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.

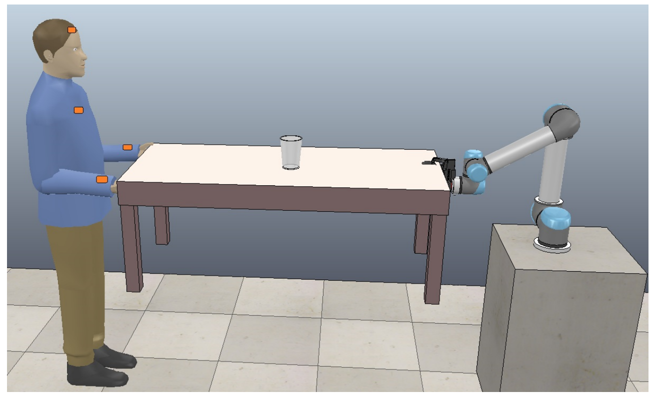

Figure 1: Illustration of inertial motion sensors placed on the wrists, torso and forehead of a human cooperating with a robot in a table-lifting operation (V-REP PRO EDU).

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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