A wireless integrated haptic data suit for controlling humanoid robots

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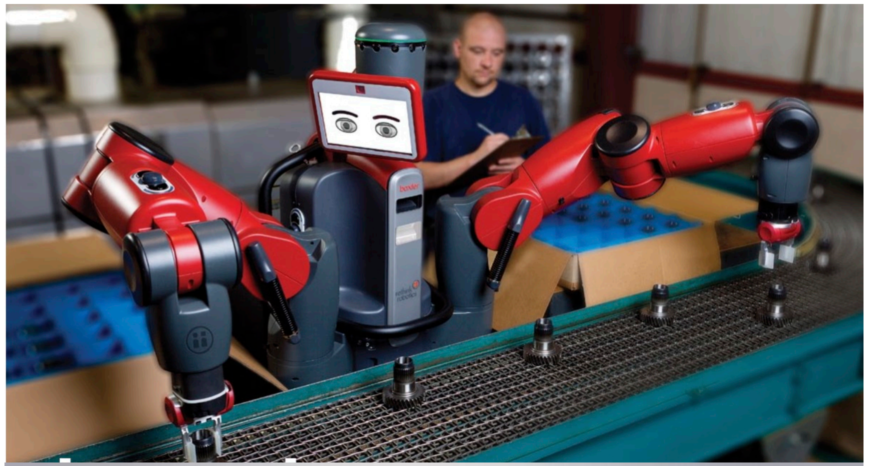
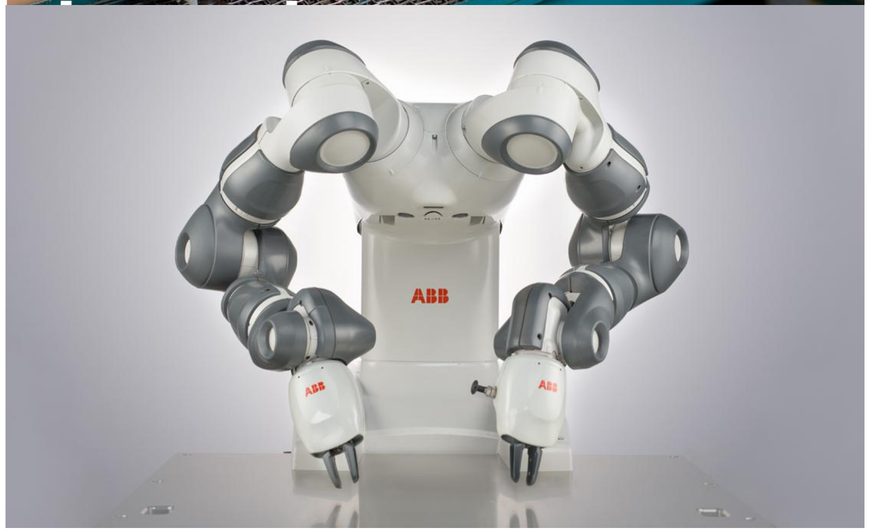
OUTLINE

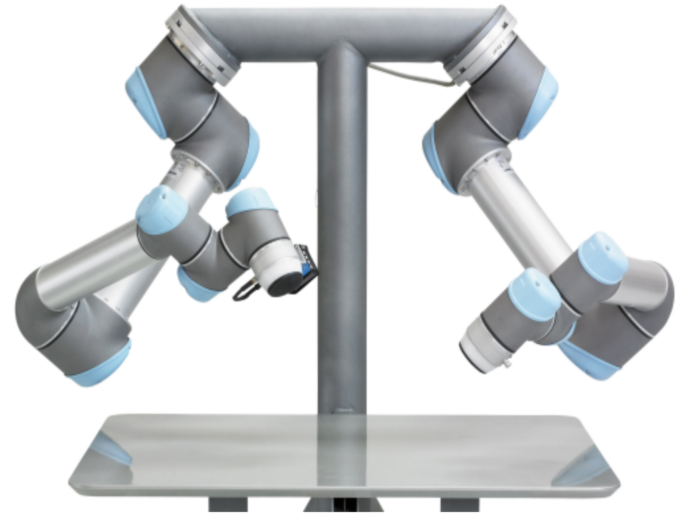
1. **Context and Motivations**
2. Proposed Solution
3. Operator's Body Tracking
4. Teleoperation and Feedback
5. Evaluation
6. Conclusions

Context and Motivations

- Industry 4.0: Raise of semi-humanoid robots
- ... Cosa ci serve? Cosa manca
- Linea di ricerca
- Online PbD + Cooperation what we need for that?
    - Operator tracking
    - Robot feedback wearable

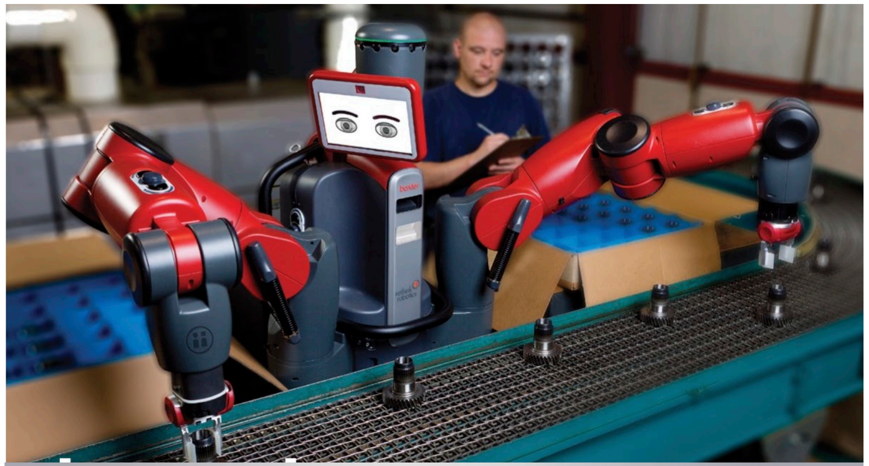
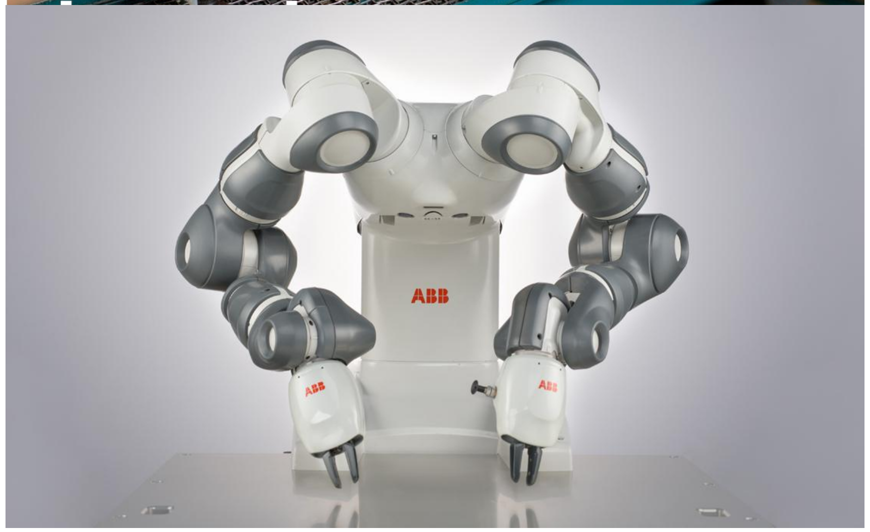


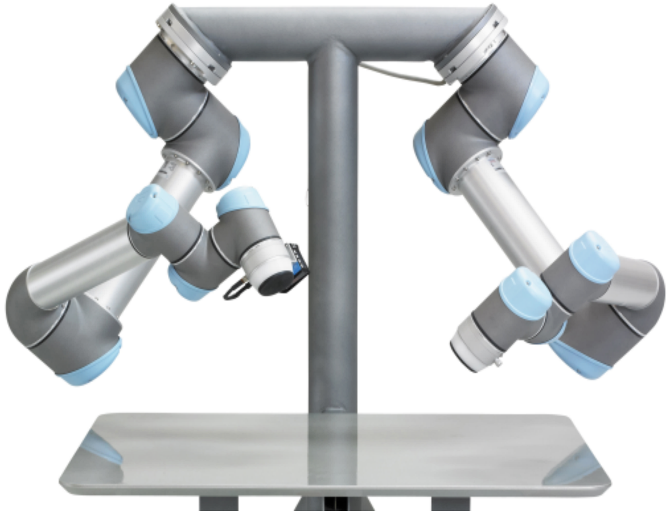




Contribution

- We propose an Integrated Suit for:
  - Inertial Based Upper Body Motion Tracking
  - Control a 1-DOF Robotic Gripper with Haptic feedback
- Tested with a **teleoperation** task of the Baxter (©Rethink) Robot



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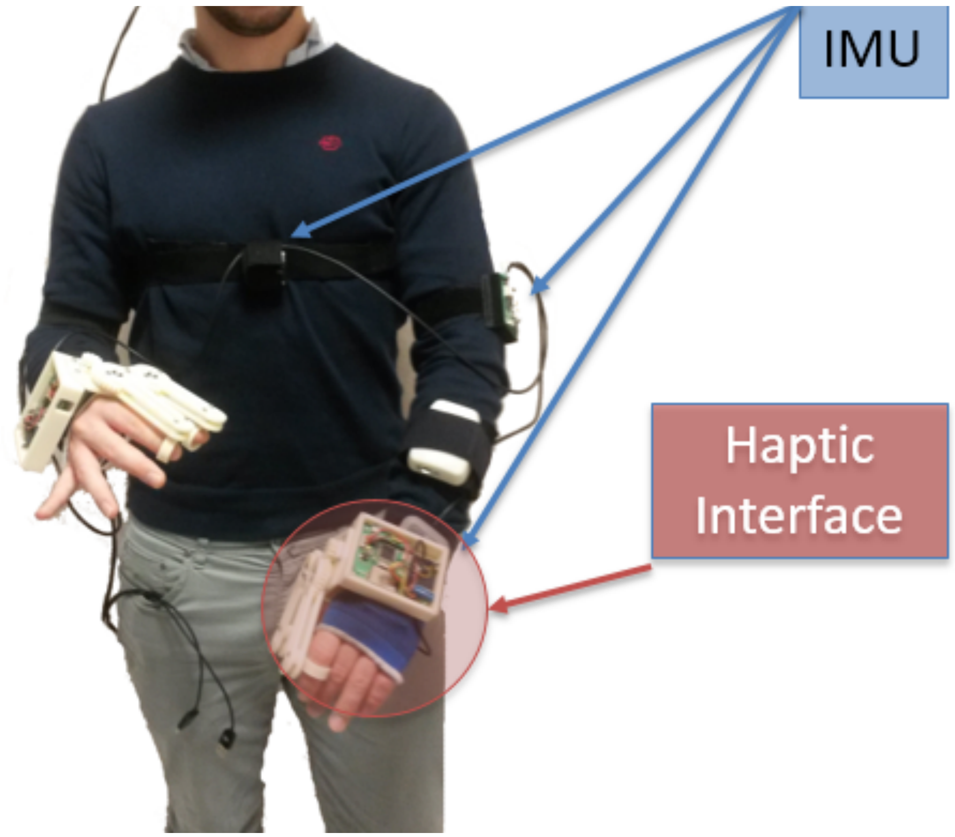
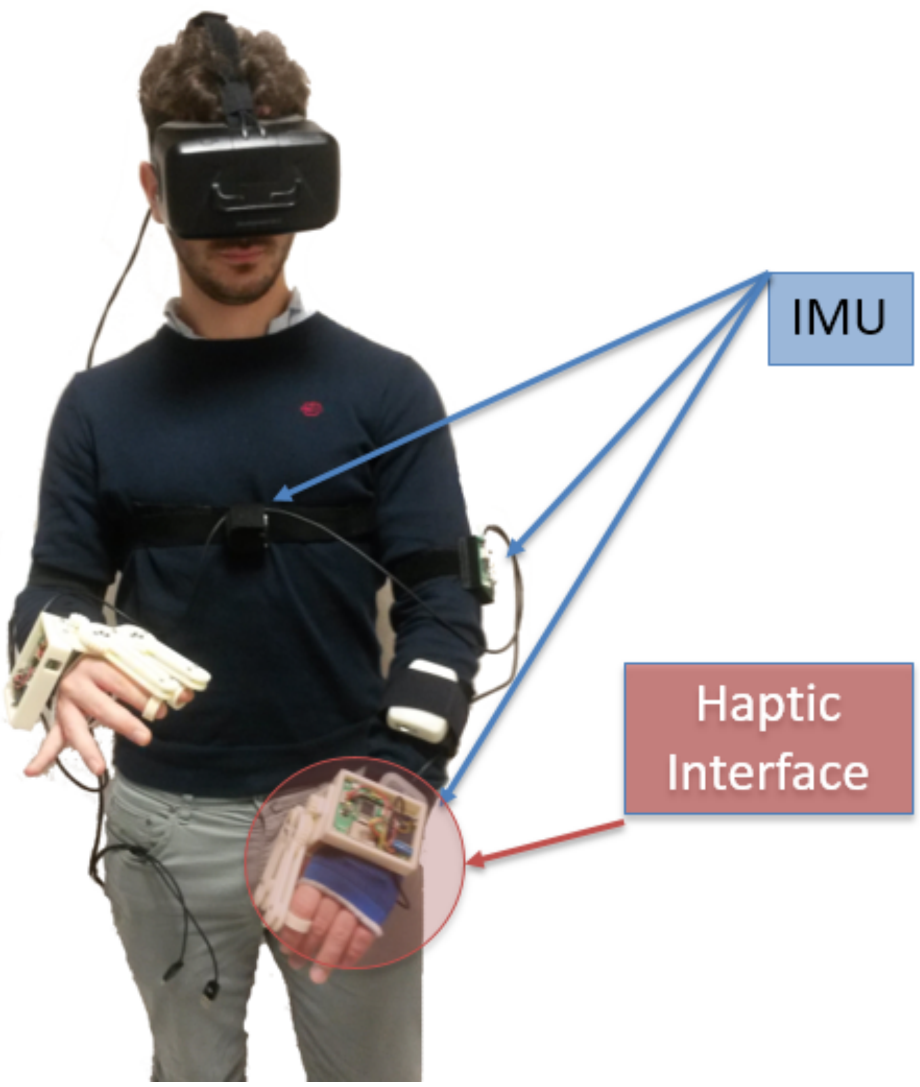
Suit Description

Features:

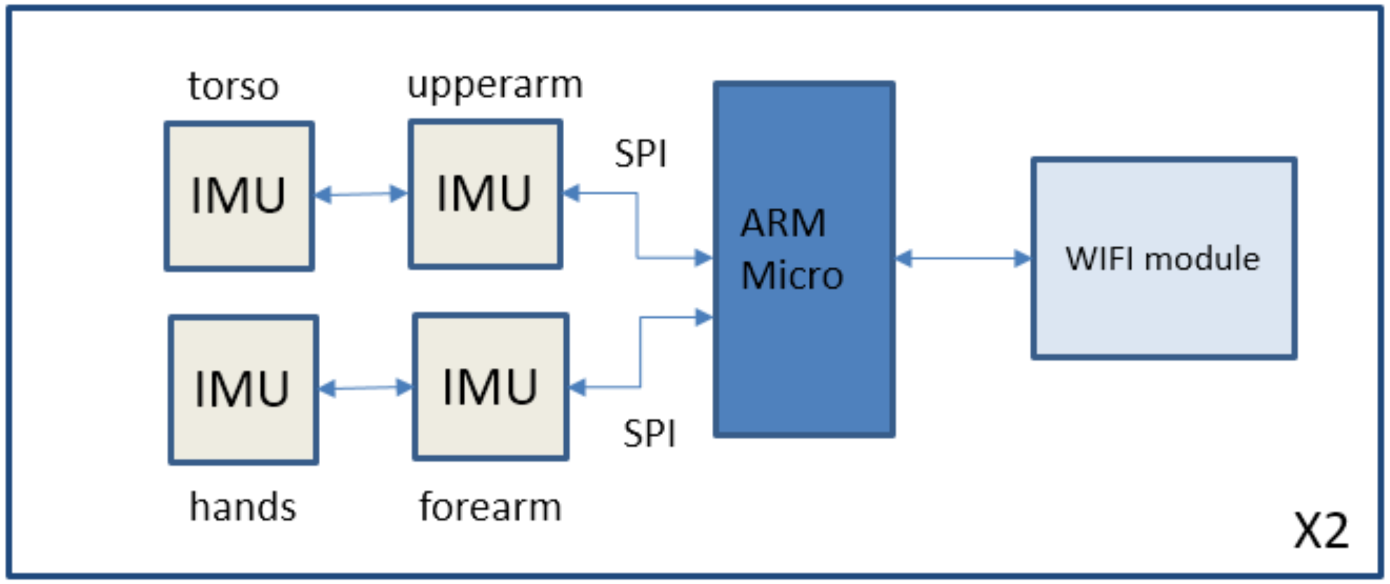
- Fully portable: battery-powered, Wireless, Modular
- Elastic strips easily wearable for different sized people
- Modularity:
  - Motion Capture System
  - Haptic Gripper Controller

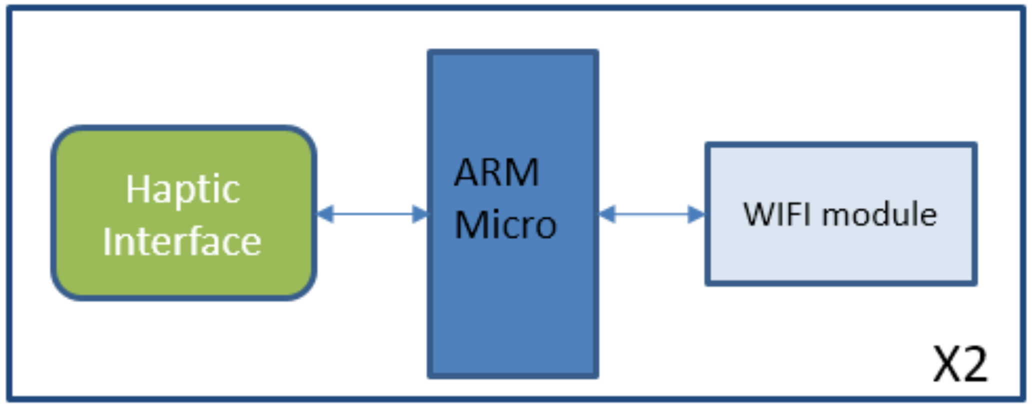


System Architecture Overview



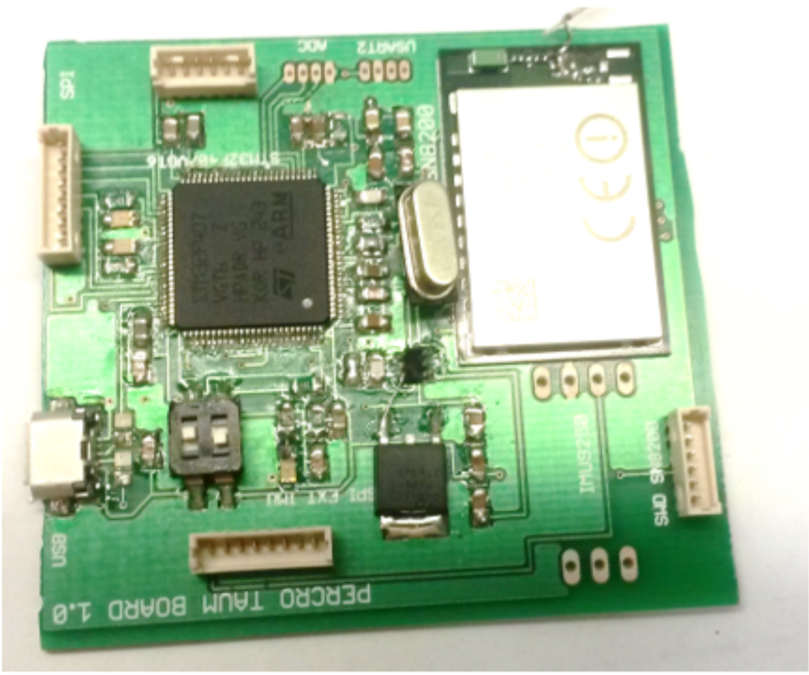
For each arm:

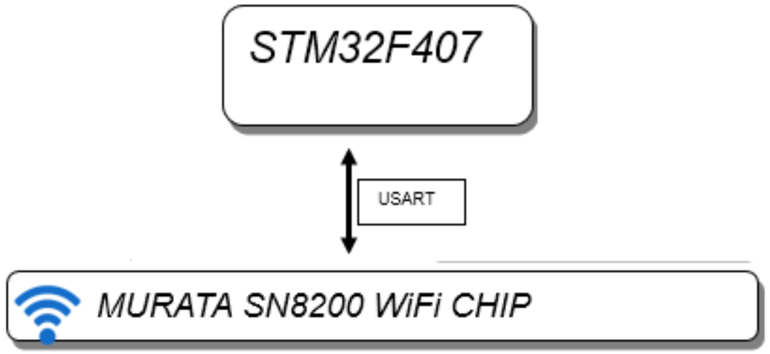




Custom Designed Electronics

- STM ARM based 32 bit μC
- Broadcom WiFi Chip
- Compact: 5cmx5cm
- Versatile Board:
    - Can read IMU via SPI
    - Can Control a DC motor by reading a digital encoder and sending a PWM signal





Employed Sensors and Actuators

Motion Capture System:

Inertial sensors (Invensense 9250):

- 9 sensors
  - 3 accelerometers
  - 3 gyroscope
  - 3 magnetometers
- 16bit resolution on each axis of acc. and gyro.
- 14bit resolutin on each axis of mag.
- Gyro. full scale range: $\pm 250 \frac{deg}{s}$
- Accel. full scale range: $\pm 2g$
- Mag. Sensitivity $0.6 \mu T\ /LSB$

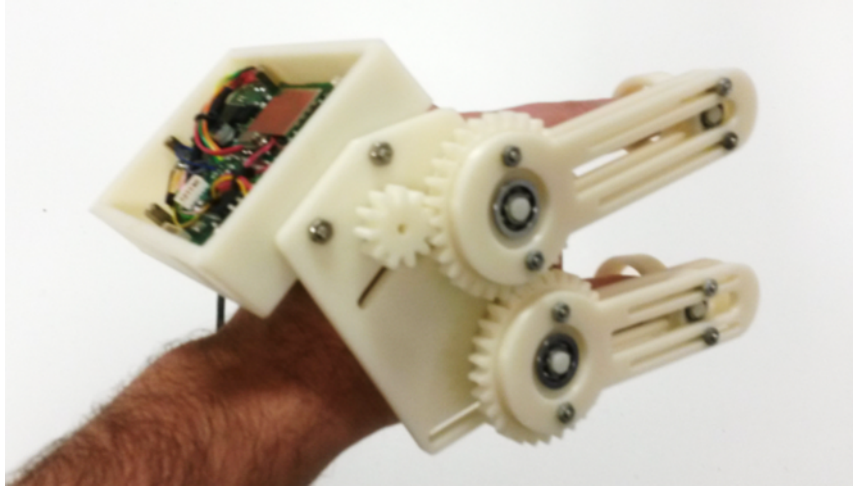
Haptic device:

DC motor:

- Highly reduced (300:1)
- 16 count Encoder of motor shaft
- Low voltage power supply (5V)

STM integrated H-bridge

- 20kHz max PWM frequency



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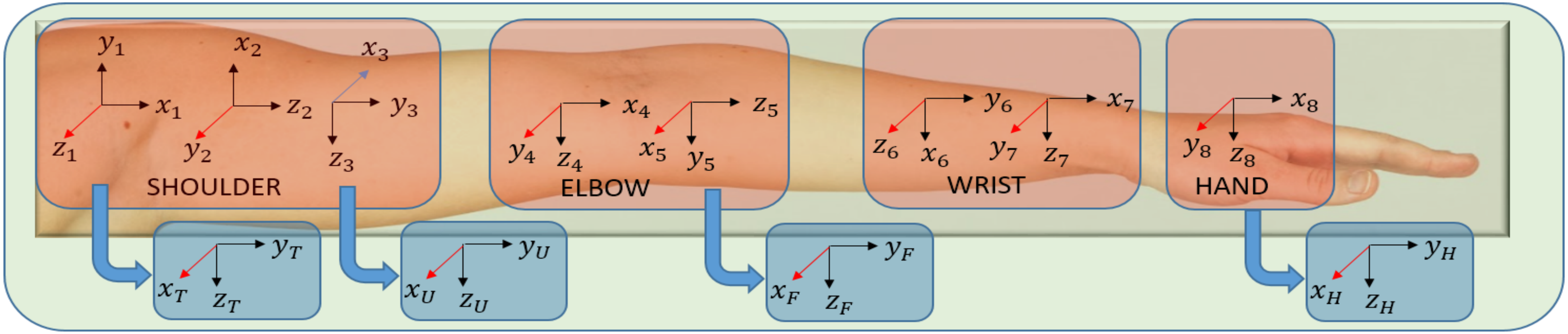
Algorithms: Arm Pose Estimation

- 7DoF kinematic chain to model human arm
- Joint angles obtained by estimating relative attitudes of the sensor frames

Frame	a_i	α_i	d_i	θ_i
1	0	$\frac{\pi}{2}$	0	$\theta_1 + \frac{\pi}{2}$
2	0	$\frac{\pi}{2}$	0	$\theta_2 - \frac{\pi}{2}$
3	l_{ua}	0	0	$\theta_3 + \frac{\pi}{2}$
4	0	$\frac{\pi}{2}$	0	$\theta_4 + \frac{\pi}{2}$
5	0	$\frac{\pi}{2}$	l_{fa}	$\theta_5 + \frac{\pi}{2}$
6	0	$\frac{\pi}{2}$	0	$\theta_6 + \frac{\pi}{2}$
7	0	0	0	θ_7



Algorithms: IMU attitude estimation

- The attitude estimation of the sensor frame is performed by using the filter presented in Madgwick et al. [1]
- The filter estimates the attitude by combining:
  - Integration of the angular velocity
  - Minimization of the difference between the expected magnetometer and accelerometer measurements and the actual ones. The minimization is performed with gradient-descent method.

[1] Madgwick, Sebastian OH, Andrew JL Harrison, and Ravi Vaidyanathan. "Estimation of IMU and MARG orientation using a gradient descent algorithm." Rehabilitation Robotics (ICORR), 2011 IEEE International Conference on. IEEE, 2011.

Algorithms: Compass calibration

- Soft-Iron and Hard-Iron distorsions.
- Static Calibration Vs. Dynamic Calibration
- Calibration can be lost if the user moves from the calibration place.
- An affine model can describe the distortion error:

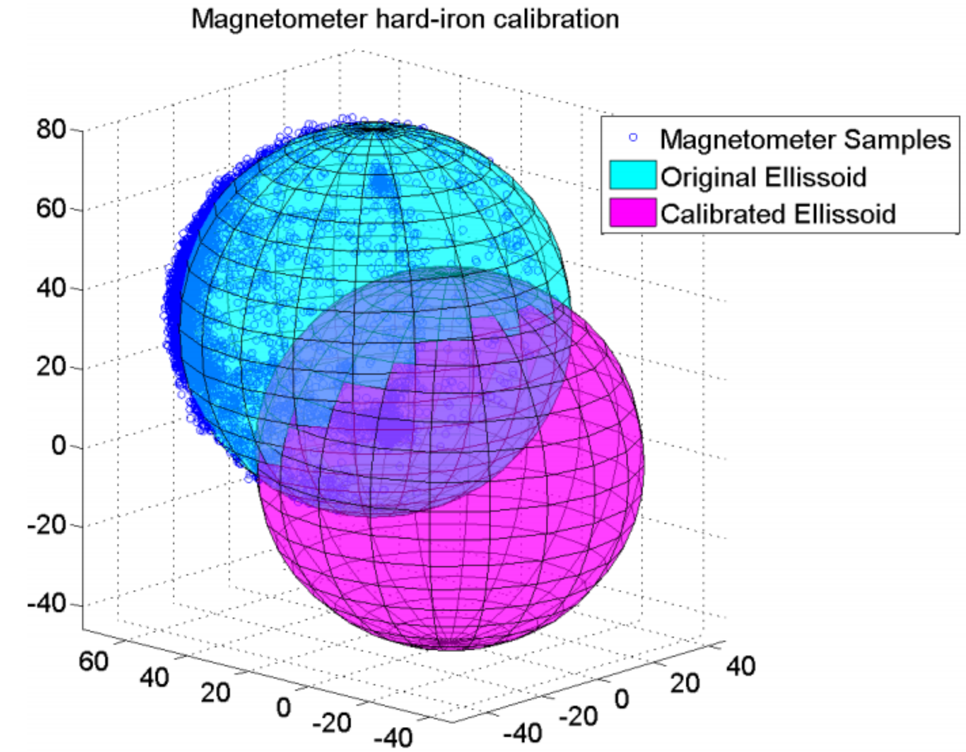
$$ {}^{s}\widehat{m} = A_s\,{}^{s}m + {}^{s}c \qquad {}^{s}c = \begin{bmatrix} {}^{s}c_x \\ {}^{s}c_y \\ {}^{s}c_z \end{bmatrix} \quad {}^{s}m = \begin{bmatrix} {}^{s}m_x \\ {}^{s}m_y \\ {}^{s}m_z \end{bmatrix} $$

Algorithms: Compass calibration

Kalman filter to solve the IMU calibration problem

State and Measurement models:

$$x_{k+1} = x_k, \qquad x = \begin{bmatrix} 1 \\ {}^{s}c \\ R^2 \end{bmatrix}$$



$$y_k = Cx_k + \varepsilon$$

$$C = \left({}^{s}_{x}m^2 + {}^{s}_{x}m^2 + {}^{s}_{x}m^2 \quad -2\,{}^{s}_{x}m^2 \; -2\,{}^{s}_{x}m^2 \quad -2\,{}^{s}_{x}m^2 \quad 1 \right)$$

Algorithms: Compass calibration

The final estimation equations are:

$$x_{k+1}^{-} = x_k^{-}$$

$$x_{k+1}^{+} = x_k^{+} + L(0 - Cx_k^{-})$$

$$R = \begin{cases} \frac{1}{\|\omega\|}, & \text{if } \|\omega\| < l \\ \frac{1}{l}, & \text{otherwise} \end{cases}$$

$$L = Q_k C \left(C^T Q_k C + R\right)^{-1}$$

$$Q_{k+1} = Q_k - LC^T Q_k$$

Q_k is the estimation covariance at step k

R is the measurement error covariance

Algorithms: Sensors orientation calibration

$$ {}^{A}_{B}\hat{q} = \min_{{}^{A}_{B}q} \sum_{j=1}^{m} \sum_{k=1}^{3} \left\| {}^{A}_{E}q_k - {}^{A}_{B}q \, {}^{B}_{E}q_{est,j,k} \right\| $$

with $(A,B) \in \{\{S_T, S_1\}\{S_U, S_3\}\{S_F, S_5\}\{S_H, S_8\}\}$

See also [Peppoloni et al. 2013 SISY]

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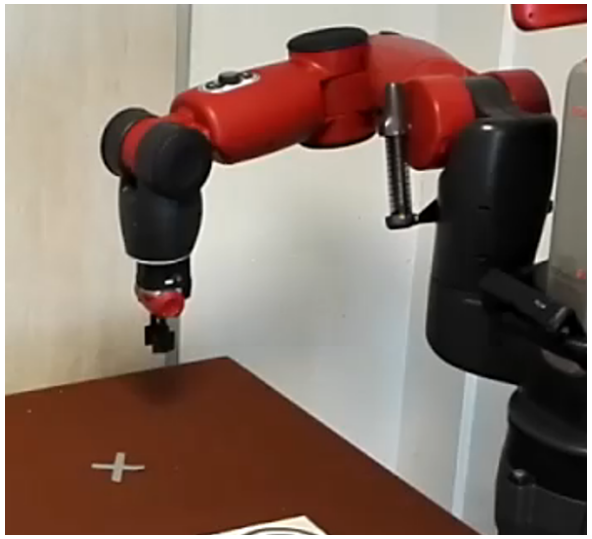


Robot Teloperation

3DOF control of the Robot Gripper

A closed loop inverse kinematics scheme (CLIK) with EE Robot Jacobian Pseudo-Inverse matrix was adopted.

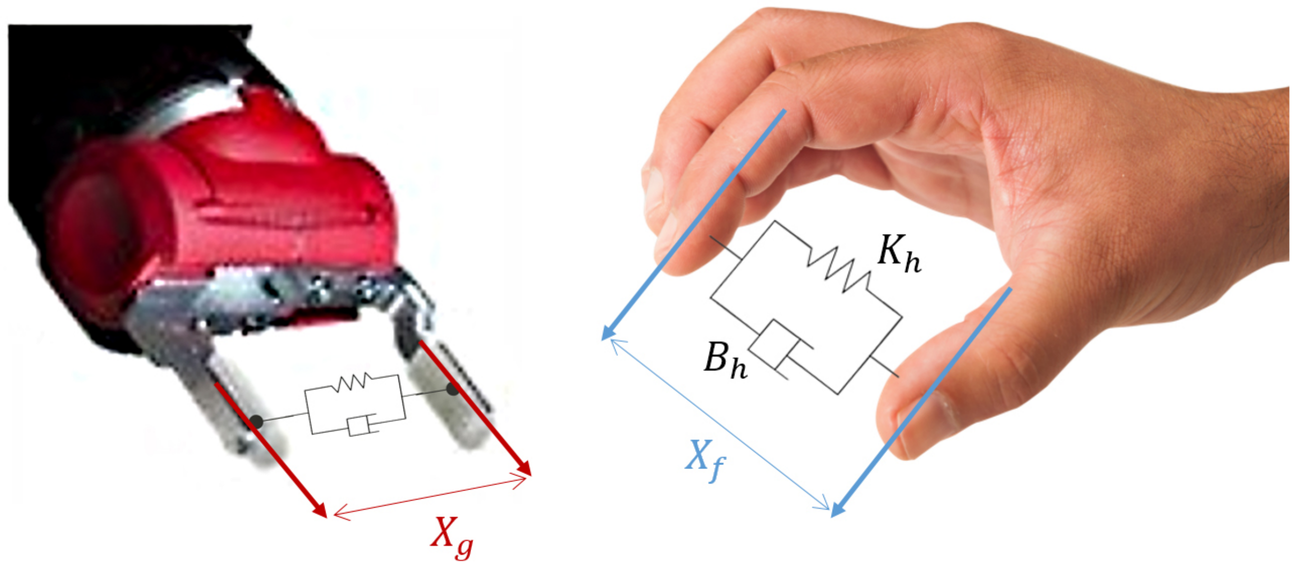
$$q_{R,k+1} = q_{R,k} + J^{+}\left(x_{H,k} - x_{R,k}\right)$$

To obtain a real-time inverse kinematics we perform only three steps of such iterative equation for each new estimated hand pose

Algorithms: Haptic Rendering

Classical Virtual Coupling Control Law between robot gripper and operator fingers

$$F = -K_h(X_f - X_g) - B_h(\dot{X}_f - \dot{X}_g)$$



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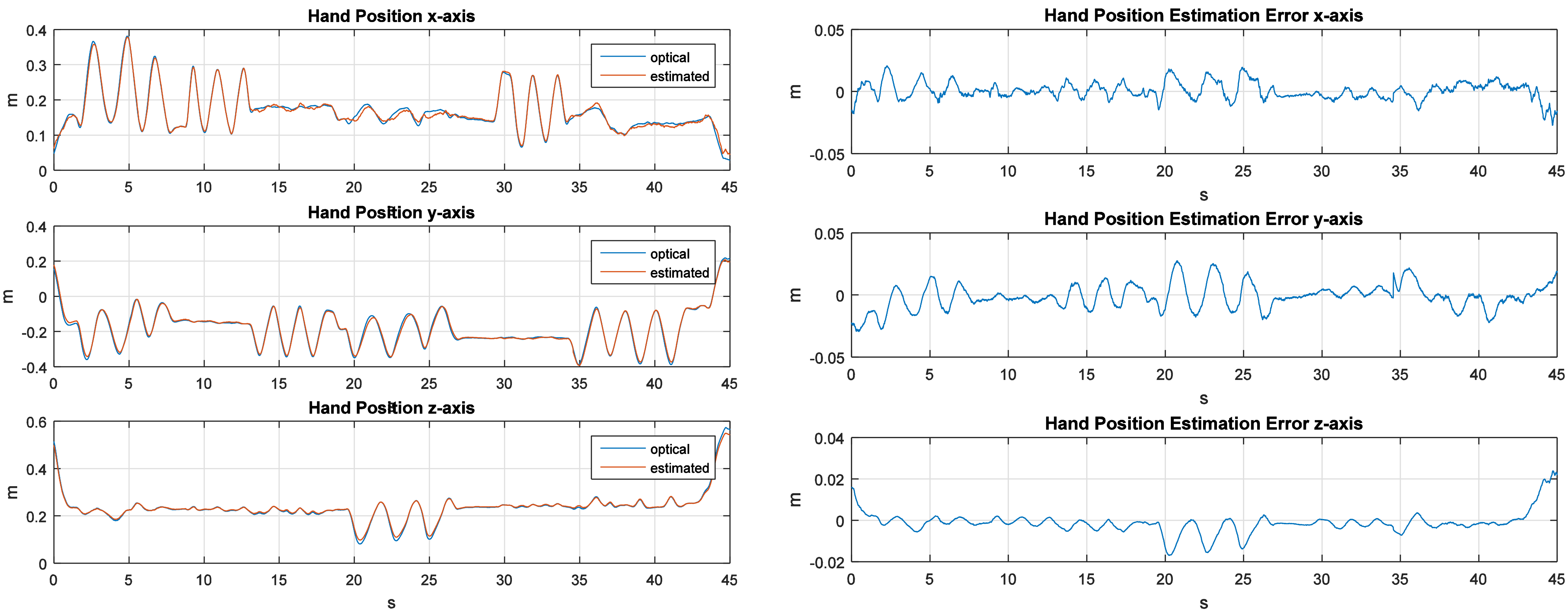
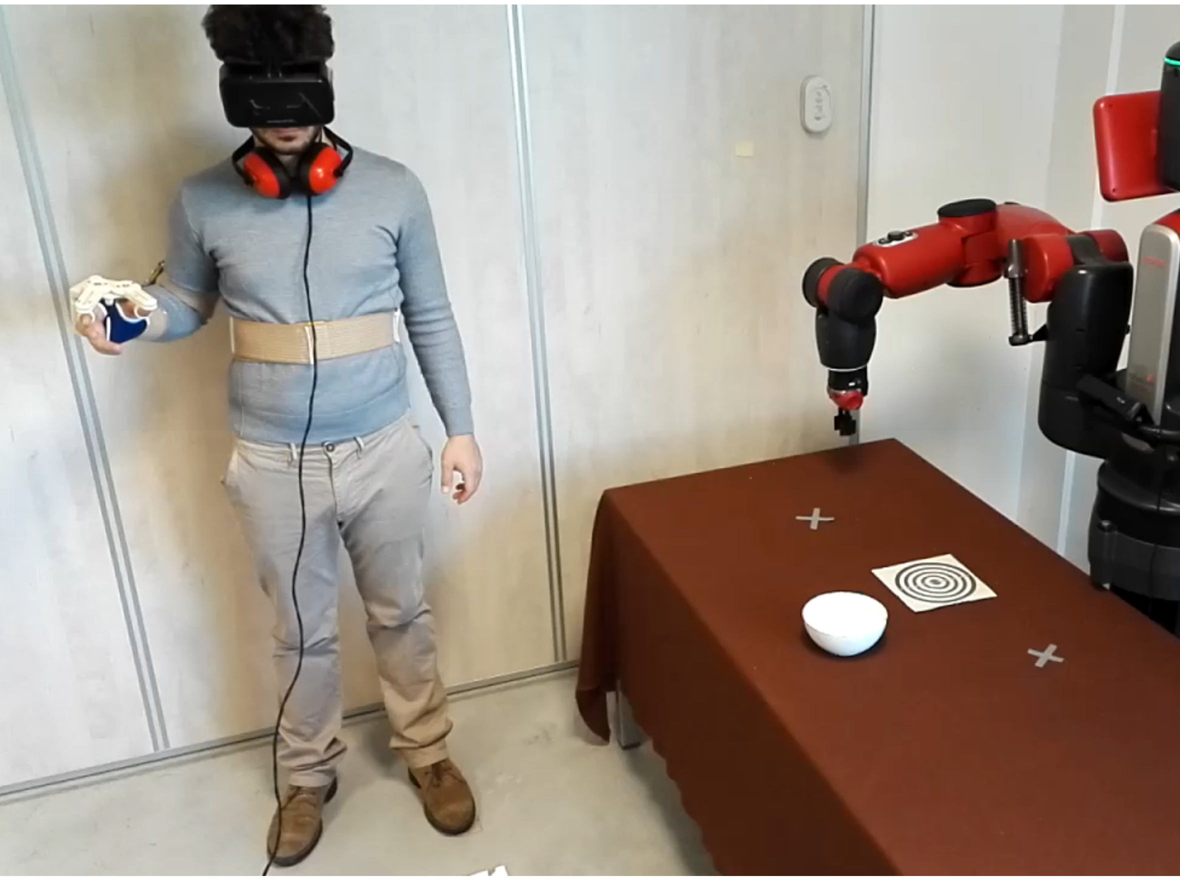
Evaluation Reconstruction

Validation with the OptiTrack TRIO system

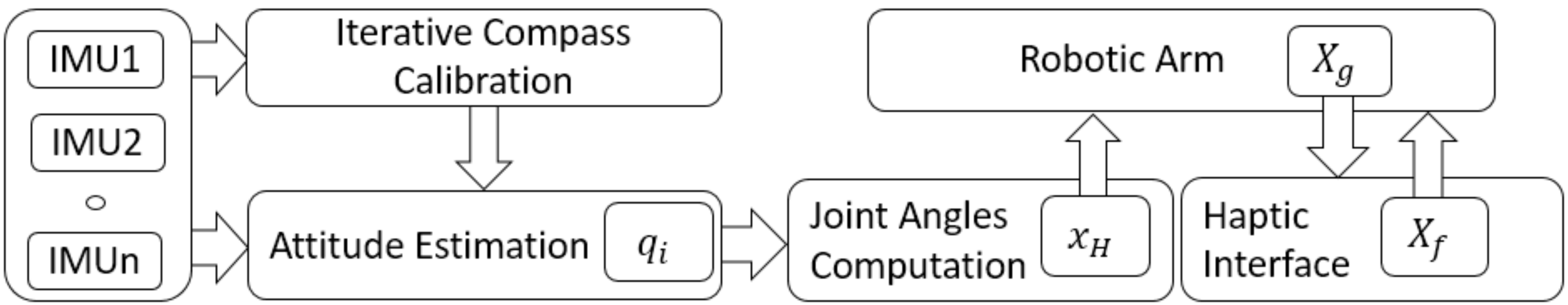


Teleoperation Setup

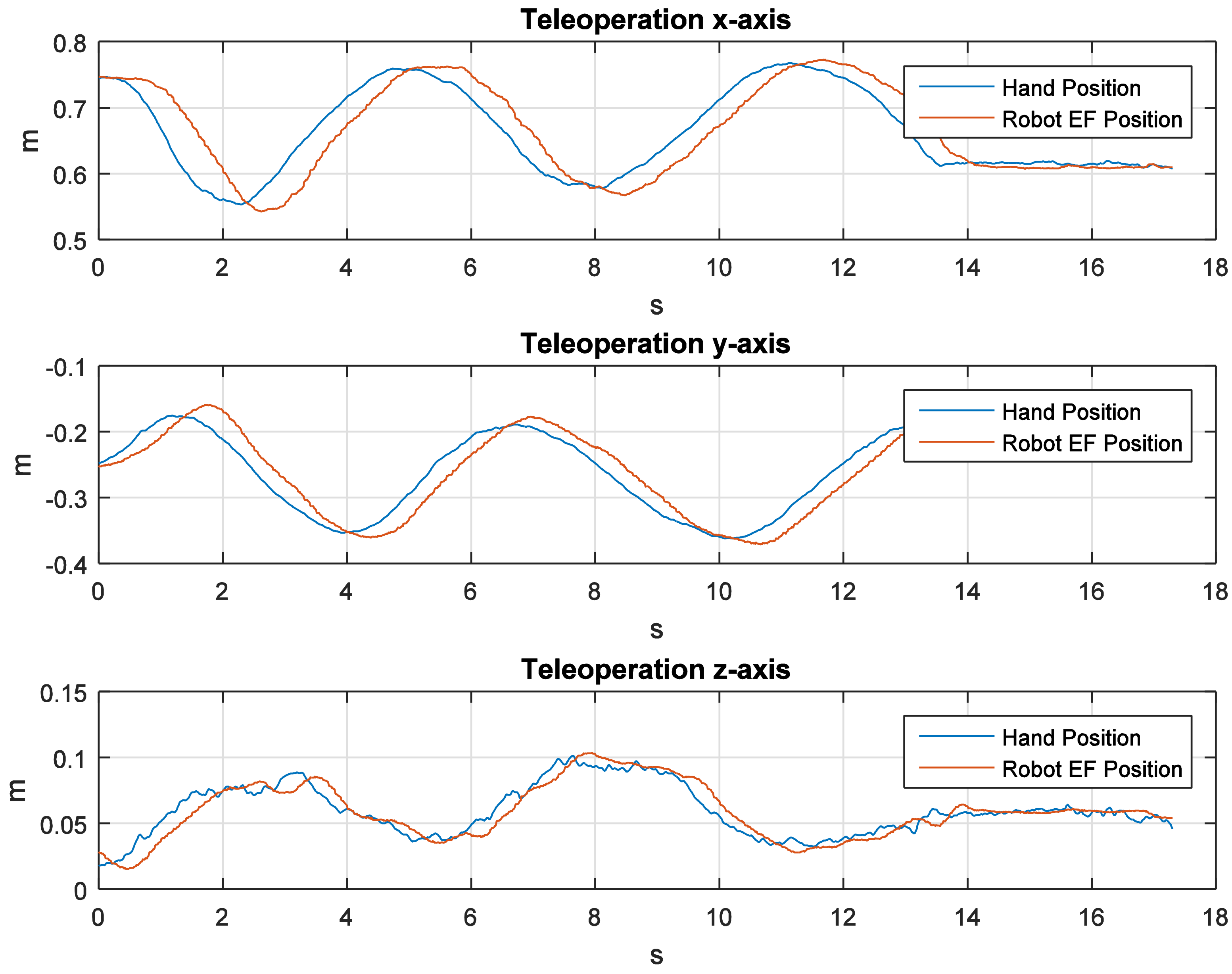


Right arm Tracking and Gripping with Oculus

Right arm Tracking – Left arm Gripping



Teleoperation



Conclusions and Future Work

Issues and Future work

Dual-arm ...

Full-dof safe of the Robot End-Effector

Questions?