Towards mixed reality system with quadrotor: Autonomous drone positioning in real and virtual

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***Abstract*— 3D Positioning in real and virtual spaces is needed for mixed reality robotic systems. In normal conditions achieving 3D positioning can be done by using traditional GPS systems. However, in confined spaces these systems constraints such as reception dropout, localization error and noise, make them impractical or impossible to implement. We introduce a cheap, high precision 3D positioning system leveraging the HTC Vive TM VR lighthouse that allows a drone to autonomously fly in real space as well as virtual space. We built and tested the new system to determine feasibility and accuracy.**

I. Introduction

Interactions between objects in physical and virtual spaces are a central piece in the virtual reality ecosystem. Having the ability to blend items from the real world into a virtual environment allows systems to perform complex and valuable tasks using VR tools and to provide an immersive and rich experience for users. To do so, virtual reality systems must rely on high accuracy 3D positioning, without the ability to consistently and accurately locate an object in the real world it becomes impossible to program any interaction between this object and a functionality in a virtual environment. This means, the mix of physical and virtual reality can only be achieved by having detailed information of the changes in location from every item existing in both ends.

Traditionally 3D positioning has been solved using a wide range of solutions, such as global satellite systems [1], sound waves [2], WIFI signal [3], and computer vision techniques [4]. These technologies allow systems with multiple devices to perform synchronized tasks and navigate complex geometries. However, when applied to a blend of physical and virtual reality, there are some constraints that made them impractical or, even sometimes, impossible to implement. For example: GPS will not perform consistently indoors and the standard error margin will prevent any fine interaction from working. Using WIFI signal and sound waves for positioning works well indoors but accuracy and external contamination made them impractical and ineffective. On the other hand, computational complexity, environment preparation and a slow refresh rate make using a computer vision system with landmarks extremely complex to implement in small robotic devices.

We propose the use of the HTC Vive™ Lighthouse [5] to obtain consistent and accurate 3D positioning in reduced spaces with low processing cost and at a fast refresh rate. The system relies on high precision infrared laser beams and infrared sensors to work, which prevents most of the external contamination problems and provides accuracy. We designed and built the necessary electronics to evaluate the concept and tested the final device on a flying drone holding position in both real and virtual spaces.

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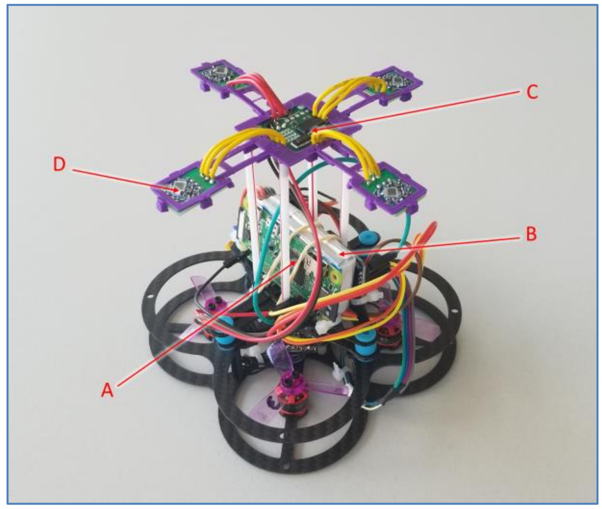

Fig. 1. Quadcopter drone with the Raspberry PI Zero W board (A), a 500mAh battery (B) and the high resolution 3D positioning device (C) showing the set of four Vive™ sensors (D).

II. The Vive™ System

The HTC Vive™ Lighthouse [5] contains two sets of infrared light emitting devices (Fig 2): An omnidirectional IR flash used to synchronize all the devices receiving positioning information; and a high precision IR laser working together with a high speed moving mirror to perform sweeps in two axes.

A high-level description of the interaction between the lighthouse and the devices is as follow: The Lighthouse emits a series of precisely-timed (and thus, recognizable) omnidirectional synchronization flashes, then it sweeps along the x axis using the laser bean, when it finishes it then emits another omnidirectional flash, and proceeds to sweep along the y axis. This process is repeated thirty times per second.

In the other end of the HTC Vive™ system, the device receiving the localization information waits until it detects a synchronization flash. As sensors perceive both signals (flash and laser) identically, the device rely on the time between signals to determine if it is, in fact, a synchronization flash or not. Once the device and the lighthouse are synchronized, the device expects to receive a series of signals in a specific order.

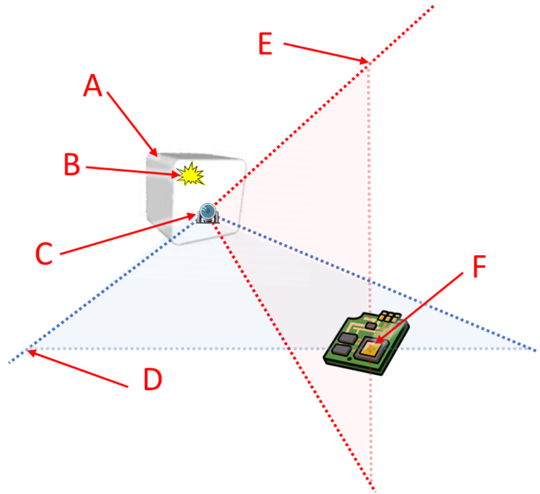

Fig 2: (A) Vive Lighthouse. (B) Omnidirectional IR Flash. (C) High speed mirror and laser beam. (D) Y axis value. (E) X axis value. (F) Vive sensor.

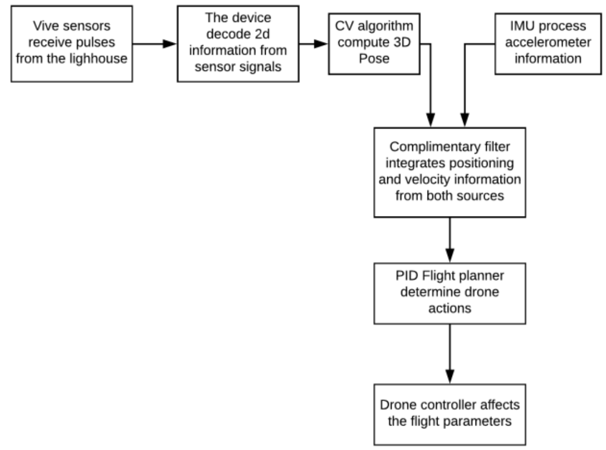

Fig. 3. Data gathering and processing flowchart.

The resulting 2D position of the sensor is estimated by computing the time difference between the flashes and the corresponding laser beam signals. Objects in the physical space need to gather 2D information from multiple sensors to avoid ambiguity and effectively determine their location in a 3D space [6].

III. THE DEVICE

To simplify and encapsulate the complexity of the interaction with the HTC Vive™ system, we designed a lightweight and cheap device with four coplanar HTC Vive™ sensors, that synchronizes with the lighthouse and computes the 2D position of each sensor.

The device uses a PIC32 microcontroller that gets interrupted when one of the sensors receives a signal from the lighthouse. Using an 8MHz crystal oscillator, the device measures the time between signals to differentiate sync flashes from positioning laser beam pulses. Once all signals from all four sensors are received and the 2D data decoded (time to x-y axis values), then the information is transmitted to the quadrotor flight controller using standard UART serial communication.

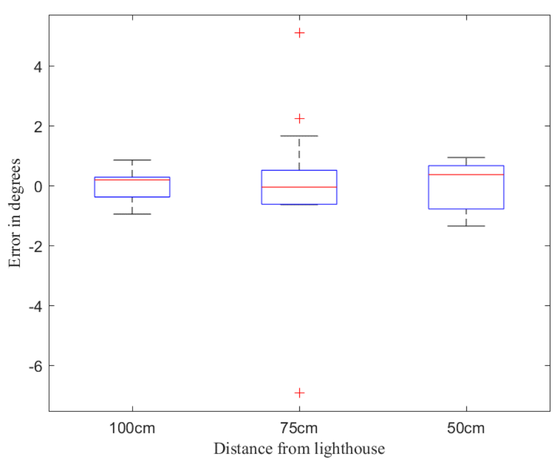

Fig. 4. Yaw error boxplot, by distance. Computed from 6000 measurements, 2000 in each distance, 50% facing forward (0 degrees) and 50% facing sideways (90 degrees).

IV. FROM 2D TO 3D

Estimating the 3D position of a known object from an image is a classical computer vision problem. To leverage existing algorithms [7] available, two things were necessary: an image and a 3D model of the device.

To artificially create an image, the 2D position from each sensor was used as a point in a plane. This provided a simple image with four points (in excess to the minimum three points needed by the algorithm to recover from an occasional sensor occlusion) to feed the estimation process. The final step was the creation of the 3D model of the device specifying the location of each one of the sensors and running the pose approximation algorithm [7].

The implementation took the form of a C program that reads UART to receive information from the device and process the pose. We tested this program successfully in a Raspberry PI Zero W to ensure it could be added to a flying device later and it was able to compute the device full pose thirty times a second consistently.

V. RESULTS

After the device and the program started running together we tested the accuracy of the pose estimation using only four degrees of freedom: X, Y, Z and yaw and computed the results.

To determine yaw accuracy, 2000 measurements were performed at different distances from the lighthouse (6000 measurements total), 1000 measurements with the device facing forward and 1000 with the device rotated 90 degrees. We were able to obtain the device yaw information within 2 degrees of error 99% of the time (fig 4).

After performing 1000 measurements at two different distances from the lighthouse we were able to obtain Z axis positioning within a 5cm error 98% of the time (fig 5). However, when obtaining information on the X and Y axis, the error and noise reduced significantly. On the same

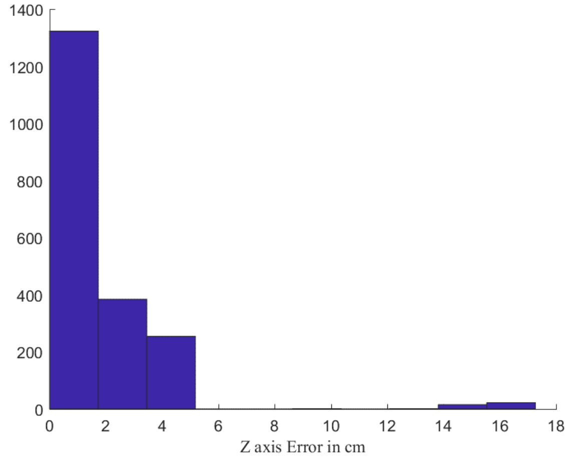

Fig. 5. Z axis error histogram in cm. Computed from 2000 measurements, 50% at 100cm and 50% at 75cm from the lighthouse.

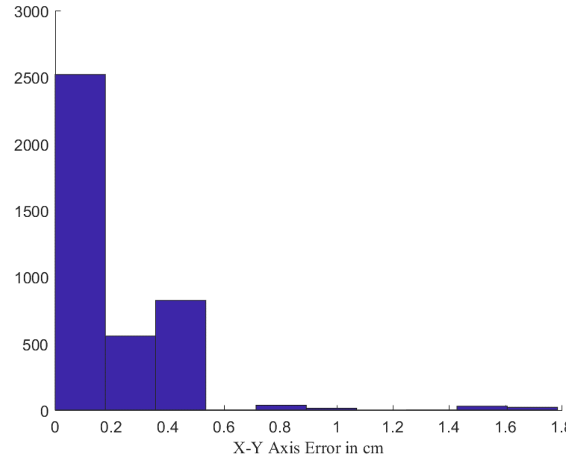

Fig. 6. X&Y axis error histogram in cm. Computed from 2000 measurements, 50% at 100cm and 50% at 75cm from the lighthouse.

measurements we obtained values within 1cm error 98.75% of the time (fig 6).

This difference in the order of magnitude of the positioning error in the X and Y axis (plane used to locate the sensors) with respect to the Z axis is due to the device’s planar structure; an easy way to understand it is to see the Z axis positioning as depth estimation with a single image.

VI. In Action

Once the preliminary results were satisfactory, the next step was to test the sensor on a flying device. To do so, we mounted a Vive™ lighthouse on the ceiling facing down and attached the sensor to a quadcopter (Fig 1). The goal was to perform a series of autonomous flights simultaneously computing the position of the device in a virtual space.

To autonomously control the drone effectively, sensor aggregation was added using higher refresh rate data coming from the quadcopter accelerometer (Fig 3). This allowed the drone to sense and evaluate speed information (by integrating accelerations) hundreds of times per second, in orders of magnitude faster than what our device can do. We used a complementary filter aggregating both sources, Vive™ device and IMU, to have current, accurate and reliable information.

After all positioning and velocity information was obtained, a PID[8] flight planner processes it and outputs a set of high-level instructions to affect the drone behavior in four degrees of freedom: roll, pitch, yaw and thrust. From then on, the drone controller takes over and implements the new flight parameters.

With this implementation the quadcopter successfully maintained a stationary position in a virtual box during an autonomously-controlled flight while reporting its 3D positioning.

VII. Conclusion

In this paper, we tested an approach to effectively perform 3D positioning in confined spaces at a high refresh rate, using a inexpensive device and a HTC Vive™ Lighthouse. We performed preliminary tests on flying devices to determine the feasibility and practicality and we showed initial results.

Designs and source code

Electronics design blueprints, printable 3D models and source code can be downloaded and shared freely from: https://github.com/germanespinosa/vive_device.

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