Vision Navigation System to Manoeuvre Unmanned Aerial Vehicle (UAV)

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***Abstract*— This paper describes the development and the implementation of an omnidirectional multiple stereo cameras vision system. The vision system is compact and light enough to operate on board a commercially available off the shelf miniature UAV (Unmanned Aerial Vehicle)-Quadrotor. The vision system contains several stereo cameras ruggedly fixed on-board the UAV-Quadrotor, it is oriented in such a way that it has a 360 degrees omnidirectional visual coverage. The paper demonstrates that by combining several stereo cameras, it can provide and combine depth information and optical flow data in real time to an on-board image processing computer. One can estimate the position and the orientation such as roll, pitch and yaw of the UAV in 3D (three dimensions) space accurately without the aid of GPS (Global Positing System), IMU (Initial Measurement Unit) or any other external navigation or orientation aid. This method can be described as "Simultaneous Localization and Exploration Oriented Visual Navigation". It is a development of a vision system capable of navigating autonomously an UAV-Quadrotor through random free spaces within an unknown complex environment and without any mapping, it simply performs by detecting and avoiding obstacles calculating the required "through flight path".**

Keywords*— UAV-Quadrotor, vision system, GPU, stereo camera, visual navigation, Homography planer surface.

I. Introduction

Airborne mobile robots localisation is the determination of the robot position and orientation in 3D space. Much research has been conducted in order to estimate accurately the robot position and orientation utilising different types of perception methods [1]. GPS and Laser detection and ranging sensor (LIDAR) [2] are among the most popular available positioning and mapping sensors.

Due to the latest advances in cameras sensors technology, cameras have become lighter and more power efficient, they operate at high image resolution and ultra-fast processing power. Hence, this results in increased research in the field of computer vision [1], specifically in visual perception. Many researchers utilise mono and stereo cameras systems for mobile robot localisation and navigation with acceptable result [3] [4]. The proposed vision system has 360 degrees of stereo vision coverage compared with [4][5][6]. It enables an aerial robot to navigate autonomously in a complex non pre-mapped 3D environment. The onboard vision system utilises a robust and light weight low power perception system containing five stereo camera modules, further simply referred as stereo cameras. Each stereo camera consists of one (RGB) Red, Green, Blue camera, one infrared (IR) camera and one IR laser illuminator depicted in Fig.1. Considering the optical flow measurements this approach is multispectral diverse from the other approaches utilising just one RGB stereo camera dedicated only for depth measurements [4] [5] [6]. To process the visual information obtained from the five stereo cameras, an on-board Nvidia Jetson TX2-256 core GPU (Graphic Processor Unit) Pascal processor board is used. The power requirement of the entire vision system when measured on average does not exceed 50 watts which makes it very suitable for autonomous airborne applications.

Fig. 1. Stereo camera module just 28 grams in weight.

The airborne robot platform used in this research is a miniature custom build Unmanned Arial Vehicle (UAV) - Quadrotor shown in Fig. 2. The Quadrotor is inherently less unstable than a conventional helicopter. It is a multi-rotor under-actuated helicopter. It has four propellers, each diagonal facing propellers pair rotating in opposite direction cancelling out each other generated rotational torque, all four propellers powered by electric DC brushless motors (BLDC), which are powered from on-board DC voltage.

The UAV-Quadrotor is capable of performing a vertical flight and transition to and from a horizontal flight. Its flight control method depends mainly on controlling the variation of the distribution of the propellers lifting force and propellers generated torques about its center of gravity. Controlling these forces enables the onboard control system to stabilize it during hovering and performing complex flight. The UAV-Quadrotor is capable of lifting a payload weight of up to 1100 gram.

Fig. 2. The research custom build UAV Quadrotor

II. EXPERIMENTAL METHOD

The research method investigates the development of a multiple stereo vision system utilising off-the-shelf hardware and software. The developed system contains five stereo cameras, image processing and navigation computer, off-the -shelf flight controller, wireless communication devices, DC power source and the UAV-Quadrotor frame. The vision system has 360 degrees of stereo vision coverage shown in Fig. 3. It processes in sequence the images obtained from the upward looking stereo camera, forward looking stereo camera, downward stereo looking camera, left-backward looking stereo camera, and right-backward stereo looking camera. The entire vision system operates at up to speed 20 fps at image pixel resolution of (1280 x 720) and given pixel areas of (921,600 pixels) per direction calculating position and orientation of the UAV Quadrotor with the reference to any detected environment features or landmarks. The vision system will compare its position and orientation measurements accuracy during flying, in real time with the on-board high grade IMU and GPS measurements specifically within an indoor low light environment. The obtained experimental data will be sent in real time to a ground station for processing and analysis. Furthermore, the vision system will provide in real time the horizontal and vertical flying control commands to the on-board flight control system, also occasionally for safety reason in conjunction with the UAV-Quadrotor's remote control.

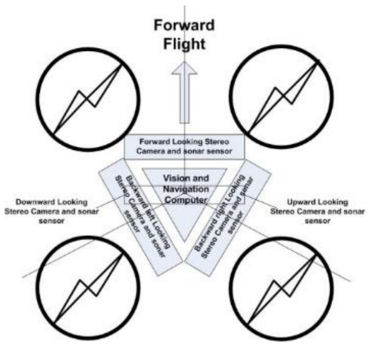

Fig. 3. The UAV-Quadrotor top view showing the stereo cameras orientation.

III. THE VISION AND NAVIGATION ALGORITHM

Considering any 3D environment whether it is known or unknown, empty or equipped, in its simplest description it contains a combination of flat surfaces, edges, corners, and bends or curves. These combinations of environment features present the environment in terms of walls, floor, ground, ceiling, edges, corners, and other possible shapes.

Hence, the vision algorithm will process the images depth and optical flow obtaining five data sets from five stereo cameras. Each data set contains information about the detected environment features such as corners, edges and planer (plane surfaces) estimating their position (X, Y, Z) and the orientation such as roll, pitch and yaw (φ, θ, ψ). Visual detection performed mainly by matching (features detector and descriptor) and tracking these features between the sequences of image frames obtained from the five stereo cameras video stream at 20Hz. Homographic Filter is first level filtering to reduce illumination glare and shadows followed by Bilateral Filter to remove noise and sharpen edges in images. Second level filtering commenced with RANSAC (Random Sampling Consensus), it detects data outliers and excluded them from the measurements, this enables an accurate estimation of the homography matrix and the position of each stereo camera in 3D space. The estimation is based on the assumption that the UAV-Quadrotor is reasonably stable, and it flies or hovers over or under a plan surface such as a floor or ceiling respectively. Finally, the third level filtering performs non-linear estimations utilising Extended Kalman Filter (EKF) to estimate each stereo camera's coordinates (position and orientation) in 3D space. The estimation is calculated with reference to obstacles such as landmarks or an environment features detected during the flight or hovering. The 6-DOF (Degree of Freedom) and altitude of the UAV-Quadrotor are calculated by transforming the translation and rotation corrected components of each of the five stereo cameras local frame coordinates to the UAV-Quadrotor frame coordinates expressed in the North-East-Down (NED) system. Autonomous navigation will be performed by the ability of the vision system to detect, avoid and calculate the flight path required for the UAV-Quadrotor to fly thorough hindrance free space.

IV. RESULT AND DISCUSSION

As previously discussed, the utilisation of visual perception in localizing the UAV-Quadrotor in an unknown environment appears very promising. As shown the Omnidirection stereo vision system has multidirectional field of view. It is capable to acquire distance, velocity, and rotation components of the environment visually detected obstacles in real time. Such a system is suitable for exploration navigation. It is defined as a method of detecting, avoiding, and navigating available spaces within the environment. Currently the hardware and software integration is completed within the UAV-Quadrotor including flying testing with full payload. Considering urban and industrial areas, the image-processing algorithm will be tested for robustness and the ability of estimating the translation and rotation components and navigating the UAV-Quadrotor during flying and hovering without the aid of the IMU, GPS and any external navigation aid.

V. FUTURE WORK

The multidirectional stereo vision system method for estimating position and orientation will enable the UAV-Quadrotor to fly and avoid obstacles following the required flight path through any random available space within unknown environments without any requirement for mapping. It allows the exploration of the environment at a very fast pace. It is also possible to utilise such a vision system to perform complex flight formation of multiple UAV-Quadrotors. This is achievable by measuring visually the attitude and speed of each UAV in the visual vicinity and coordinate collectively the required flight manoeuvre to fly along a specific flight path to explore a large and complex environment. The proposed system may provide new opportunities of visual oriented navigation and exploration such exploring un-mapped area, performing ad-hoc fast exploration mission of a very large urban site or navigating planetary landscape where there is uneven landscape with many valleys and hills.

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