Wearable-based Human-Computer Interaction with LimbMotion

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ABSTRACT

LimbMotion is a limb tracking system which enables accurate and real-time tracking with one wearable device on the wrist/ankle of a user. By integrating inertial sensing and acoustic sensing, LimbMotion significantly reduces the search space of a moving limb, and provides accurate limb tracking for further human computer interaction (HCI). Objectives of this demo are to show how LimbMotion works and two HCI applications supported by LimbMotion.

KEYWORDS

Limb tracking, wearables, human-computer interaction

ACM Reference Format:
Han Zhou,Yi Gao, Xinyi Song, Wenxin Liu, Wei Dong and Yuefang Jiang. 2018. Wearable-based Human-Computer Interaction with LimbMotion. In *Proceedings of ACM Conference (Conference'17).* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

Human-Computer Interaction (HCI) is becoming increasingly popular in our daily lives [2]. Some HCI applications require an accurate and real-time limb tracking to know the user's posture, e.g., video game [4] and assisted rehabilitation [3]. In the past decades, researchers and start-ups have studied the limb tracking problem using different technologies, e.g., computer vision-based solutions and wearable-based solutions. Vision-based solutions are not available in some public places since they usually require pre-deployed cameras [1]. ArmTrak [5] tracks the arm posture with one smartwatch on a wrist of a user. However, due to the inaccuracies of inertial sensors and the computation constraint of smartwatches, the real-time tracking accuracy of ArmTrak is only 13.3cm, which is not sufficient in many HCI applications.

Thus we propose LimbMotion, which utilizes a wearable to track the user's limb in a fast and accurate manner. Here we describe how a user would use LimbMotion. The user is expected to wear a wearable on the wrist/ankle and then perform the interacting gestures in front of an edge device (a smartphone or a smart TV). LimbMotion would track the limb (arm/leg) posture and send the posture data to specific applications for further analysis. One typical application is self-guided weight training.

Conference'17, July 2017, Washington, DC, USA

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM.
https://doi.org/10.1145/nnnnnnn.nnnnnnn

The biggest challenge in limb tracking is the large motion space of a limb. Such a large search space results in the low accuracy and high latency. LimbMotion leverages the inertial and the acoustic sensing and this combination of sensing techniques will significantly reduce the search space of the limb and improve the tracking performance. Experiments show that LimbMotion provides real-time tracking with a median error of 8.9cm.

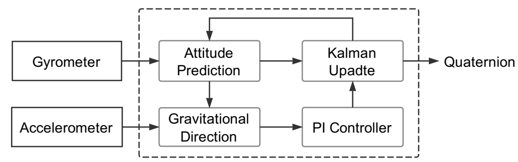

Figure 1: Architecture of the complementary Kalman filter.

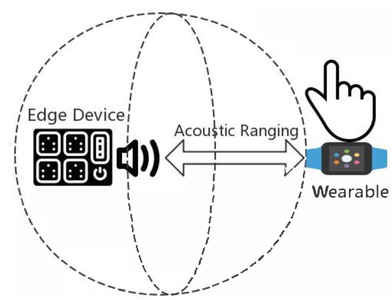

Figure 2: Architecture of acoustic ranging in LimbMotion.

2 SYSTEM OVERVIEW

LimbMotion collects inertial sensor readings (accelerometer and gyroscope) and acoustic ranging measurements to estimate the limb posture. Three key components are implemented to process the measurements which are an attitude estimator, an acoustic ranging component and a point-cloud-based positioning component.

2.1 Attitude Estimator

The attitude estimator estimates the device/limb attitude using the accelerometer and gyroscope readings. Existing attitude estimation techniques could work well in outdoor environments because of the stable magnetic fields. However, when used indoors, complementary-filter-based solutions will suffer from the noise of the compass or gravity-caused attitude drift. We combine a complementary filter and a Kalman filter to prevent such error and reduce the high computation overhead in an extended Kalman filter (EKF). This complementary Kalman filter (CKF) shows robust attitude outputs overtime in experiments. Figure 1 displays the design of the CKF.

2.2 Acoustic Ranging

LimbMotion adopts an acoustic ranging component which continuously measures the distance between the wearable device and the edge device. In the above we mentioned that this measurement could reduce the search space of the limb. Figure 2 shows the ranging result limits the limb position into an elbow surface which takes the edge device position as the center and the distance as the radius. Therefore, this limited space will improve the tracking performance in both accuracy and latency.

2.3 Point-Cloud-Based Positioning

ArmTrak [5] proposed point clouds that work as a database and store all possible limb postures by medical criterion. We can transform the problem of tracking the user's limb into finding the corresponding limb posture in the point clouds. However, too many postures in the point clouds request computation and storage resource. We reduce the point clouds size by using a simplified limb attitude, and then an octree structure is used to speed up the query process.

LimbMotion generates candidate postures based on the attitude estimation and point clouds, and then determine the final estimation using available measurements including attitude, acceleration and distance.

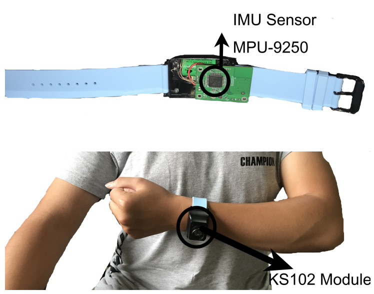

Figure 3: LimbMotion prototype.

3 IMPLEMENTATION AND DEMO DESCRIPTION

3.1 Implementation

We built a prototype smartwatch based on a development board STM32L151 to show how LimbMotion works in reality. Figure 3 shows this prototype. An IMU sensor MPU-9250 was attached to the board by soldering, which consists of a 3-axis accelerometer and a 3-axis gyroscope. The sampling frequency of the IMU is set at 100Hz. We attached a commercial ultrasonic distance measuring module KS102 to the board by soldering. This module has a specialized speaker which emits 40KHz ultrasonic signals and a specialized microphone which is able to capture these signals. Experiment results show that distance measuring error in LimbMotion is 1cm in average. The ranging frequency is set at 10Hz. A Raspberry Pi 3 model B is used as the edge device which has a has a 1G RAM and a 1.4GHz microprocessor. We developed the tracking algorithm with C++ language in Linux platform.

3.2 Demo Description

The demo is a basic implementation of LimbMotion which has been described above. The hardware of the demo consists of a LimbMotion prototype, a Raspberry Pi 3 model B and an LED monitor screen.

We developed two HCI applications for the demo. One is the assisted rehabilitation where we try to use LimbMotion to help the user maximize the rehabilitation benefits. We choose six rehabilitation movements for shoulder and elbow injuries and let the user perform the movements using LimbMotion. During the rehabilitation movement sensor data will be continuously sent from the prototype to the Raspberry Pi with RF communication. The arm posture estimations will be generated and displayed in the screen using a 3D human body model. And we make rules for each movement in advance. LimbMotion will keep analyzing the detected arm posture and hint the user for two occasions. If the detected arm posture is close the ordinary end point posture of the movement, the screen will display a "Movement Completed" message. If the detected arm posture is too far from the postures of the standard movement, the screen will display a "Wrong Movement" message.

The second application is to control a robot car. We developed a robot car which receives the control signals from the Raspberry Pi. The control signals contain moving towards four directions and stop. We let the user wears LimbMotion and using arm swing to make controls. LimbMotion analyzes the posture series and mapping them into control orders. When the robot car receives the control order from the Raspberry Pi, it will moves as expected.

4 CONCLUSION

In this demo we present a wearable-based posture tracking system called LimbMotion. Two novel methods are proposed to improve the tracking performance. The two-step filter outputs accurate attitude estimations, and the point-clouds-based positioning method combines inertial and acoustic sensing results to generate the posture estimation. Our demo demonstrates the performance of LimbMotion for two common HCI applications.

ACKNOWLEDGMENT

This work is supported by the National Science Foundation of China (No. 61872437 and No. 61772465), and Fundamental Research Funds for the Central Universities (No. 2017FZA5013 and No. 2018FZA5013).

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