Gesture Tracking Using on MEMS Inertial Sensor and Low Resolution Imaging Sensor

D. Sridhar Raja, R. Abinethri and B. Kalaiselvi

Abstract--- *In this paper, we present an algorithm for hand gesture tracking and recognition based on the integration of a custom-built microelectromechanical systems (MEMS)-based inertial sensor (or measurement unit) and a low resolution imaging (i.e., vision) sensor. We discuss the 2-D gesture recognition and tracking results here, but the algorithm can be extended to 3-D motion tracking and gesture recognition in the future. Essentially, this paper shows that inertial data sampled at 100 Hz and vision data at 5 frames/s could be fused by an extended Kalman filter, and used for accurate human hand gesture recognition and tracking. Since an inertial sensor is better at tracking rapid movements, while a vision sensor is more stable and accurate for tracking slow movements, a novel adaptive algorithm has been developed to adjust measurement noise covariance according to the measured accelerations and the angular rotation rates. The experimental results verify that the proposed method is capable of reducing the velocity error and position drift in an MEMS-based inertial sensor when aided by the vision sensor. Compensating for the time delay due to the visual data processing cycles, a moving average filter is applied to remove the high frequency noise and propagate the inertial signals. The reconstructed trajectories of the first 10 Arabic numerals are further recognized using dynamic time warping with a direct cosine transform for feature extraction, resulting in an accuracy of 92.3% and individual numeral recognition within 100 ms.*

Keywords---Imaging Sensor, Inertial Sensor, Gesture Tracking.

I. INTRODUCTION

HUMAN gestures are expressive, meaningful body motions involving physical movements of the fingers, hands, arms, head or body with the intent to convey meaning- ful information or to communicate with the environment [**1].** With the rapid development of computer technology, human- computer interaction has become an ubiquitous activity in oudaily life [2]. More attention has been focused on translating these human gestures into computer-understandable language in the past few years. Many gesture tracking and recognition technologies have been proposed. In general, these current gesture tracking technologies derive pose estimates from electrical measurements received from mechanical, magnetic, acoustic, inertial, optical, radio or microwave sensors [3]–[5]. Each sensor has its advantages and limitations. For example, mechanical sensors provide accurate pose estimates and have a low latency, but their mobility is low and they usually occupy a large volume of space.

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II. VISION AND INERTIAL TRACKING

For gesture recognition, high recognition rate can be obtained by independently using inertial sensors [**5]**–[**26]** or vision sensors [**27]**, especially when real-time recognition is not required. But for real-time gesture tracking, inertial sensors suffer from the zero-drift problem while vision sensors have poor performance for resolving fast motions due to motion blur and occlusions. Hence, neither of them is perfect for gesture tracking alone. Hybrid gesture tracking base on vision and inertial sensor fusion offers not only fast motion tracking and good stability, but also robust performance over occlusions [**28].**

Gesture tracking has a wide range of real- world applications, such as augmented reality (AR) [**29]**, surgical navigation [**30]**, ego-motion estimation for robot or machine control in industry, and in helmet-tracking systems. Ego-motion estimation using a monocular camera, sampling at approximately **25** Hz, and an inertial sensor, sampling at **100** Hz, has been addressed in the literature [**31]**, [**32].**

As reported in those work, an artificial planar object with seven known features was chosen for camera pose estimation. For gesture recognition, high recognition rate can be obtained by independently using inertial sensors [5]–[26] or vision sensors [27], especially when real-time recognition is not required. But for real-time gesture tracking, inertial sensors suffer from the zero-drift problem while vision sensors have poor performance for resolving fast motions due to motion blur and occlusions.

Hence, neither of them is perfect for gesture tracking alone. Hybrid gesture tracking base on vision and inertial sensor fusion offers not only fast motion tracking and good stability, but also robust performance over occlusions [28].

Gesture tracking has a wide range of real- world applications, such as auThe tracked 2D features from at least two different images were used to obtain the 3D position of the feature by linear triangulation. Measurements of inertial system were fused with measurements from the vision system by using a multi- rate Kalman filter without synchronization.

With predefined process noise and measurement noise, the system demon- strated the ability to estimate the ego-motion of a sensor rig by fusing vision and inertial data. Furthermore, a hybrid EKF estimator that integrates a sliding window EKF and EKF-based SLAM, and an adaptive image-processing module that adjusts for the number of detected images were utilized for visual-aided inertial navigation as reported in [33]. These reported experimental results indicate that the proposed estimation framework in the next section is capable of real-time processing of image and inertial data on a typical microprocessor found in current mobile phones, in real-time. In [34], two web cameras, three gyroscopes and three accelerometers were used for the tracking and control of a quadrotor helicopter. Four active markers were precisely designed to improve visibility and robustness towards disturbances in their image-based pose estimation. Moreover, position and heading controllers for the quadrotor helicopter were implemented to show the system's capabilities, and the performance of the controllers was further improved by the use of onboard inertial sensors.

III. EXPERIMENTAL SETUP

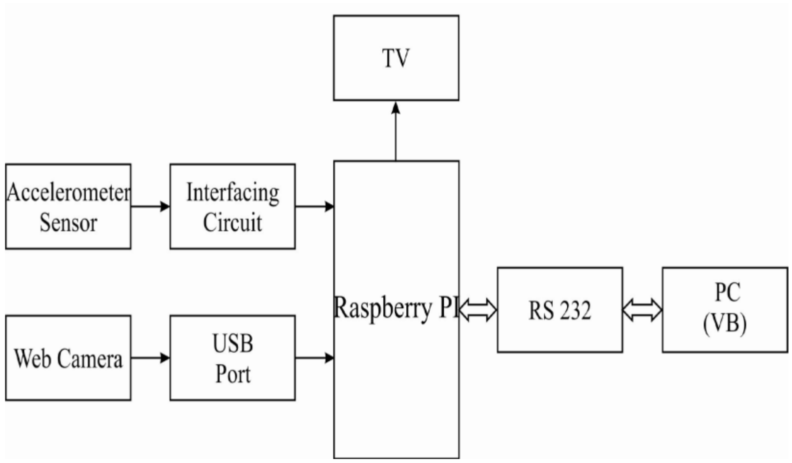

Fig 1. **Block Diagram**

The experimental setup, consists of one 4 × 3 checkerboard pattern, one CMOS image sensor (Logitech QuickCam Pro 9000), a three axis MEMS accelerometer (Freescale MMA7260 accelerometer) and three MEMS single-axis gyroscopes (LISY300AL gyroscope). The sampling rate of the μIMU is 100 Hz. The maximum frame rate of the imager is 30 fps but is reduced to 5 fps for this study.

The imager and the μIMU are fixed inside a box, so their relative position will not be changed during the experiments. A pen is attached to the outside of the box so that the trajectory of the box will be recorded during the movement. Then the trajectory of the camera will be recovered from the recorded trajectory of the pen. There are two main approaches for visual trajectory track- ing: one is recognition-based, and the other is motion-based.

We choose recognition-based visual tracking because the accumulated error is bounded in this situation. Even though motion-based approaches, which detect motion through optical flow tracking and motion-energy estimation are easier to use, they cannot be used if the camera motion is more than a few pixels [39]. Moreover, they are subject to noise, leading to imprecise values and the pixel motion is often detected but not quantified [39]. The detailed dimensions of the μIMU and camera (μIC) system, the grid size of the checkerboard, and the dimensions of the whiteboard are recorded in Tabl**.**

IV. ACCELEROMETER SENSOR WITH I2C PROTOCOL

A microcontroller (RASPBERRY PI MODEL B) is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications. I²C (Inter-Integrated Circuit generically referred to as "two-wire interface") is a multi-master serial and Multi-Slave Protocol used as communication Protocol in this project.

Accelerometer Sensor is some special types of transducers which convert one form of physical (acceleration) quantity to electrical quantity. Accelerometer Sensor continuous senses the detail of 2-D gesture recognition and tracking position and sends the related data to Micro-Con.

V. RASPBERRY PI

The Raspberry Pi is a single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools. Although Raspberry Pi is as small as the size of a credit card, it works as if a normal computer at a relatively low price. It is possible to work as a low-cost server to handle light internal or web traffic. Grouping a set of Raspberry Pi to work as a server is more cost-effective than a normal server. If all light traffic servers are changed into Raspberry Pi, it can certainly minimize an enterprise's budget.

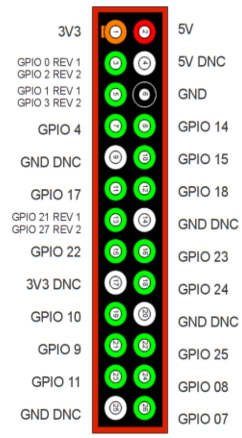

Fig 2. **Pin Diagram**

Features

- Boot up and configure your Raspberry Pi
- Navigate files, folders, and menus
- Create Python programs using the IDLE editor
- Work with strings, lists, and functions
- Use and write your own libraries, modules, and classes
- Add Web features to your programs
- Develop interactive games with Pygame
- Interface with devices through the GPIO port
- Build a Raspberry Pi Robot and LED Clock
- Build professional-quality GUIs using Tkinter

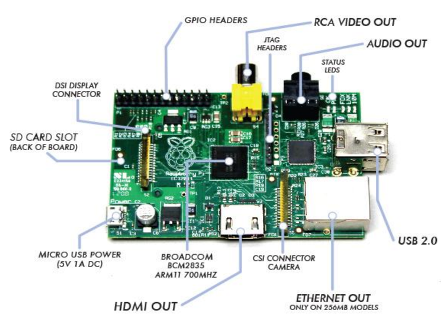

Fig 3. **Raspberry processer**

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VI. ACCELEROMETERS

An accelerometer is an electromechanical device that will measure acceleration forces. These forces may be static, like the constant force of gravity pulling at your feet, or they could be dynamic - caused by moving or vibrating the accelerometer.

Triaxial:

Triaxial accelerometers measure the vibration in three axes X, Y and Z. They have three crystals positioned so that each one reacts to vibration in a different axis. The output has three signals, each representing the vibration for one of the three axes. The ACC301 has lightweight titanium construction and 10 mV/g output with a dynamic range of +/-500 g's over a range of 3 to 10 kHz.

Fig 4. **RS 232**

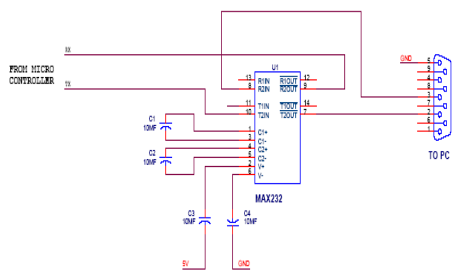

Fig 5. **RS232 COMMUNICATION**

RS232:

In telecommunications, **RS-232** is a standard for serial binary data interconnection between a *DTE* (Data terminal equipment) and a *DCE* (Data Circuit-terminating Equipment). It is commonly used in computer serial ports.

Experimental Results For Trajectory Reconstruction

For the experiments, we wrote ten Arabic numerals and a cursive word with five English letters on a whiteboard using the μIC system. The corresponding experimental results are shown in Fig. 9 and Fig. 10. From Fig. 9, we notice that the reconstructed trajectories by using only inertial data are very different from the true trajectories. Especially for the static state after the movement is finished, the trajectories are still increasing with time. It is difficult to even recognize the trajectories from visual examination of the graphed data.

Inertial Sensor And Vision Sensor Calibration

The drift rate depends largely on the minimization of the μIMU residual errors. If these errors are minimized, then the drift problem will be greatly reduced. Among all the sources of error, the constant bias and calibration error (including the scale factor and alignment) are the dominant error components. The constant bias for an accelerometer is the offset of its output signal from the true value. It is often estimated by measuring the long term average of the accelerometer's output when it is not undergoing any acceleration [40]. A six-position static and rate test calibration method is utilized to estimate the constant bias and scale factor [41]. This requires that the inertial system be mounted on a leveled surface with each sensitive axis of every sensor be pointed up and down in an alternating manner. However, in practical situations, perfect alignment is usually not possible without the aid of some reference devices**.**

Experimental Results With Different Sampling Frequencies

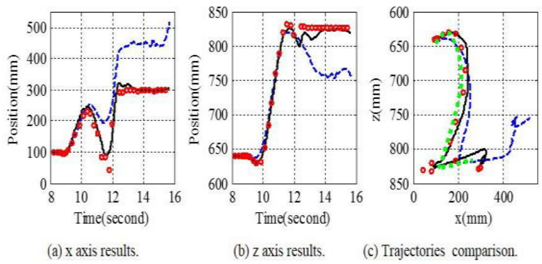

Fig 6. **2D Human gesture tracking**

The current sampling frequency of the inertial sensor is 100 Hz. The actual frequency of our hand motion is around 10 Hz, so the sampling frequency is much higher than needed. Moreover, more data output and processing means more power consumption.

Therefore, the tracking results at a 50 Hz sampling frequency have also been examined. The experimental results when the sampling frequency of the inertial sensor is 100 Hz and 50 Hz are shown in Fig. 7. From Fig. 7, we find that the system is capable of tracking the dynamic motion from about the 10th second to the 12^{th} second, and is able to follow the visual measurements when the sensor stops moving. The 50 Hz sampling frequency reaches a steady state faster than the 100 Hz data. For the overall performance, the reconstructed trajectory at 50 Hz seems to be closer to the reference than the 100 Hz data.

For the results using only the vision sensor, due to the unstable performance of the imager, the estimated positions at some positions deviate too much from the real values, for example, for the number 2 and the number 3. Fortunately, by fusing the inertial and vision data, we can compensate for the individual disadvantages of the inertial sensor and the visual sensor. Even if the reconstructed trajectories are not exactly coincident with the ground truth, we can still easily recognize which numbers or characters correspond to which trajectories, from the black solid lines. The results are greatly improved compared to the results using only the inertial data.

VII. CONCLUSION

An algorithm has been developed to track the real-time position and orientation of a μIC system by fusing data from a MEMS-based inertial sensor and a vision sensor. The 100 Hz inertial data and the 5 fps vision data are fused by using an EKF. The measurement "*reliability*" is calculated based on the measured accelerations using a linear update model. Since tracking a motion that contains both translation and rotation is much more difficult than pure translation or pure rotation, we demonstrate that the algorithm is capable of reconstructing andwritten Arabic numerals and cursive words in real-time. The experimental results also prove that the reconstructed ten Arabic numerals can be recognized with an accuracy of 92.3% within 100 ms by using the DTW intuitive gesture recognition method.

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