

Context

Instrumentation able to estimate upper limbs kinematics has a lot of relevance in the context of rehabilitation of stroke patients.

- ➡ Quantitative evaluation of rehabilitation and pharmacological treatment effects
- ➡ Quantitative assessment of the patient progress
- ➡ May serve as an input for a virtual visual feedback

Many solutions exist but the use of sensors for rehabilitation imposes lots of constraints

- ➡ Inertial systems seem to be most suited for an utilization during rehabilitation sessions

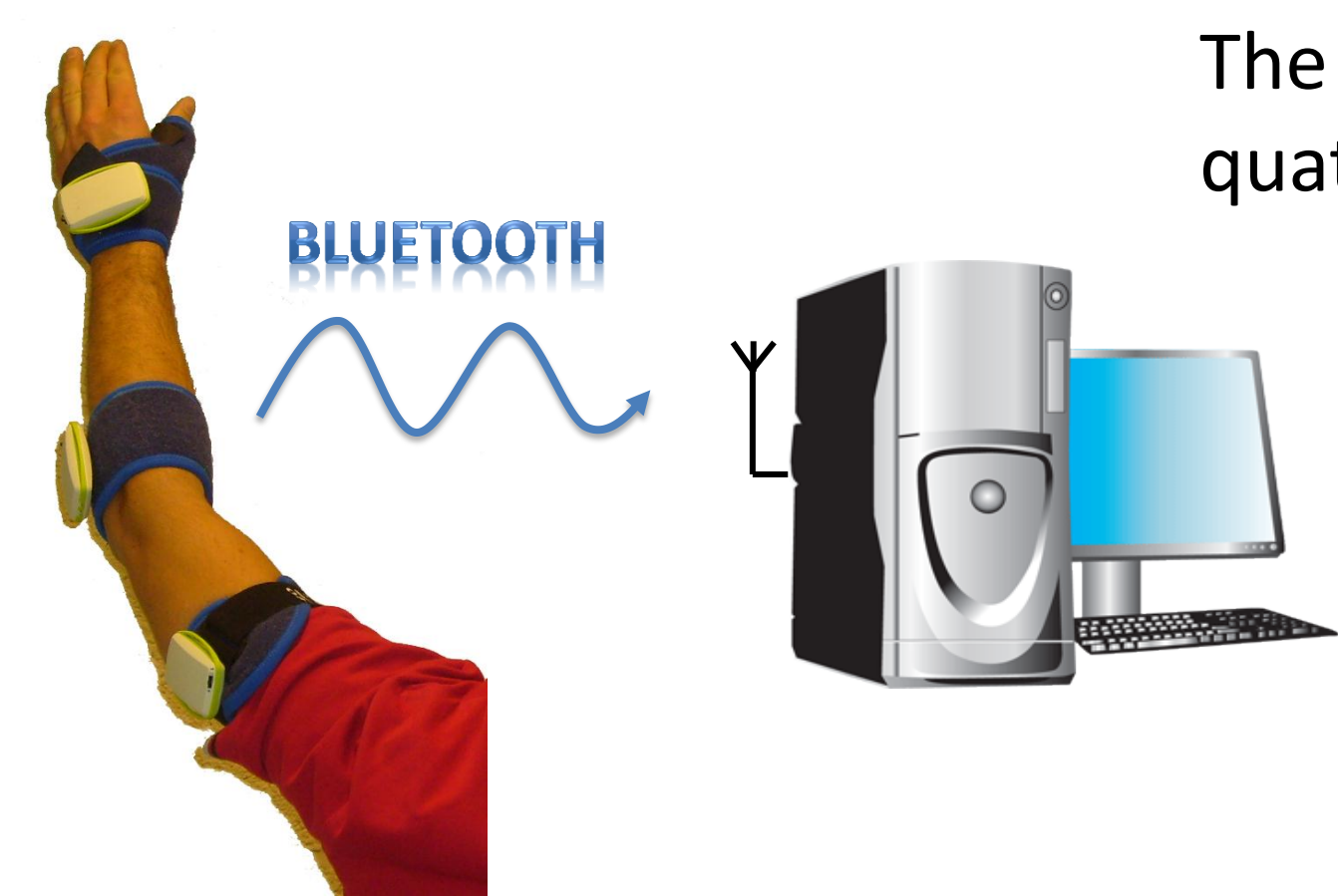
As sensors can not be placed on the limb with a known orientation, an initialization procedure is mandatory in order to find their relative orientation to the skeleton.

- ➡ Several methods exist but there is a **lack of justification about the choice** to use an initialization method rather than another

This study aims at **comparing the initialization procedures** regarding the error on the estimation of upper limb kinematics taking into account non-idealities in the respect of initialization procedures.

Skin movement artefacts are not discussed in this study because they could introduce unnecessary noise in the evaluation of different initialization procedures. Their inclusion would impact all initialization procedures in the same way and it would complicate unnecessarily the discussion about the results.

MARG sensors



The absolute orientation of the sensor is represented by a quaternion and is sent to a computer via Bluetooth.

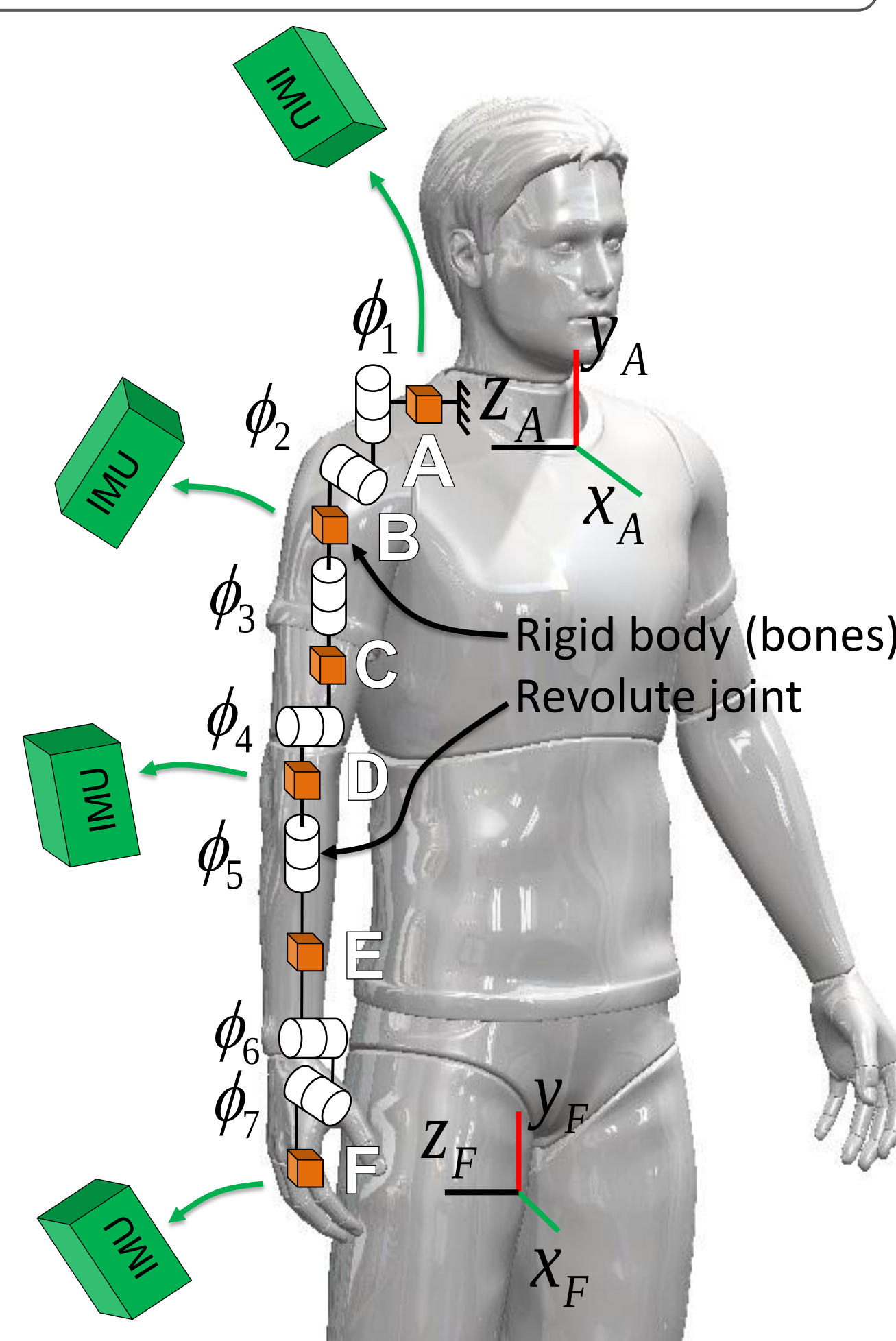
X-IMU sensors were packaged in ergonomic boxes with a long life battery. They can be fixed on the arm using hook-and-loop fasteners. It weighs 42 [g] and has size of 69x43x17 [mm³].

Upper limb model

The International Society of Biomechanics proposes an upper limb model where each link can be represented by three angles.

- ➡ Too complex for our application

According to literature, it is possible to describe precisely enough human arm kinematics with a model composed of **seven revolute joints**.



Sensors positioning

Sensors could be fixed on **six different areas** on the arm. Neglecting the skin movement, these areas are rigidly linked to the skeleton chain of the arm corresponding to rigid bodies **A B C D E F**.

Two sensors can be separated from each other at most by three revolute joints in the model. Since our model has seven joints, **four sensors** have to be placed on the upper limb.

The first sensors acts as reference and is placed on the trunk. The three others can be placed following four configurations : **A-B-D-F**, **A-C-E-F**, **A-C-D-F** or **A-B-E-F**. However, the only configuration **avoiding gimbal locks** during inverse kinematics calculation is **A-B-D-F**.

Initialization procedure 1

As a sensor is disposed with an **unknown orientation** relative to the model, the initialization aims to determine the initial sensor orientation relative to the segment coordinate frame. This is done by estimating at least **two axes of bone segment** coordinate frames in the sensor coordinate frame.

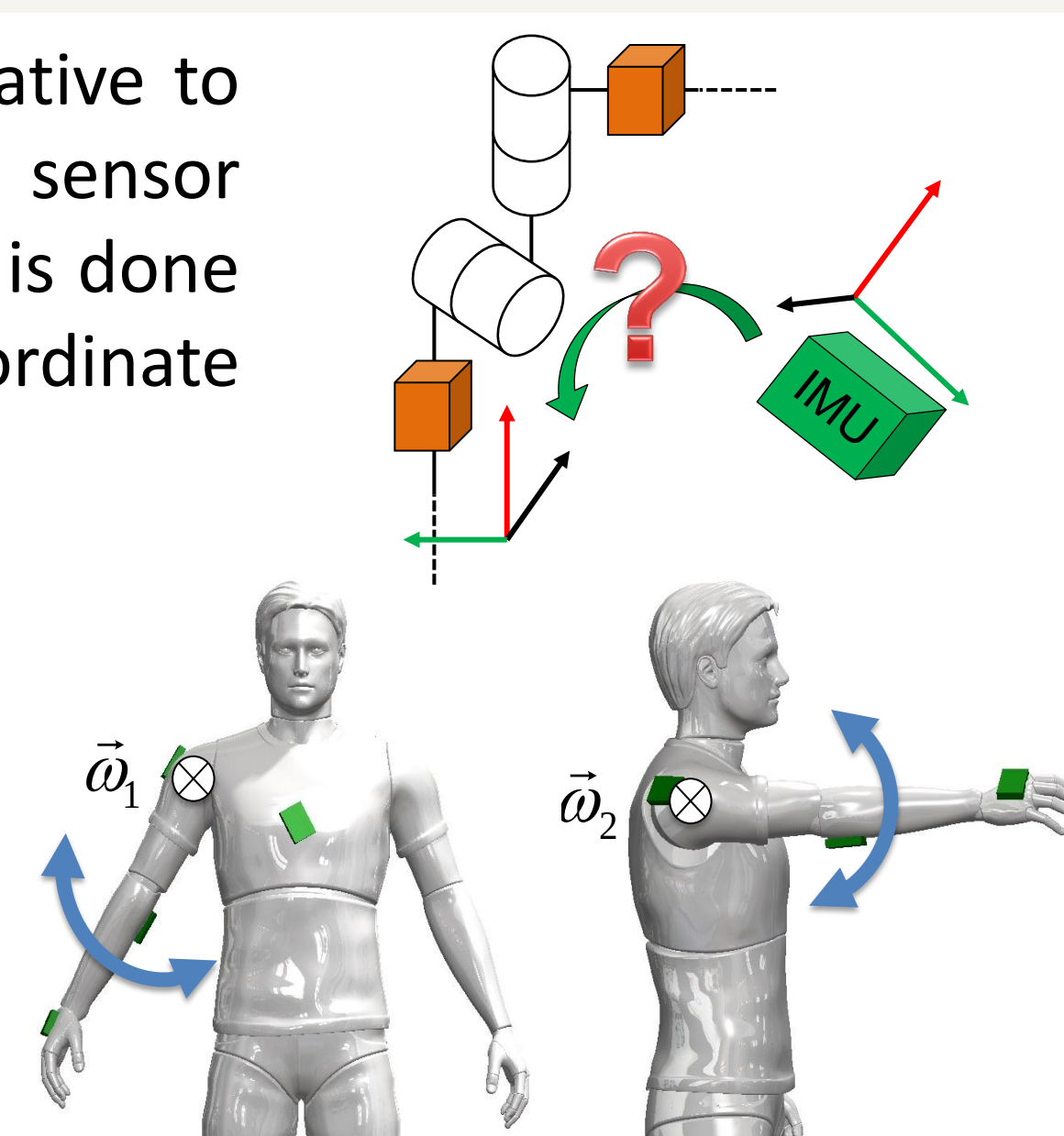
In a first step, **two single DOF movements of abduction-adduction of the arm** are performed in order to deduce two functional axes:

- ➡ One in the frontal plane (x_b)
- ➡ One in the sagittal plane (z_b)

These are calculated from angular velocities measured by gyroscopes.

The second step aims to obtain the relative orientation of the three others sensors. For this step, the patient is placed in a reference position where the relative orientation of bodies **A B D F** are supposedly known and the relative orientation of sensors is recorded.

- ➡ The arm is positioned along the trunk



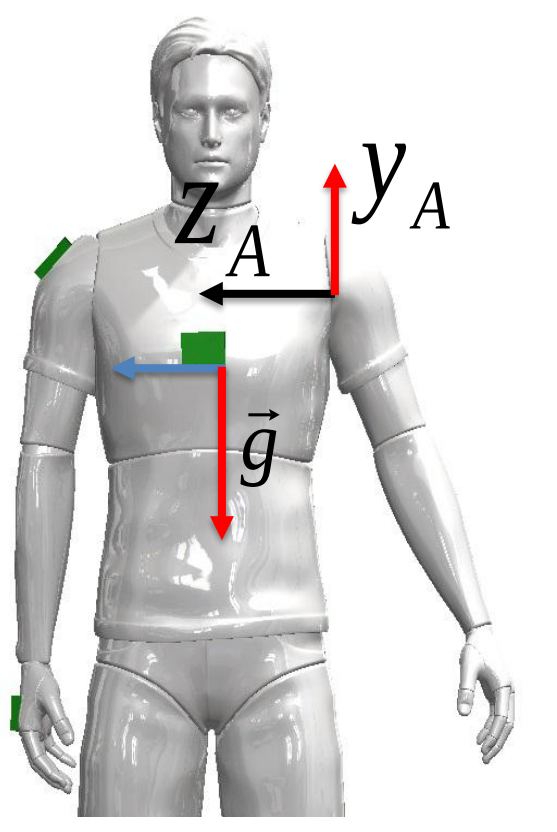
Initialization procedure 2

In this procedure, the **first sensor is aligned** on the trunk (aligned with axis z_A) and the arm is placed along the trunk (aligned with axis y_A). In a first step, the gravity axis is measured and one functional axis is deduced from the gravity vector estimation.

- ➡ The upper limb is supposed aligned on gravity vector

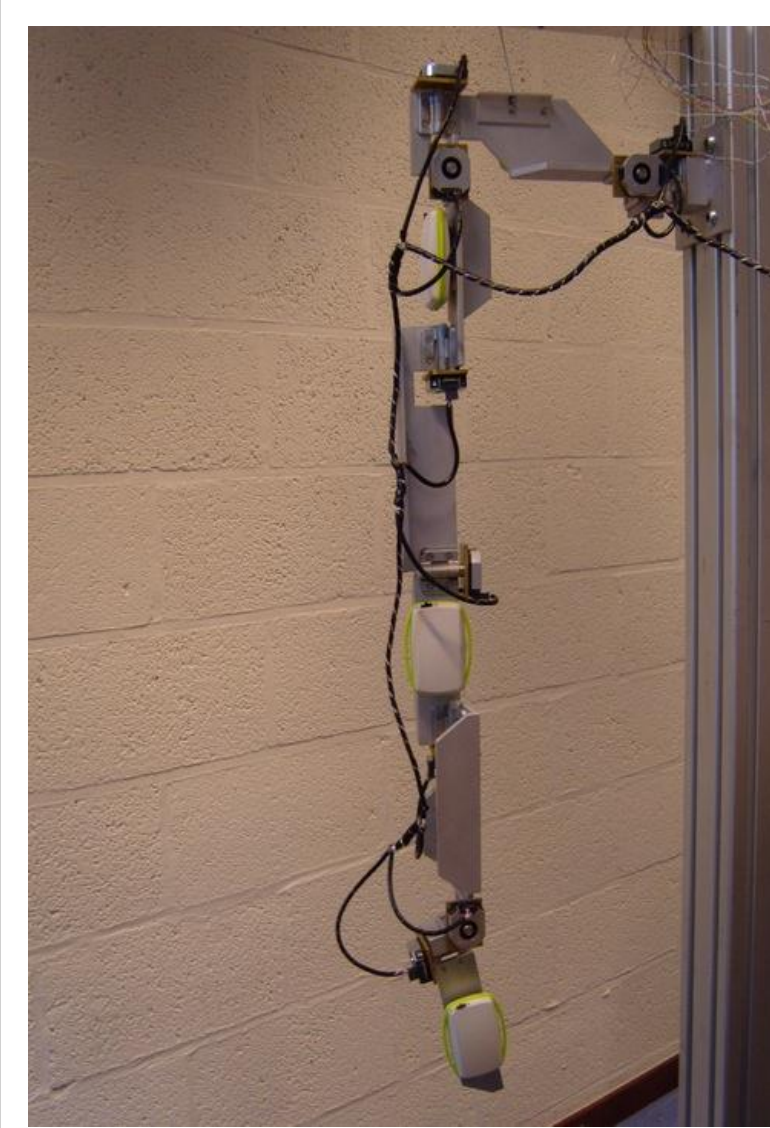
The second step aims to obtain the relative orientation of the three others sensors. For this step, the patient is placed in a reference position where the relative orientation of bodies **A B D F** are supposedly known and the relative orientation of sensors is recorded.

- ➡ The arm is kept along the trunk



Evaluation method

The evaluation of the initialization procedures were performed on an **artificial arm equipped with absolute encoders** rather than on a real one in order to not taking into account skin movement artefacts.



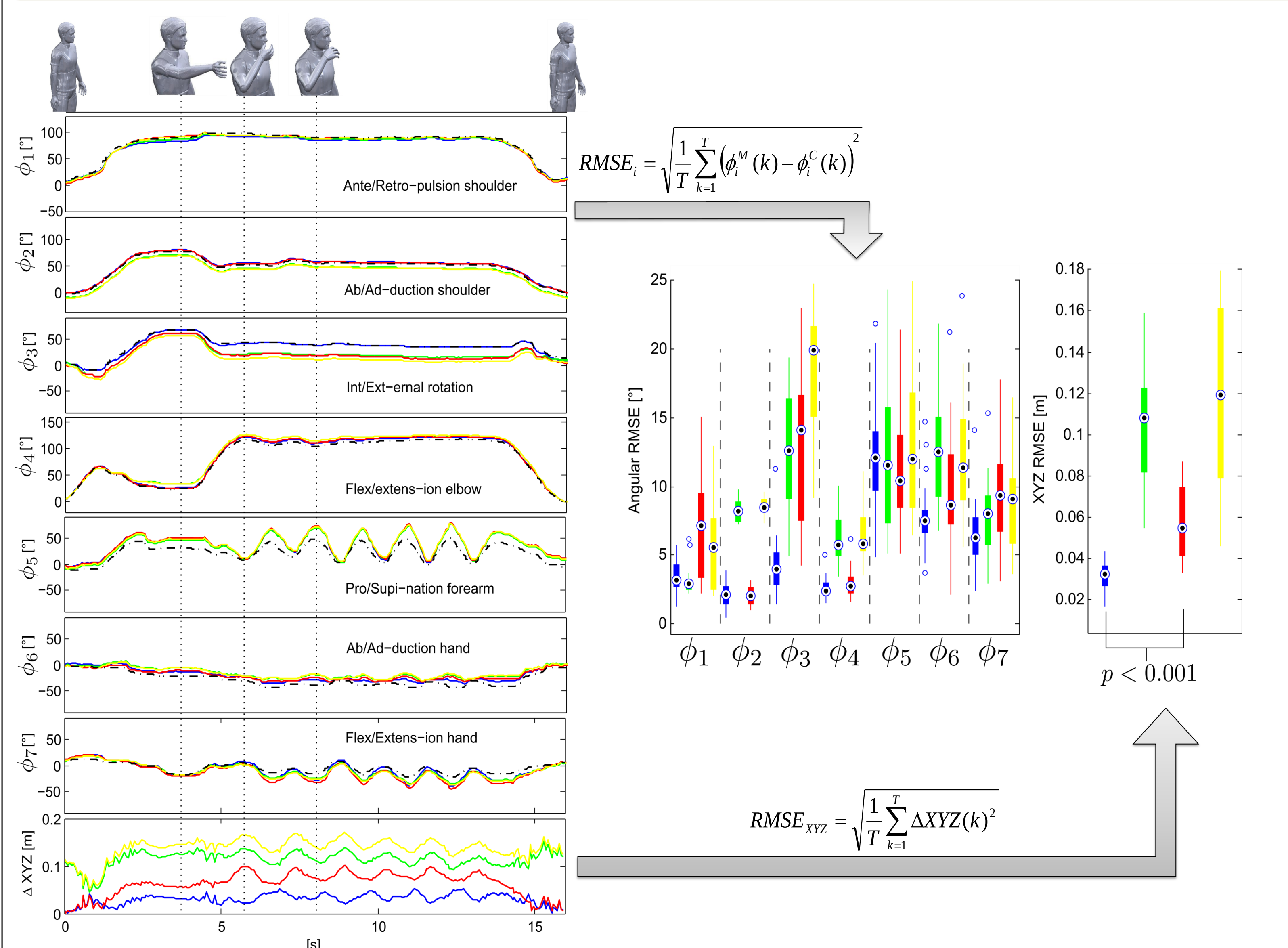
On the basis of two presented procedures, **four different initialization procedures** were performed in a first step :

1. **Ideal Init 1** : the procedure is respected as best as possible.
2. **Non ideal Init 1** : the functional movements are performed with 10° coupling with another axis.
3. **Ideal Init 2** : the procedure is respected as best as possible.
4. **Non ideal Init 2** : the upper limb is positioned with an abduction of 10° during the recording of the reference position.

Five trials of four Activities of Daily Living movements were performed on the artificial arm in a second step :

1. Reach and drink
2. Perineal care
3. Comb hair
4. Triple flexion to triple extension position

Results



Conclusion

Two initialization procedures has been described and compared for upper limb kinematics estimations using MARG sensors. The results have shown that an initialization made through **functional axes** is **less dependent** to the strict observance of the initialization procedure. However, initialization made through **alignment on gravity vector** could make sense for weak patient because it does not require any movement.

Given the analysis presented, it seems clear that **an initialization made through functional axes is the recommended procedure** if functional movements can be done by the patient.