IMU-based Motor Intent Decoding With Full Kinetics Information

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I. INTRODUCTION

Lower-limb exoskeletons augment, rather than replace, the assisted joints thus can enhance mobility of users. Users' locomotion therefore is the result of the collaborated contributions of biological and exoskeleton efforts. Essentially, the efforts of exoskeletons derive from the assistive force profile. Compared with assistance determined from a nominal curve, a subject-specific assistive force profile enabled by real-time decoding human motor intent is, not surprisingly, able of providing better biomechanical interaction and improved assistive performances [1]. Decoding human motor intent, which is the key function of exoskeletons' high-level control strategies [2], provides reference for determining a subject-specific assistive force profile from four aspects, i.e. assistance's timing, magnitude, shape and duration. According to different subsets of the four aspects, assistance with various subject-specific levels is applied to users. Gait phase detection technologies [3] and some strategies based on detecting key points of kinematics [4], [5] (e.g. zero-crossing point of angular rates) enable the determination of subject-specific timings of assistance. The remaining three aspects of assistive force profile are determined by either a nominal curve or manually tuning. Although human-in-the-loop optimization can be applied to tune the remaining parameters, as argued in [6], assistance parameters are often held fixed after optimization, even when users may still be changing their patterns. Some customized pressure insoles can indicate ground-feet reaction force precisely and thus can determine the timing and magnitude of assistance [7], [8]. Myoelectric signal-based methods can reflect the kinetics variation during locomotion [9], [10], where musculoskeletal model can further provide full kinetics information of all the four aspects [11]. However, the characteristics of myoelectric signals varies with many factors, such as fatigue, sensor placement and tissue artifacts, which makes the performance unstable.

To this end, we propose to develop a novel algorithm to decode human motor intent that can give full kinetics information in real time with stable signals as input. In this way, all of the four aspects of the assistive force profile can be indicated with a subject-specific reference. Also, because of decoding kinetics in real time, the changing patterns of users can be reflected. In this abstract, one first step was made toward our final goal, which is the kinematics and kinetics calculation using inertial measurement units (IMUs) and some initial results.

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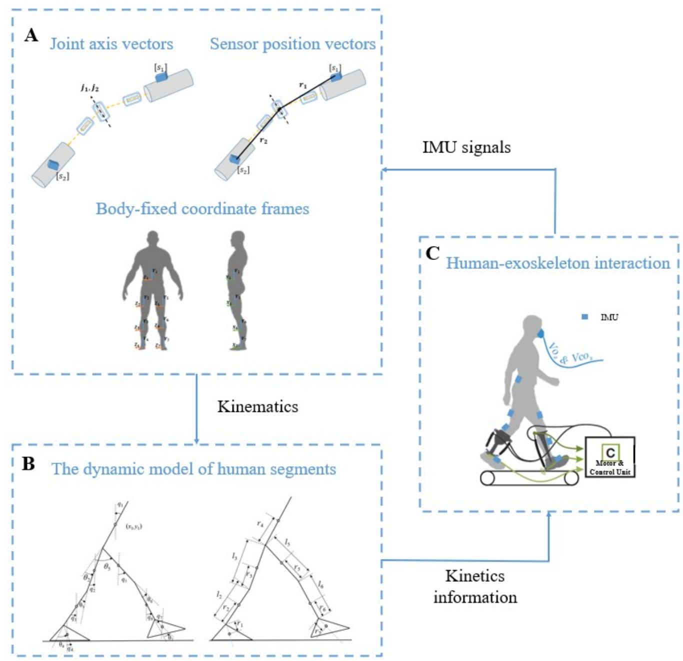

Fig. 1. A schematic diagram of the information flow. (A) Kinematics calculation. (B) Kinetics calculation. (C) The diagram of sensing signals from human and applying calculated kinetics to controlling exoskeletons..

II. METHODOLOGY

As shown in Fig1 (C), seven IMUs were attached to lower back and each segment of lower limb. With IMU signals as input, the algorithm in [12] was employed to estimate joint axis vectors and joint position vectors in order to establish the body-fixed coordinate frames without calibration postures (Fig1. (A)). In this way, lower-limb kinematics information in the sagittal plane, including angles, angular rates and angular accelerations of each lower-limb joint, can be calculated. A two-dimensional dynamic model, consisted of seven links, were built to approximate humans dynamics of locomotion in the sagittal plane. During double-support phases, smooth transition assumption was employed to estimate the ground-foot reaction force and moment of each foot. Finally, moment of each lower-limb joint can be calculated and provide full kinetics information for determining the subject-specific assistive force profiles.

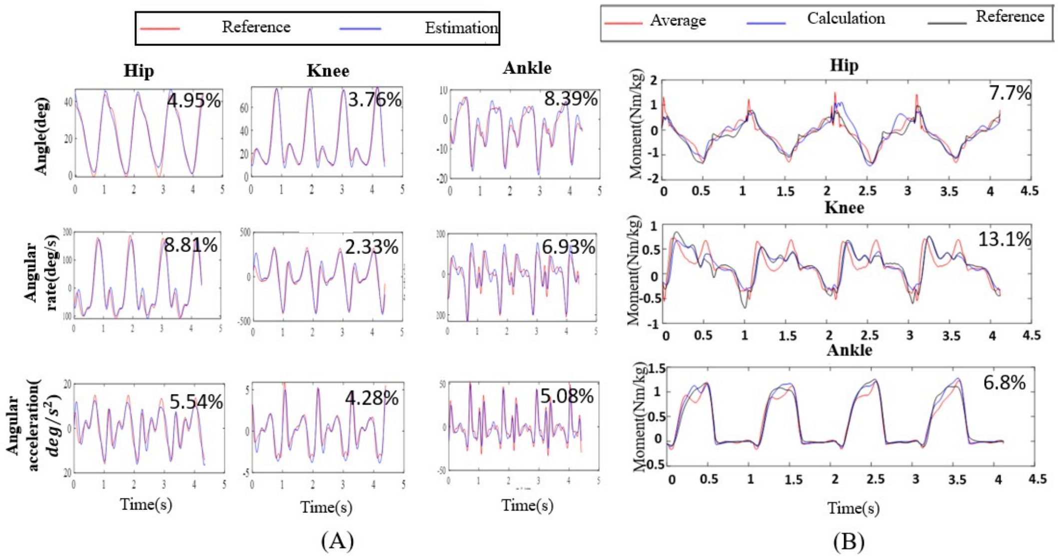

Fig. 2. Representative plots. (A) Calculated kinematics in the sagittal plane. Red lines denote the reference curves from optical motion capture systems; Blue lines denote curves calculated from the algorithm. (B) Calculated kinetics in the sagittal plane. Red lines denote the curves averaged over calculated joint moment of the five subjects; blue lines denote the curves of calculated joint moment of one subject; black lines denote the reference curves of the same subject.The percentages on each subfigure denote the averaged RMSE relative to the magnitude of each curve.

III. RESULTS

Five healthy subjects were included in the test, during which subjects were asked to walk with self-selected speeds. Seven IMUs were attached on subjects' body, as shown in Fig.1 (C). Meanwhile, optical motion capture system and force plates were employed to give a gold reference for kinematics kinetics calculation. Fig.2 presented the representative plots of our algorithms performances. The percentages on the figure depicted the accuracy of calculations with root mean square errors(RMSE). It is shown that the calculated curves meet the trend of reference and the RMSE of the calculations is the acceptable for controlling exoskeletons.

IV. FUTURE WORK AND PERSPECTIVES

Extensive experiments will be carried out with several subjects to demonstrate the performance of applying this intent decoding method on lower-limb exoskeletons, in order to indicate this algorithm's feasibility in improving metabolic cost and muscle activations, as well as to present the variation of gait caused by applying the algorithm.

This study fulfilled the minimal risk from the ethical checklist. Participants had been informed of their right to withdraw from the study at any time, without giving explanation; the data used in this research were anonymized and no children, people with disabilities have been involved in this study.

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