3D PAINTING USING INERTIAL SYSTEM AND MONOCULAR VISION FOR LOCALIZATION OF HANDHELD CONTROLLER IN VIRTUAL REALITY

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Abstract - The motivation for this research comes from Google Tilt Brush which is expensive for general people. That is why a concept which emphasize on the betterment of software than hardware is considered. We have worked on some problems like removing noise from sensor data, drift due to double integration and cost. People who have smart phone will be able to paint in virtual reality using cardboard and daydream of google without buying Oculus Rift and HTC Vive which are too costly for mass people. External sensors like satellite positioning sensor, barometer, laser, ultra- wideband system, ultrasonic positioning system are not being used. In this research, along with extended Kalman filter, Butterworth filter has been used to estimate position from 6-DOF (Degrees of Freedom) MEMS (Microelectromechanical Systems) sensor data. A monocular visual method, SLAM (Simultaneous Localization and Mapping), measures the distance or localization using smartphone camera in the controller application to eliminate drift. The painting application utilizes Google VR (Virtual Reality) Software Development Kit (SDK) with Unity3D engine. Experimental results reveal that proposed research can paint using virtual reality headset along with controller application using mobiles instead of external controller device i.e. Oculus Rift and HTC Vive with satisfactory precision rate.

IndexTerms - 3D painting, extended Kalman filter, monocular SLAM, sensor, virtual reality.

I. INTRODUCTION
With the advent of technology portable, compact, easily accessible, and cost effective means of services are of great use in recent times. A lot of work have been carried out in the field of computer algorithm and application development which is based on mobile and portable workstations like cellphone, smartphone, tablet, Personal Digital Assistant (PDA) etc. These devices are especially opted since they feature few unique characteristics i.e. portability, cost effectiveness, multiple platform and OS compatibility, easy internet connectivity for firmware update, user friendly UI etc. Moreover, with the advances in semiconductor chip and integrated circuits technology, these devices now boast highly powerful processors and a wide range of sensors. A developer hence can take advantage of this powerful yet portable computing ability of these devices to design innovative applications. In this regard, two applications have been developed in this present work which take advantage of the accelerometer, gyroscope, magnetometer sensors of the smartphone. One application is the controller application, and the other is the painting application. The controller application works by sending the real-world coordinates of the smartphone to the painting application through Wi-Fi using User Datagram Protocol (UDP).

Then the painting application will paint in open space which is visible via virtual reality headset. The noise filtering here has been done by signal processing. The novelty of the work lies in the fact that it is a prospective cost effective approach in comparison to the already established ones, which uses external base station.

II. LITERATURE REVIEW
Various types of sensors have been used in recent times to accomplish various task. Miniature inertial sensors based on biomechanical models and sensor fusion algorithm have been developed to accurately track human motion [1]. This cost-effective system does not require external camera, emitter, marker and can accurately track all types of motion i.e. running, jumping, crawling. However, it requires specific hardware and software systems to process data, and it is unable to track any motion that does not comply with the laws of physics. An effective head-tracking system based on miniature 6-DOF using head-mounted displays (HMDs) have been reported which tracks changes in orientation and position by integrating the outputs of its gyroscope and accelerometer sensors [2]. The system has several advantages such as low cost, low jitter, high update rates and low latency. However, the tracking area is reasonably small in this system. Sensor fusion is another effective approach where data from several sensors can be combined in a time triggered network that can correct deficiencies from individual sensors to calculate accurate position and orientation information [3], [4]. This sensor fusion can be used in android devices for indoor positioning quite satisfactorily [5]. Sensor fusion technology can also be implemented for accurately estimating the position of an automotive vehicle using Global Positioning System (GPS) [6]. Sensor such as accelerometer has
been widely used for various purposes. It is reported that mobile robot position can be accurately recorded using accelerometer [7]. Although it can reduce error caused by random noise as well as having low cost and small size, random bias drift problems can occur here. Tri-axial accelerometer has also been used to determine position and orientation precisely [8]. Using tri-axial sensor is cost effective and improves tangential sensitivity. However, this is bulkier in size. A combination of accelerometer, gyroscope, magnetometer can be used as well for 3D knee kinematics, having low error percentage results [9]. A combination of two sensors has also been used to develop the error propagation equations [10]. Sensors can be incorporated in a wrist-worn system as well that can recover the 3D pose of the user’s hand [11]. However, this approach is not cost effective yet.

To accurately navigate and accomplish orientation directions various approaches have been implemented. Integrated electronic devices containing accelerometers, gyroscopes, magnetometers are incorporated in Inertial Measurement Units(IMU) [12]. However, this system is not free from drift error, a difference between the actual position and system detected position. To mitigate drift error, MEMS based low cost system has been designed for pedestrian navigation using only accelerometer and gyroscope sensors without incorporating a magnetometer [13]. Inertial measurement units have been used for gait analysis as well [14]. A miniature inertial/magnetometer package wirelessly coupled to PDA is reported to track pedestrian position effectively with or without GPS availability [15]. Though the system does not require calibration and is stride length independent, it can be affected to render erroneous data from surrounding metal infrastructures or buildings. Foot mounted inertial sensors have also been used in indoor environment for pedestrian localization [16]. The system takes advantage of the low cost and small size of inertial sensors but it requires dedicated experiment space and walking range. Moreover, high accuracy position estimation can be obtained using a common position shift approach [17].

A widely-used approach of accurate tracking is Kalman filtering [18], [19]. This approach has several advantages. It requires smaller memory allocation which makes it well suited for real time problems and embedded systems. It is a convenient form for online real time processing. However, use of Kalman filter can sometimes make the final error level worse. 1D Kalman filter, a statistical technique, can adequately describe the random structure of experimental data through a connection with GPS and Wiener filter [20]. Kalman filter can be implemented with an accelerometer sensor that gives excellent noise reduction, increases dynamic range, and reduces displacement of mass under closed loop structure [21]. Kalman filter fusion algorithm in IMU/UWB can be used to track human operators effectively [22]. Though this system can have high data rates, it requires more computational resources. Kalman filter approach has also been used for global pose estimation using multi sensor fusion [23]. This technique increases accuracy and robustness of pose estimates by correction of distortion of 3-axis magnetic compass. Moreover, inertial head tracker sensor fusion has been implemented with Kalman filtering as well [24].

A nonlinear version of Kalman filter, extended Kalman filter, is another approach which linearizes about an estimate of current mean and covariance [25]. Extended Kalman filtering usually gives less accurate measure of covariance. Extended Kalman filtering has been incorporated in designing indoor positioning system based on IMU/magnetometer [26]. This filter also renders better and faster result when used in accelerometer sensor.

III. METHODOLOGY

Android sensor manager API provides the raw sensor data for using in developing the software of the controller device. The virtual rotation vector sensor is used to get rotation matrix of the controller phone’s rotation around an arbitrary axis. Multiplying invert rotation matrix with linear acceleration vector which was obtained from Android sensor manager gives us phone’s linear acceleration vector in earth’s co-ordinate system. Acceleration vector based on only raw sensor data is not smooth. To get a smooth 3-axial acceleration with a constant bias we must reduce noise. For our implementation, we used Extended Kalman Filter (EKF) to do so. A nonlinear version of Kalman Filter is Extended Kalman Filter(EKF) whose goal is to find the most optimum averaging factor for each consequent state by using the data from past states. In our implementation, we needed to find the average of 3-axial acceleration. After filtering noisy data using extended Kalman filter we get smooth 3-axial acceleration with a constant bias. Getting a long-term average while the controller phone is in stationary position we can estimate the bias and subtract it from respective axes of acceleration. Now, the obtained linear acceleration is integrated to get velocity and integrated again over time to obtain displacement. We follow dead reckoning approach for accumulating positional information. Because of accelerometer bias prolonged use of the application introduces sensor’s temperature dependent errors, which contributes to drift in position over time.

Current existing sensor fusion systems use various types of external sensor, such as GPS, ultrasonic beacons to compensate for the drift. In our approach, we propose to implement Monocular SLAM [27], [28], with controller phone’s camera to obtain visual odometry of the handheld device in the real-world
environment. Monocular SLAM is a concept to build and navigate a map using images from a single camera while tracking the relative position and orientation [29], [30]. Here, we propose to use Lucas-Kanade sparse optical flow [31] to track Good Features between frames and calculate the essential matrix to obtain rotation and translation information, by which the dependency on any external positioning system is eliminated. The controller application provides a dedicated button which works like mouse button or brush pressure. Our system connects the VR headset and controller phone in a local Wi-Fi network, and then UDP socket protocol is used to transmit the position co-ordinate vector along with a timestamp immediately after the sensor data is collected. The datagram is collected at a constant frequency to paint in the air which can be experienced in virtual reality. Our method depends on Android SDK for building controller application, OpenCV for image processing tasks, Unity3D for developing virtual reality environment as well as NumPy to store matrices and SciPy for signal processing.

IV. RESULTS AND DISCUSSION

Our experimental data shows white noise propagation in raw linear acceleration over constant time domain while the controller device is lying in flat position.

Relatively smooth data is found using Extended Kalman filter. During construction of Extended Kalman filter we set three values. These values are expectation value (0.001), process noise (1e-5) and measurement noise (0.019). Data from linear acceleration of X, Y and Z- axis is sent to extended Kalman filter to convert noise data into smooth data. There is still some bias found during the time of sending accelerometer data after filtering. Computing filtered or smooth data by double integration, we get position of mobile device. But it creates an issue of rise in drift. Besides, bias increases the amount of drift error. We accumulate long term average of bias for bias estimation. Then we calculate bias estimation before double integration to reduce drift.

Kalman filter for noise reduction

Inertial measurement sensors are MEMS based. That is why we found flicker noise or 1/f noise. Linear acceleration is passed through order 5 Butterworth high pass filter to avoid the contribution on velocity during the negligible movement of device. At that time, Butterworth filter attenuates the small values of linear acceleration.

Drift of position in flat platform

Accelerometer movement introduces flicker noise

Simulation of drawing in the air

We propose to use monocular visual inertial system to be integrated with the accelerometer to reduce the flicker noise in the linear acceleration data. From monocular images, we propose to create depth map using PTAM or ORB-SLAM [28], [32]. With Structure-From-Motion method we can estimate camera pose estimation and trajectory and get stable...
CONCLUSION AND FUTURE WORK

This paper illustrates comprehensive review to paint in virtual reality instead of using extra controller devices. Extensive experimentation is performed by using IMU (Inertial Measurement Unit) of mobile device. State estimation (velocity, position and pose) is done by using accelerometer, gyroscope and magnetometer sensors and extended Kalman filter. The significance of this approach is to be able to get room scale canvas and introduce immersive experience to users. Up to this time, it is possible to draw in open air.

Further analysis on estimating accurate drift and error will be performed. Monocular odometry will be further studied to compute the accurate relation between IMU provided position and Visual localization in real world co-ordinate system. Unity with Google Virtual Reality kits will be used to target and paint in virtual reality, which is under development.

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