Wearable Human Tracking: Technologies, Methods, and Experiments

Tommaso Lisini Baldi and Domenico Prattichizzo

***Abstract*—In these two pages we briefly introduce our recent results in the field of wearable human tracking. We developed an innovative sensing system based on inertial and magnetic sensors for hand tracking, extended and enhanced for different applications and body parts. It can be combined with cutaneous devices for the rendering of the force feedback, thus producing a wearable sensing/actuation system. The proposed method does not suffer from occlusion problems, it is wearable and cost effective however, since the employed sensors use the magnetometer to compensate the drift, they are sensitive to variations in the magnetic field. This property makes it challenging to interface the sensing system with wearable devices since their motors generate variations in the magnetic line field. Then, we report an improvement of the proposed glove capable of estimating fingertip contact force in grasping deformable objects. The system estimates the configuration of the hand and the deformation of the object at each contact with the fingertips of the human hand. The force exerted by each fingertip is obtained using the object stiffness matrix and the hand pose. We conclude detailing two more possible uses of the tracking system: the former is a wearable interface for controlling lightweight robotic arm, the latter is a wearable input interface which allows interactions through fingers tapping.**

I. Introduction

Capturing, analyzing, and interacting with the human body, and in particular with the human hands, is fundamental in several applications such as rehabilitation, human-robot interaction, and gaming. In these contexts, wearability represents a key point since it improves the way humans interact with each others and the surrounding environment. In the last years, there has been an increasing interest in developing new solutions to accurately track the human hands, but most of the existing solutions are not completely wearable or portable. They usually rely on grounded devices and/or structured environments. Towards the concept of portability, camera-based tracking algorithms became a widespread solution due to improvements in computer vision techniques and progressive growth in computers computational capabilities. Commercial devices, like the Leap Motion (Leap Motion Inc., USA), allow to simultaneously estimate the full hand configurations of both hands. However, camera-based solutions have some limitations: RGB-D cameras might not work properly in an outdoor environment due to the infrared interference, and occlusions of the fingers may cause a poor estimation of the hand pose.

An alternative solution consists in using fabric-integrated devices, *e.g.*, datagloves or suits based on Micro Electro-Mechanical Systems (MEMS) technology. In particular, a MARG (Magnetic, Angular Rate, and Gravity) board consists of a MEMS triaxial gyroscope, accelerometer, and magnetometer. The sensors board can be integrated with a wearable device and used to reconstruct the pose of the human body. In the next sections we present our developments in the field of werable human tracking, presenting and discussing technologies and real applications.

T. Lisini Baldi and D. Prattichizzo are with the Department of Information Engineering and Mathematics, University of Siena, 53100 Siena, Italy

Fig. 1: The glove is made by 11 MARG boards (blue) for sensing. It allows to estimate the joints values and rotation of the human hand with respect to a global reference frame. The last phalanx of each finger is left uncovered to not affect the user's tactile perception.

II. Interface for hand tracking

In this Section, we introduce the wearable sensing/actuation system GESTO (Glove for Enhanced Sensing and TOuching) [1], Fig. 1. It is based on inertial and magnetic sensors for hand tracking, coupled with cutaneous devices for the force feedback rendering. Unlike vision-based hand tracking systems, the sensing glove does not suffer from occlusion problems and lighting conditions. An optimization algorithm, based on the one presented in [2], is used to estimate the orientation of each phalanx with respect to the previous one. For what concerns the actuation part, we properly designed the cutaneous devices in order to reduce possible interference with the magnetic sensors and performed an experimental validation on ten healthy subjects. To measure the estimation accuracy of GESTO, we compared the results with a high precision optical tracker. A comparison between using the glove with and without the haptic devices shows that the presence of them does not induce a statistically significant increase in the estimation error. Experimental results revealed the effectiveness of the proposed approach. The accuracy of our system, 3.32

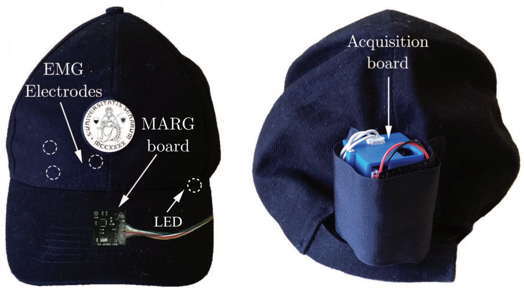

Fig. 2: The wearable control interface is made by a MARG board for tilt estimation, three EMG electrodes, and an acquisition board, based on a ATMega328 microcontroller. The system is capable of collecting the values from the MARG board and from the electrodes and send them wireless to the robot controller. A LED is used for provide the user with visual feedback.

degrees mean estimation error in the worst case, is comparable with the human ability of discriminating finger joint angle.

III. Interface for fingertip force estimation

In the previous Section we addressed the problem of reconstructing the hand pose in a wearable way, the following step in the journey towards the human body tracking deals with the problem of forces estimation. Here, we present a novel method to estimate the fingertip contact forces in grasping deformable objects with known shape and stiffness matrix [3]. The proposed approach exploits the same hardware described previously, *i.e.*, a sensing glove instrumented with inertial and magnetic sensors. Data obtained from the accelerometers and gyroscopes, placed on all the phalanges, are used to determine the hand posture and the event when the fingers establish contacts with the object. In addition, the sensing glove is used to estimate the deformation of the object at each contact with the fingerpulps. The force exerted by each fingertip is computed multiplying the stiffness matrix of the object and the vector of object local deformation in the contact point. Extensive simulations were performed in order to evaluate the robustness of the proposed method to noisy measurements and uncertainties in human hand model. Experimental validations with a virtual object were performed. A high precision grounded haptic device was used to simulate a virtual object and accurately measure the forces exerted by the users during the interaction.

IV. Interface for controlling a robotic arm

Many common activities of daily living like open a door or fill a glass of water, which most of us take for granted, could be an insuperable problem for people who have limited mobility or physical impairments. For years the unique alternative to overcome this limitation was asking for human help. Nowadays, thanks to recent studies and technology developments, having assistive devices to compensate the loss of mobility is becoming a real opportunity. Off-the-shelf assistive robotic manipulators have the capability to improve the life of people with motor impairments. Robotic lightweight arms represent one of the most spread solutions, in particular some of them are designed specifically to be mounted on wheelchairs to assist users in performing manipulation tasks. On the other hand, usually their control interface relies on joystick and buttons, making the use very challenging for people with limited motor abilities. In this Section, we introduce a novel wearable control interface for users with limb mobility impairments. We make use of muscles residual motion capabilities, captured through a Body-Machine Interface (BMI) based on a combination of head tilt estimation and electromyography signals. We exploited for this purpose a single module of GESTO system to estimate the head orientation. The proposed BMI (Fig. 2) is completely wearable, wireless and does not require frequent long calibrations [4]. Preliminary experiments showed the effectiveness of the proposed system for subjects with motor impairments, allowing them to easily control a robotic arm for activities of daily living.

V. Interface for finger tapping

This Section presents a further wearable tracking interface developed as a branch of the GESTO project. Hand in Air Tapping (HAT) is an innovative controller which allows interactions through fingers tapping. It consists in a Bluetooth Low Energy rings system enabling wireless communication with any compatible device [5]. Each ring is hardware-wise independent from the others. This allows full modularity, *i.e.*, the number of employed devices can be chosen to meet each application requirements. The proposed system was evaluated in two user studies, both on text input: (i) users learning curve in terms of writing speed; (ii) rate of text entry comparison between the proposed interface and that of numpad style keyboards. We associated each keystroke to a set of letters/symbols and compared two approaches: one based on T9 technique and the other on multi-tap input method. Results show comparable performance between HAT and numpad style keyboards. HAT keeps the hands free, not affecting hand movements and human interactions with the surroundings. Moreover, as a general input technology, it might have several potential applications in the field of computer-humaninterfaces.

References

[1] T. L. Baldi, S. Scheggi, L. Meli, M. Mohammadi, and D. Prattichizzo, "Gesto: A glove for enhanced sensing and touching based on inertial and magnetic sensors for hand tracking and cutaneous feedback," *IEEE Transactions on Human-Machine Systems*, vol. 47, no. 6, pp. 1066–1076, 2017.

[2] D. Comotti, "Orientation estimation based on gauss-newton method and implementation of a quaternion complementary filter," University of Bergamo, Tech. Rep. 2, 2011.

[3] M. Mohammadi, T. Lisini Baldi, S. Scheggi, and D. Prattichizzo, "Fingertip force estimation via inertial and magnetic sensors in deformable object manipulation," in *Proc. IEEE Haptics Symposium*. IEEE, 2016, pp. 284–289.

[4] T. Lisini Baldi, G. Spagnoletti, M. Dragusanu, and D. Prattichizzo, "Design of a wearable interface for lightweight robotic arm for people with mobility impairments," in *Proc. IEEE Int. Conf. on Rehabilitation Robotics*. IEEE, 2017, pp. 1567–1573.

[5] L. Meli, D. Barcelli, T. Lisini Baldi, and D. Prattichizzo, "Hand in air tapping: A wearable input technology to type wireless," in *Proc. IEEE Int. Conf. on Rehabilitation Robotics*. IEEE, 2017, pp. 936–941.