Upper Limb Posture Estimation in Robotic and Virtual Reality-Based Rehabilitation

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Introduction

Robotic and Virtual Reality (VR) technologies are important components of the modern neurorehabilitation systems for pathologies such as stroke or spinal cord injury [1-3]. In this field, our general research has two main goals:

1. to improve the assessment of the rehabilitation progress through precise estimation of the patient kinematics. This is the focus of this work;
2. to optimize the rehabilitation processes by using the kinematic (and other) patient models. This optimization includes hybrid technologies (e.g., robotics, virtual reality, functional electrical stimulation [4], etc.).

In the mentioned scenario, the proper estimation of the patient limb posture is a fundamental prerequisite for the following:

1. design and control of the advanced robotic exoskeletons which provide assistance to the patient during motor rehabilitation [5],
2. animation of realistic avatars representing the patient in virtual reality (VR) scenarios (e.g., games, bionics), and
3. acquisition of kinematic data of the patient during the training exercises to assess improvement along the therapy.

Here we present a method for estimation of limb posture from the exoskeleton posture. Notice that such an estimation is not trivial, since the limb is not rigid, is not standard, and has kinematic topology different from the exoskeleton topology. Our method delivers limb postures estimates to strengthen and to enable downstream applications in robotic rehabilitation (among others, using VR [4]).

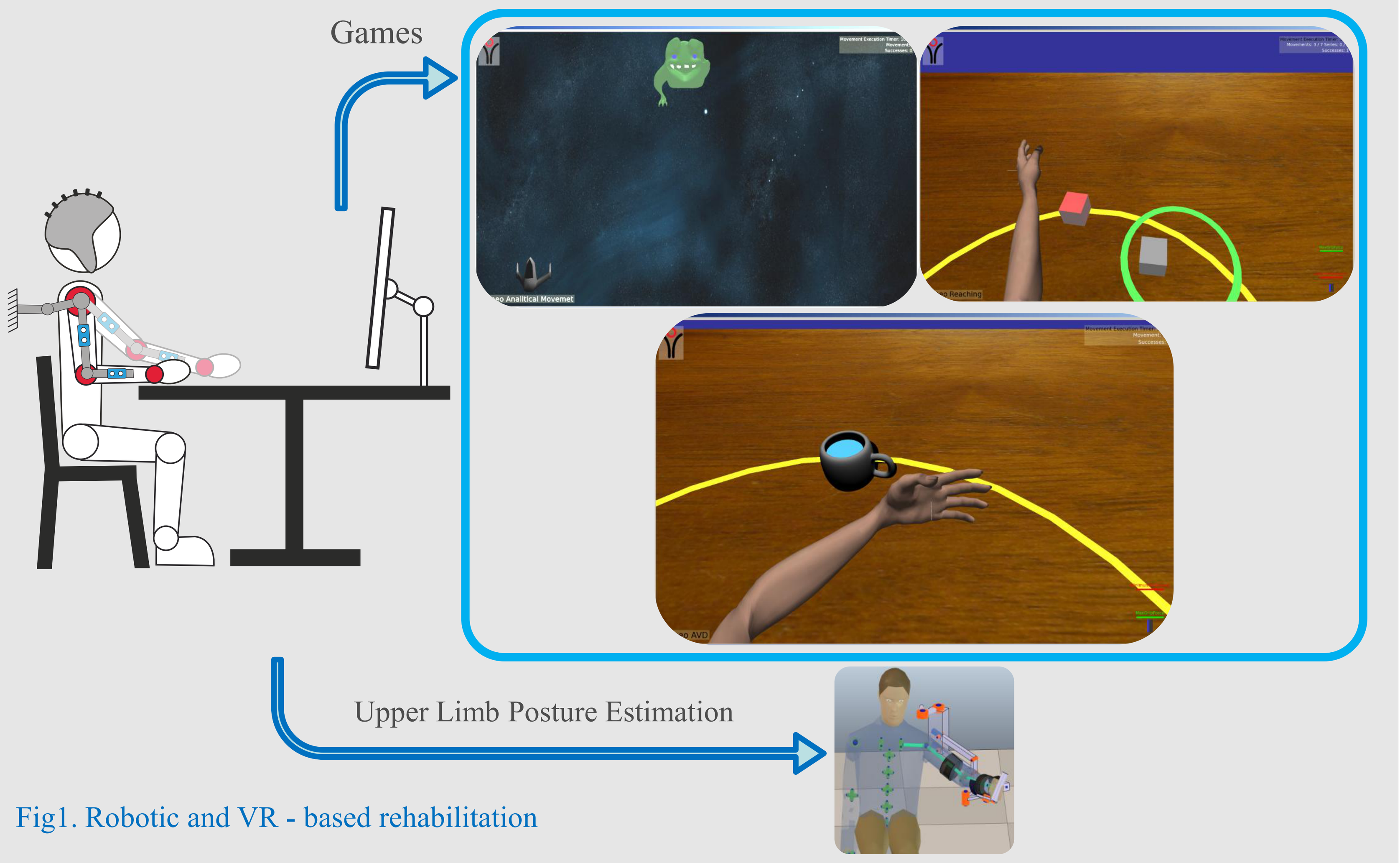


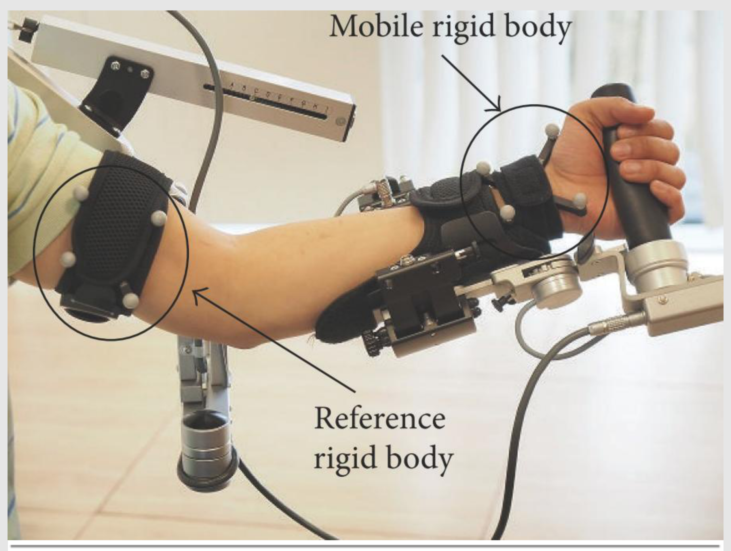
Fig1. Robotic and VR - based rehabilitation

Results and discussion

○ Posture Estimation Accuracy

To determine the accuracy of our method, the joint angles of voluntary healthy test subjects were measured by using an optical tracking system (adapting the method in [6]) and compared with the angles obtained from our posture estimation algorithm during the execution of the following exercises:

1. wrist flexion/extension (WFE),
2. elbow flexion/extension (EFE),
3. forearm pronation/supination (FPS),
4. simultaneous elbow flexion/extension and forearm pronation/supination (SEFEFPS)



Number of test subjects	Number of exercises performed by each test subject	Number of trials per exercise	Joint angles measurements per trial
4	4 (WFE, EFE, FPS, and SEFEFPS)	4	2960 at 66.6 Hz

Fig 5. Validation Setup and protocol.

○ Estimation Errors

Subject	Average WFE RMSE	Average WFE ROM
1	1.137	53.389
2	1.432	54.824
3	3.282	63.869
4	3.555	53.977
Average	2.351	56.265

Table 1. Errors in WFE exercise (degrees)

Subject	Av. EFE RMSE	Av. EFE ROM	Av. FPS RMSE	Av. FPS ROM
1	1.636	36.948	0.980	4.148
2	1.553	33.897	1.408	4.921
3	2.815	49.333	2.187	5.216
4	4.381	36.442	1.128	7.160
Average	2.596	39.150	1.426	5.361

Table 2. Errors in EFE exercise (degrees)

Subject	Av. EFE RMSE	Av. EFE ROM	Av. FPS RMSE	Av. FPS ROM
1	1.221	5.799	1.965	70.453
2	1.799	7.395	2.639	48.500
3	1.627	9.691	4.147	90.527
4	1.132	2.459	4.568	37.717
Average	1.445	6.336	3.330	61.799

Table 3. Errors in FPS exercise (degrees)

Subject	Av. EFE RMSE	Av. EFE ROM	Av. FPS RMSE	Av. FPS ROM
1	2.224	35.762	2.707	59.878
2	2.773	40.837	3.037	58.441
3	5.212	47.850	4.429	55.228
4	2.679	36.654	2.158	59.673
Average	3.222	40.276	3.083	58.305

Table 4. Errors in SEFEFPS exercise (degrees)

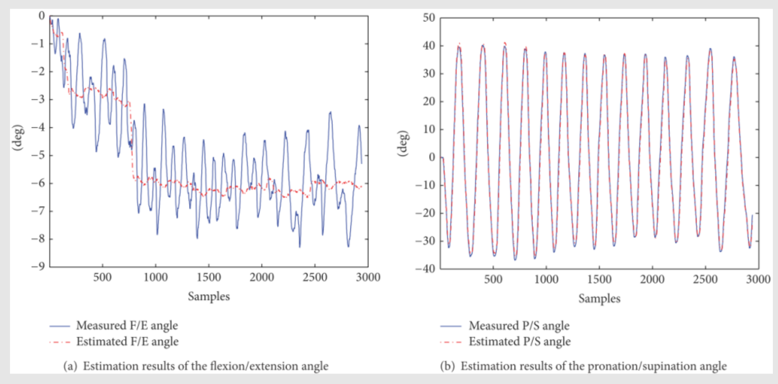


Fig 6.Estimation results during FPS for a trial of subject 1

The results show that our approach presents an accuracy that is better than the one provided by goniometry (minimum detectable change is 8 degrees [7]). Compared to the accuracy provided by IMMSs-based methods, which are considered enough accurate to measure clinical relevant limb joint angles (RMSE 3.6 degrees [8]) in non robotic-assisted scenarios, we have obtained very similar results.

Methodology

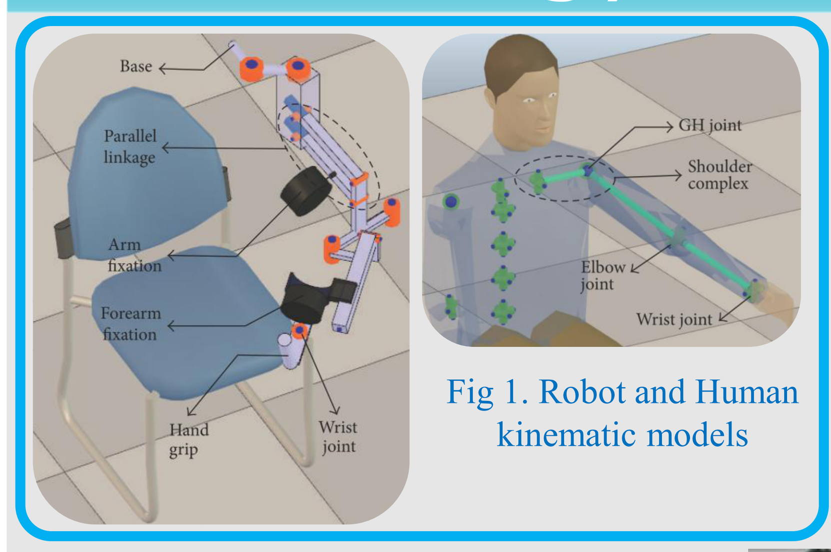


Fig 1. Robot and Human kinematic models

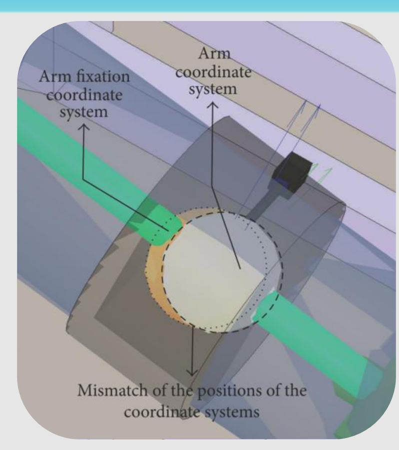


Fig 2. Human-robot interaction constraints

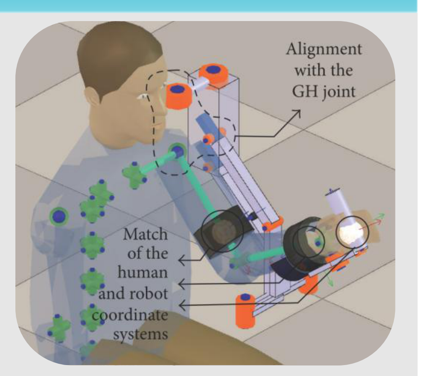


Fig 3. Models initialization

○ Problem

Estimate the joint angles of the patient limb during robotic-assisted rehabilitation therapy from the kinematic information provided by the exoskeleton.

○ Solution approach

It is based on Inverse Kinematics (IK). It consists of the following steps:

1. Build a kinematic model of the exoskeleton
2. Build a kinematic model of the human upper body
3. Identify the kinematic constraints of the human-robot interaction
4. Initialize (couple) the human and robot kinematic chains
5. Solve the IK of the human upper body for a given pose of the exoskeleton
6. Get the resulting joint angles of the upper limb

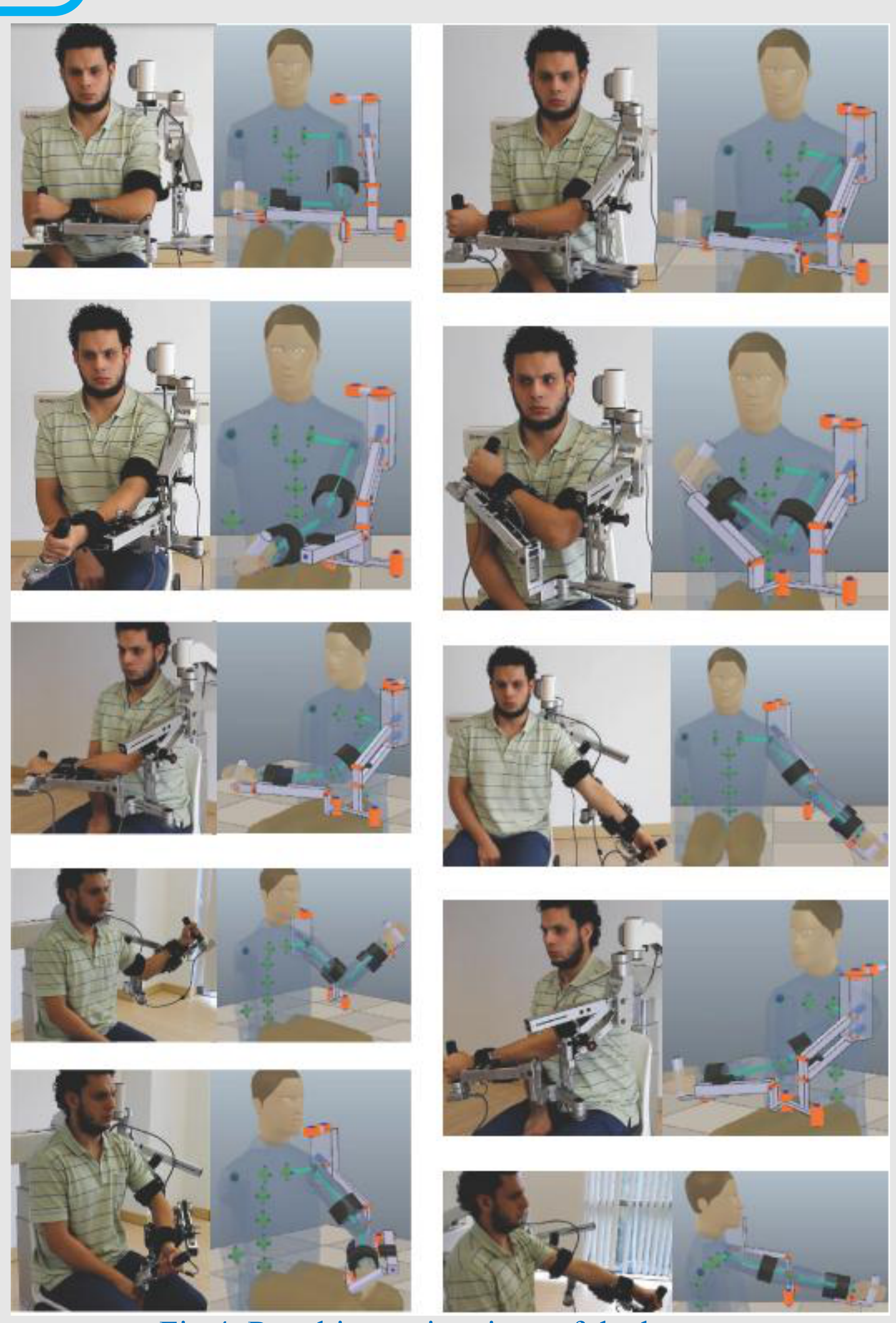


Fig 4. Resulting estimations of the human pose

Conclusions

1. We present a method that can be applied to estimate the posture of the human limbs during the interaction with exoskeletons by solving the limb IK problem extended with the kinematic constraints of the exoskeleton fixations on the limb.
2. We show the implementation of our method to provide upper limb posture estimations, in real time, using the Armeo Spring. We also present the use of the resulting limb postures estimations in the animation of avatars in VR rehabilitation games.
3. The validation results show that our approach provides enough accuracy to obtain the kinematic data for the patient assessment during analytic training of the elbow and wrist.

References

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