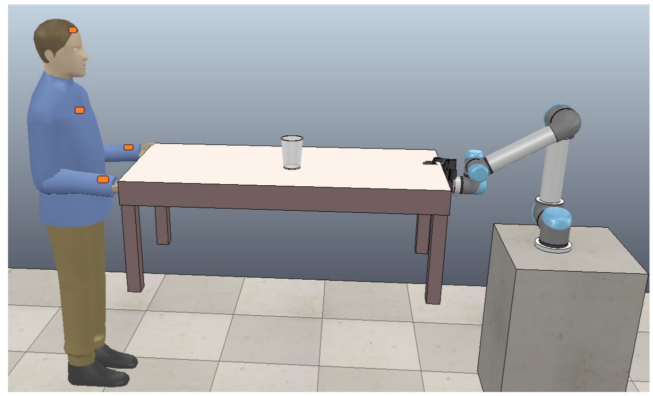

Figure 1: Illustration of inertial motion sensors placed on the wrists, torso and forehead of a human cooperating with a robot in a table-lifting operation (V-REP PRO EDU).

3 DISCUSSION

We propose to use the physical interaction between the human and the robot to reset the velocity drift and as an external motion reference for inertial human motion estimation systems. Our hypothesis is that the approach has the potential to give sufficiently accurate and robust human motion information for safe cooperative pHRI. The approach requires that the manipulated object is rigid and of a known geometry to reset the position and velocity drift of the inertial sensors, and that the inertial motion sensor is augmented with, for example, magnetometers to reduce drift during non-contact phases of the cooperation. While the main advantages of the approach are that the system is low-cost, allows for high sampling rates, and is not subject to the typical disturbances of vision-based systems, the system may also be used as a valuable addition to vision-based human motion tracking systems. Future work aims at experimentally verifying the proposed design.

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