A New Affordable Visual-Inertial Human Motion Capture System

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***Abstract*— This paper proposes anew affordable, portable and simple to use system for human joint angles and torques estimation. The system is based on a camera, a set of augmented reality markers, low-cost inertial measurement units (measuring 3D linear accelerations and 3D angular velocities), and a low-cost force plate (Wii Balance Board). The markers tracked position and orientation are fused synchronously with the inertial measurement units data into an Extended Kalman Filter based on a biomechanical model of the investigated segments. The method has been tested with both human upper limbs and human-exoskeleton lower limbs models. In the latter case, a NRMS lower than 6% was observed when comparing estimated and measured external ground reaction force and moments.**

I. INTRODUCTION

The accurate quantification of human motor act is a major concern in rehabilitation field. Usually, stereophotogrametric systems are used to obtain highly accurace motion estimate. However, these systems, beside being costly, are restricted to laboratory environments due to complex experimental protocols. Alternatively, portable and affordable motion capture systems based on Inertial Measurement Units (IMU) are gaining popularity.

Thanks to their low cost, light weight and small dimensions, IMU can be used in daily free-living environments. An IMU may incorporate 3D accelerometers, gyroscopes and magnetometers that measure respectively the linear accelerations, angular velocities and magnetic field in the sensor's coordinate system. However, the sensor's pose, *i.e.* position and orientation, obtained from the integration and fusion of IMU data migth be largely corrupted due to nonlinear and time-dependent drift. Moreover, in the vicinity of ferromagnetic materials, magnetic field may be disturbed resulting in additionnal drift [1]. Being transportable and simple to use, RGB-Depth camera-based systems have been also investigated in tracking human limbs position and orientation [2]. In a previous work, we have already used a visual system tracking the position of augmented reality (AR) markers to estimate human lower limbs kinematics [3]. However, this system has a limited workspace and is sensitive to markers occlusions.

In this context, we propose a new affordable and user-friendly motion capture system that combines both a visual and inertial measurements. In order to compensate for drift and occlusions drawbacks, all data were fused into a multi-modal Extended Kalman Filter (EKF). The proposed system has been experimentally tested with a human subject wearing a full lower limbs exoskeleton as well as with an arm model. Estimated kinematics were used together with Ground Reaction Forces and Moments (GRFM) recorded with an affordable Wii Balance Board (WBB) to identify body segments inertial parameters (BSIP) of both human and exoskeleton models.

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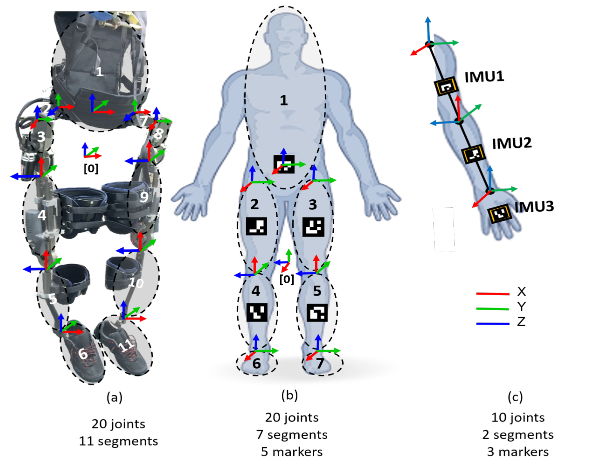

Fig. 1. Mechanical models of: (a) E-ROWA exoskeleton, (b) human lower limbs and (c) human upper limbs.

II. METHOD

A. Mechanical Model

In order to assess the proposed motion capture system, both human arm and lower limbs models were developed. A mechanical model of the E-ROWA exoskeleton was also considered while assuming rigid connections between the robot's and the wearer's body segments (see Fig.1). The 3D Cartesian pose, linear accelerations and angular velocities of each sensor were modeled by computing the Forward Kinematic Model (FKM) and its first and second derivatives respectively.

B. Kinematics estimation

The equipements and sensors described in Fig.2 were used to estimate both arm and lower limbs kinematics. Segments of interest were each equipped with an IMU sensor covered by an ARUCO marker [4]. A low-cost RGB camera allowed markers 3D pose detection while IMU sensor provided additional 3D linear accelerations and angular velocities. The joint center positions, segments lengths and markers local poses in their corresponding segment frames were priorly

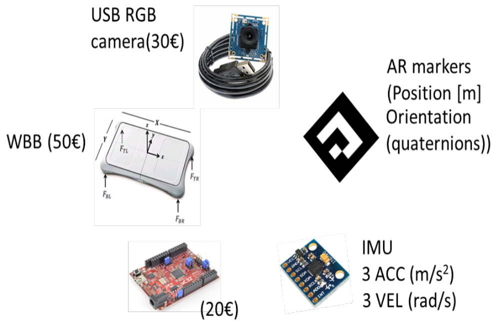

Fig. 2. The affordable elements that compose the proposed motion capture system.

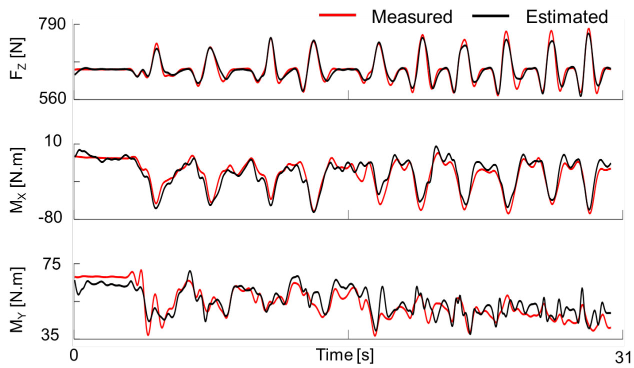

Fig. 3. Comparison between the measured (black) and estimated (red) vertical ground reaction force and moments of force when a subject is wearing an exoskeleton.

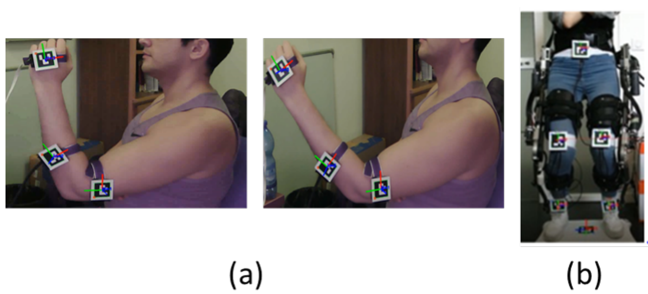

Fig. 4. (a) Elbow flexion/extension test on human arm. Each marker was located on an IMU sensor. (b) Human subject wearing the E-ROWA exoskeleton and performing squat exercise.

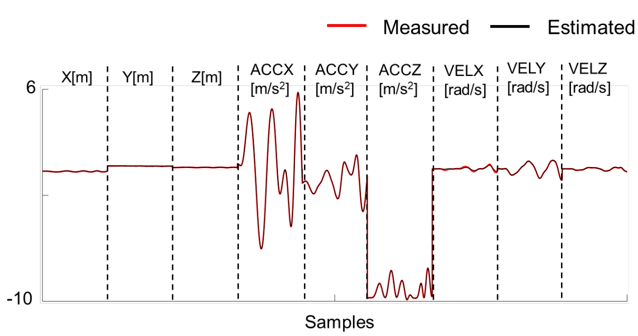

Fig. 5. Marker 2 position, IMU 2 linear accelerations and angular velocities along x, y and z axis respectively, measured (red) vs estimated (black) with the EKF.

determined with a wand-based calibration method [3]. Since each measurement is subject to inaccuracies, in particular IMU drift and markers occlusions, all data were gathered and used synchronously as inputs to the EKF. The EKF allows to estimate joint trajectories gathered in the state vector $\mathbf{x}_k$ at each time step $\mathbf{k}$ through two prediction and update phases respectively:

$$\begin{aligned} \mathbf{x}_k &= f(\mathbf{x}_{k-1}) + \mathbf{w}_{k-1} \\ \mathbf{y}_k &= h(\mathbf{x}_k) + \mathbf{v}_k \end{aligned} \tag{1}$$

where f, the state evolution, is considered as a classical constant acceleration model. h is the measurement model relating IMU data and markers pose, gathered in $\mathbf{y}$ vector, to the state variables to be estimated. $\mathbf{w}$ and $\mathbf{v}$ are assumed to be zero mean white Gaussian noises.

III. Experimental validation

The method has been experimentally tested in two cases (Fig.4). As shown in our previous work [3], the resulting kinematics were introduced into a dynamic identification pipeline and showed the possibility to identify human-exoskeleton BSIP from affordable sensors. Fig.2 presents a comparison between the GRFM measured by the WBB and their estimates from the identified model ontained during a cross validation trial. In this case the average NRMS difference was lower than 6%. Subsequently, the proposed framework has been used to assess arm motions. During the experiments the same setup consisting in one marker-IMU per segment was considered (Fig.4.a). As a preliminary study, the subject was asked to perform simple elbow flexion/extension motion. Fig.5 shows the ability of the EKF to track sensors measured data during the elbow flexion/extension motion.

IV. Conclusion

The paper proposes an affordable, portable and user-friendly motion capture system with an overall estimated price of 50 Euros. It consists in fusing IMU sensors with a camera tracking visual AR markers. The sensor fusion allows to reduce the effect of each sensor inaccuracies, especially in handling markers occlusions and IMU drift. The system has been investigated experimentally during an arm motion as well as in a dynamic identification process of a human-exoskeleton system. Future works will consist in further experimental validations to compare the results obtained with the proposed system to a reference optical system.

References

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