Fuzzy Logic Based Sensor Fusion for Accurate Tracking

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Abstract. Accuracy and tracking update rates play a vital role in determining the quality of Augmented Reality(AR) and Virtual Reality(VR) applications. Applications like soldier training, gaming, simulations & virtual conferencing need a high accuracy tracking with update frequency above 20Hz for an immersible experience of reality. Current research techniques combine more than one sensor like camera, infrared, magnetometers and Inertial Measurement Units (IMU) to achieve this goal. In this paper, we develop and validate a novel algorithm for accurate positioning and tracking using inertial and vision-based sensing techniques. The inertial sensing utilizes accelerometers and gyroscopes to measure rates and accelerations in the body fixed frame and computes orientations and positions via integration. The vision-based sensing uses camera and image processing techniques to compute the position and orientation. The sensor fusion algorithm proposed in this work uses the complementary characteristics of these two independent systems to compute an accurate tracking solution and minimizes the error due to sensor noise, drift and different update rates of camera and IMU. The algorithm is computationally efficient, implemented on a low cost hardware and is capable of an update rate up to 100 Hz. The position and orientation accuracy of the sensor fusion is within $6mm$ & $1.5\,^{\circ}$. By using the fuzzy rule sets and adaptive filtering of data, we reduce the computational requirement less than the conventional methods (such as Kalman filtering). We have compared the accuracy of this sensor fusion algorithm with a commercial infrared tracking system. It can be noted that outcome accuracy of this COTS IMU and camera sensor fusion approach is as good as the commercial tracking system at a fraction of the cost.

1 Introduction

The goal of the tracking is to have a continuous estimate of 3D pose and position of the object/user of interest. The user AR/VR experience of the system depends on the accurate positioning of the objects in 3D. For tracking, we can use wide range of sensors. For example, vision-based camera/Infrared sensors, laser, inertial sensors, ultra wide band technology, RFID, radio frequency tagging, etc. Each sensor system has its own limitations which constrains it to a specific application. For instance, vision-based sensors have very good accuracy but have very low update frequency. Thus, they cannot be used for a highly dynamic tracking application or outdoors due to lighting conditions but serve

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very well in controlled environments. [1] researched this and listed the pros, constraints and best possible accuracy of several systems.

In general, most augment reality applications would demand high update frequency and accuracy with minimal constraints. Nevertheless, this cannot be achieved by single sensor, but by using a combination of sensors that are complementary in nature. For example, camera and Inertial Measurement Unit (IMU) form a complementary sensor pair. A low cost vision sensor has a low frequency of update due to computation demands and line of sight constraint. Vision-based sensors also suffer from artifacts introduced in the images due to lighting conditions and dynamic motion of the camera. On the other hand, a low cost Micro-Electro Mechanical System (MEMS) IMU operates at a very high frequency of update ($100 - 1KHz$) and has very high precision of measurement ($0.2mm$ & $0.36\,°$). All the same, accuracy of the system decays with time due to drift and noise. This error is common with all zero referencing systems.

This paper addresses the sensor fusion of an IMU and camera to achieve a sub-centimeter position and sub-degree orientation accuracy with an update rate upto 100Hz. Using the inherent complementary nature and error characteristics of the sensors we try to minimize errors. This sensor fusion methodology is validated via experiments.

2 Previous Work

2.1 Tracking Markers

Tracking systems can use retro-reflective markers, natural features or pre-defined markers for tracking. To meet our design goal of a rapid rate of detection and low cost, we cannot use the Infrared-based systems or natural markers.Owen et al. [2] researched the question what the best fiducial marker would be. They listed the requirements of a good fiducial marker being a large recognizable marker set having simple and fast detection, pose estimation and identification. The use of fiducial based markers attained wide spread popularity with the introduction of an open source library called ARToolkit. ARToolkit was developed by Hirokazu Kato and Mark Billinghurst, as part of an augmented reality video conference system [3]. The software is still actively updated by virtual reality researchers and hobbyists.

ARToolkitplus [4] is an extension on the ARToolkit software library developed as part of the Handheld Augmented Reality Project [5]. It added more accurate tracking and environment resilient algorithms to the original ARToolkit software library. The new version includes adjustment the illumination threshold which is used to filter the marker. This improves the detection rate in indoor environments which can handle more specular and bloom effects due to artificial lighting.

2.2 Sensor Fusion Techniques

Kalman filtering is a widely used method for eliminating noisy measurements from sensor data during sensor fusion. Kalman filtering can be considered as a