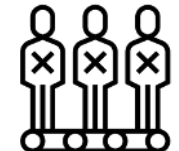






An Anatomy-Aware Shared Control Approach for Assisted Teleoperation of Lung Ultrasound Examinations

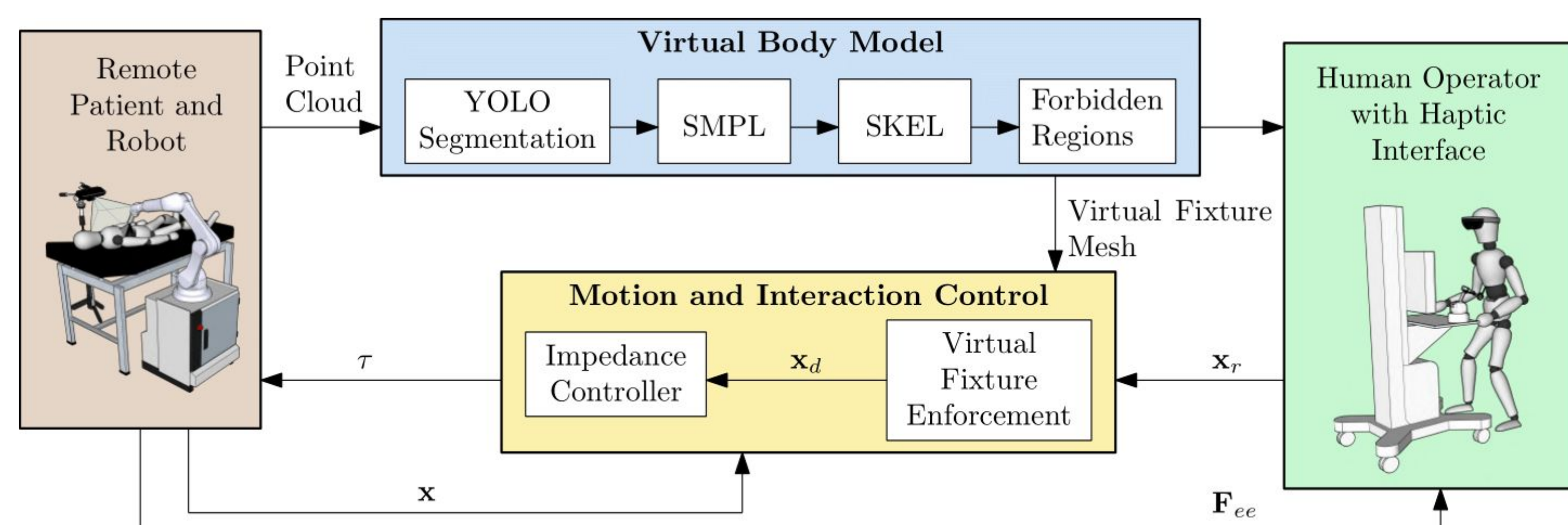
Davide Nardi

Edoardo Lamon and Luigi Palopoli

PROBLEM and MOTIVATION

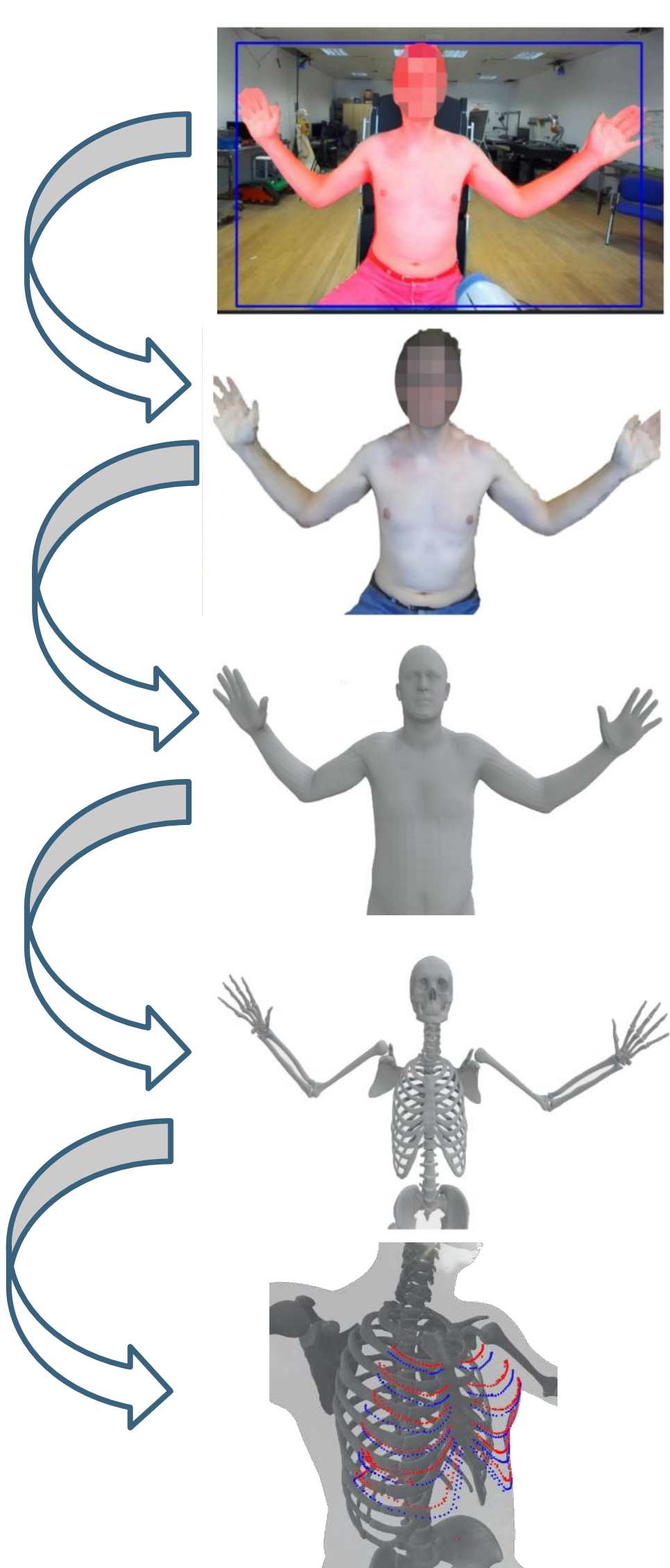
-  **Shortage** of experienced **operators** in remote areas;
-  **Long waiting times** (especially for specialists' visits);
-  **Health risks** for in-person visits (e.g. pandemics);
-  Lack of **repeatability** and objectivity of visits.[1]
-  **Patient anatomy** is still an issue for autonomous systems

PROPOSED FRAMEWORK



VIRTUAL BODY MODEL

We developed a **model-based approach** to detect **intercostal areas** from an RGB-D image using Skinned Multi-Person Linear Model (**SMPL**)[2] and Skeletal Kinematics Enveloped by a Learned body model (**SKEL**)[3].



RGB human segmentation

Segmented point cloud

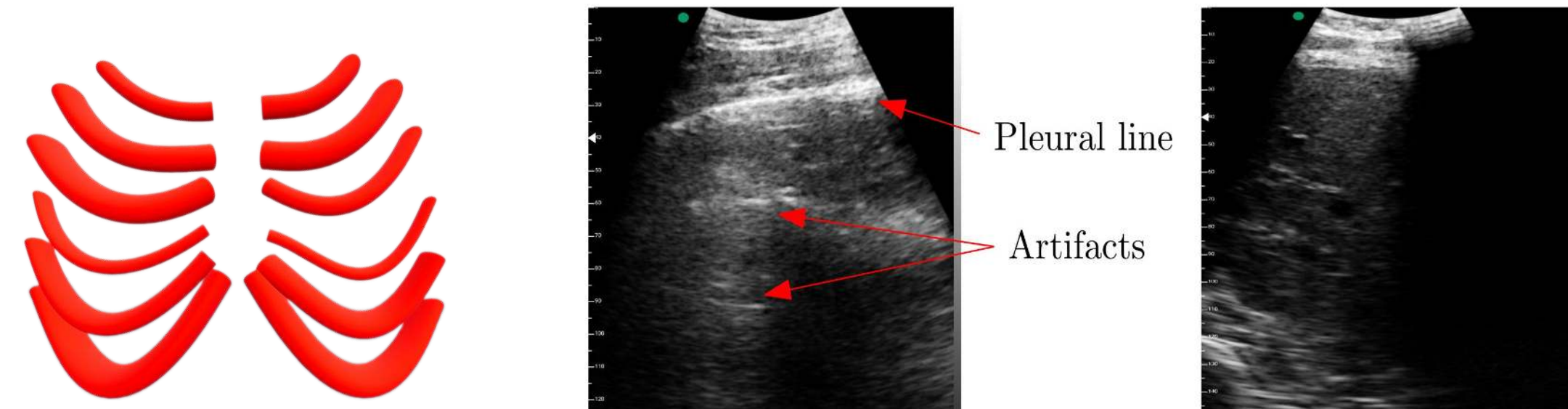
SMPL pose and shape optimization to match the point cloud

SKEL model fitting inside the SMPL

Rib cage projection onto the SMPL

MOTION AND INTERACTION CONTROL

The rib projections are used to create a **mesh** that represents the **ribs beneath the skin**, helping to **limit force** on the ribs and **prevent image shadowing**.



The mesh is enforced with a QP as **forbidden region virtual fixtures**[4] described by its planar local approximation.[5]

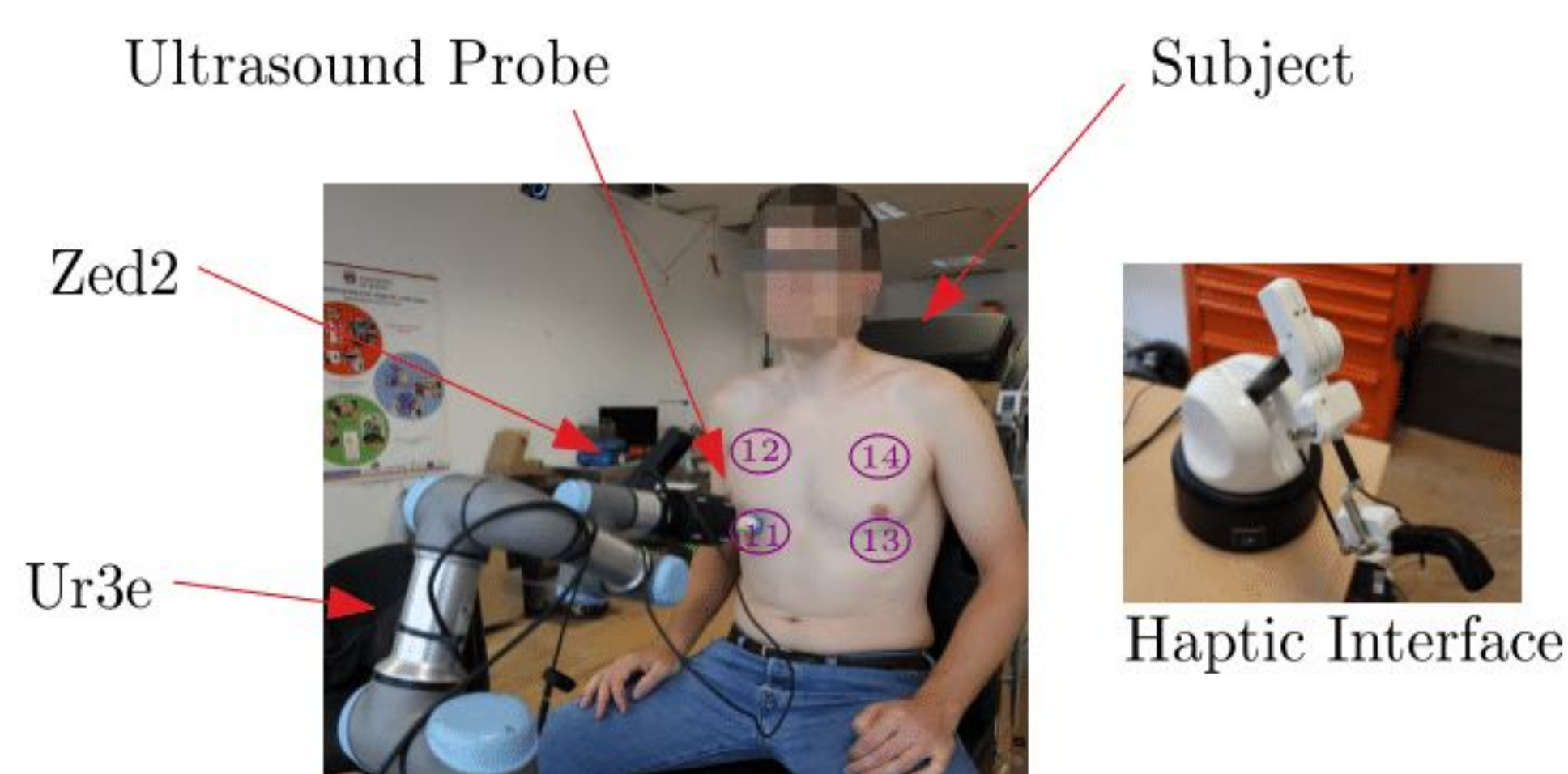
$$\arg \min_{\Delta x} \|\Delta x - \Delta x_d\|_2,$$

$$\text{subject to } n^\top \Delta x \geq -n^\top (x - p)$$

The QP **filters** the target position variation to **meet rib constraints**, and the filtered reference is sent to an **impedance controller**[6].

$$\Lambda_d \ddot{\tilde{x}}_{ee} + D_d \dot{\tilde{x}}_{ee} + K_d \tilde{x}_{ee} = F_{ee}^{ext}$$

SETUP AND EXPERIMENTS



SINGLE SUBJECT ANTHROPOMETRIC MEASUREMENTS [M] (10 SAMPLES)

MEASUREMENT	SMPL (MEAN ± STD)	MEASURE TAPE
CC	0.964 ± 0.034	0.955
WC	0.944 ± 0.054	0.885
SCH	0.664 ± 0.030	0.621





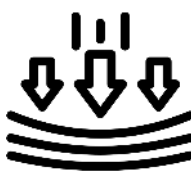
ANTHROPOMETRIC MEASUREMENTS ERRORS [M] (SINGLE SAMPLE)

SUBJECT	CC ERROR	WC ERROR	SCH ERROR
1	0.013	-0.001	0.040
2	-0.081	-0.057	-0.029
3	-0.017	0.015	0.024
4	0.045	0.140	-0.036

MEAN EXAMINATION DURATION [s] WITH AND WITHOUT THE PROPOSED SHARED CONTROL FRAMEWORK

EXPERIMENT	w/ VF, MEAN ± STD	w/o VF, MEAN ± STD
2-pts, operator #1	35 ± 8	50 ± 13
4-pts, operator #2	100 ± 15	135 ± 9

CONCLUSIONS

-  **Model-based** intercostal areas detection
-  **Reasonable reconstruction error** from simple RGB-D image
-  **Automatic way of generating virtual fixtures**
-  **Faster lung ultrasound teleoperations**
-  **Exerted forces limited** to the intercostal areas

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