Connected and Robotic Autonomous System

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ABSTRACT

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Nowadays autonomous robotic systems are the main focus of research in the tech industry. The project, connected and autonomous system, is an amalgam of embedded systems, IoT, distributed sensor networks, and deep learning applications. In this project, we aim to develop a drone that has autonomous capabilities and can track moving objects such as vehicles and people. Its application will be to capture videos or images of these moving objects autonomously. The ultrawide beacon, RTK GPS and a stereoscopic camera will be attached to the drone for tracking the object. The object is embedded with a beacon and an RTK GPS so that the drone can keep track of that object.

The low-level architecture is based on NuttX OS, with ArduPilot firmware, and Pixhawk 4 flight controller. The higher-level architecture uses Linux based systems that can support complex frameworks and computing-intensive applications such as object detection, classification, and system localization. The system makes use of a ZED stereo camera to get the depth information from the disparity map for autonomous landing and obstacle avoidance. We are making use of datasets that are relevant to train our deep learning models and avoid obstacles while in mid-air

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***Abstract*—Nowadays autonomous robotic systems are the main focus of research in the tech industry. The project, connected and autonomous system, is an amalgam of embedded systems, IoT, distributed sensor networks, and deep learning applications. In this project, we aim to develop a drone that has autonomous capabilities and can track moving objects such as vehicles and people. Its application will be to capture videos or images of these moving objects autonomously. The ultrawide beacon, RTK GPS and a stereoscopic camera will be attached to the drone for tracking the object. The object is embedded with a beacon and an RTK GPS so that the drone can keep track of that object.**

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***Index Terms*—autonomous, ultrawide-band beacon, ZED stereo camera, Pixhawk 4, Ardupilot, localization, obstacle avoidance, deep learning, RTK GPS, tracking, object detection.**

I. Introduction

In the past few decades, autonomous robotics has made a fine share of advancements in the tech industry and continues to improve every day with the applications, not only restricted for industrial purposes but also making the step forward towards other applications where it is inefficient, impossible and dangerous for human intervention. This has been possible because of drastic improvements and support for the machine learning algorithms. Robotic systems are basically the amalgam of mechanical engineering, electronics engineering, and computer science. “Research by the Japan Robotics Association (JPA), the United Nations Economic Commission (UNEC), and the International Federation of Robotics (IFR), indicates that the market growth for personal robots, including those used for entertainment and educational purposes, has been tremendous and this trend may continue over the coming decades” [1]. With the advancement of AI and Machine learning, robotic systems have become autonomous. The word “connected” comes from the fact that these systems can have IoT capabilities that can send data for monitoring and storage over to the cloud. Our paper is focused more on drones and we thus restrict the discussion of the generic robotic system towards that area.

Drones are the nickname for unmanned aerial vehicles (UAV) which can be used for various domestic to critical applications. Lian Pin Koh and Serge A. Wich (2012) explains the use of “unmanned aerial vehicles for surveying and mapping forests and biodiversity for environmental and conservation applications, which include near-real-time mapping of local land cover, monitoring of illegal forest activities (e.g., logging, fires), and surveying of large animal species” [2]. The authors Author Milan Erdelj, Michał Król, EnricoNatalizio (2017) explain the importance of drones to help the rescue services to operate efficiently at an event of natural disaster [3]. Such applications make drones, one of the useful and popular robotic systems. The drones can come in various shapes and sizes and can be used for recreational applications such as “hobby purposes while being flown in a park to take photographs from unusual perspectives and angles. It can also be used for a commercial application such as business for surveillance, domestic policing, the delivery of goods and for oil, gas, and mineral exploration. Military applications would be drones that are used for a variety of purposes such as reconnaissance, surveillance, remote sensing, armed attacks and warfare” [4]. The drones can be either remote-controlled from the ground station or made autonomous with the help of programming.

For unsupervised navigation, autonomous drones require several sensors that work together to navigate and detect obstacles. In surveillance applications, autonomous drones make use of deep learning models that are useful for detecting the objects and tracking their movements. The authors Ludovic Apvrille, Tullio Tanzi and Jean-Luc Dugelay (2014) explain the use of Sparse3D and HOG Algorithm to detect objects and avoid obstacles providing the faster response [5]. However, their system requires an efficient autonomy to manage energy, fix the hardware-software configurations and use the system in critical situations [5]. This paper explains our project implementation of a “connected and autonomous drone system” to counter these problems.

In order to fix the hardware-software configuration issues, we propose a two-level architecture, where low-level architecture takes care of the sensing units to detect and avoid obstacles using proximity sensors such as ultrasonic sensors. The stereo camera setup is used to measure the distance to the objects. This is done by generating disparity between the left and right images and extracting a depth map from it. The high-level architecture is trained by complex deep learning models to track the objects to be monitored and collect the data to be sent to the cloud. In order to monitor the drone navigation at outdoor conditions, GPS modules can be used to pinpoint the exact coordinates of the drone. There is a possibility that drone needs to perform indoor navigation and GPS module would not work. To overcome such a scenario, we are using an ultrawide-band beacon (UWB) to get the exact drone location indoors. We aim to achieve autonomous capability by incorporating the Ardupilot on the PixHawk4 platform. The Ardupilot platform has really good support for drone applications with features such as data-logging, analysis, simulation tools, etc. [6]. Since it is an open-source platform, it has a huge ecosystem of sensors, communication protocols, and compatible hardware/computers [6].

II. Related Works

There are many autonomous systems research going on that can be used as a reference to develop our project. For an indoor autonomous system, Zhengang Li, Yong Xiong, Lei Zhou (2017) explains the working of the indoor wheelchair performing the autonomous exploration based on inexpensive RGB camera and ROS. The authors explain that the wheelchair rotary systems are controlled by the robot operating system in the host computer and RGB camera is used for depth perception, indoor path planning and obstacle avoidance [7]. The Arduino microcontroller is then used to receive the data from the camera and ROS and accordingly sets the PWM signals for the motors controlling the navigation of the wheelchair.

Some of the airborne automated systems require navigation control based on IMU sensor units like accelerometers, magnetometer, gyroscope, etc. integrated along with location data. Jan Wendel, Oliver Meister, Christian Schlaile, Gert F. Trommer (2006) explain an integrated navigation system for an airborne robotic system that uses GPS and MEMS IMU sensors [8]. The authors propose the solutions for two scenarios: first when GPS data is available and second when GPS is lost [8]. Another replacement for GPS can be ultrasonic beacon which can be used for indoor positioning. Dongho Kang & Young-Jin Cha (2018) explains the use of ultrasonic beacon in the scenarios where GPS fails to work for a UAVs. The authors explain the application of a “deep convolutional neural network (CNN) for damage detection and a geotagging method for the localization of damage” [9]. “Localization, mapping, and path planning” are the most important algorithms used for any system to be autonomous. Localization, motion planning, and path planning plays an important role in deciding the shortest path that any autonomous system can travel in minimum time [10].

The paper [14] describes object detection and tracking for Drones such as Parrot AR drone. It uses an SSD CNN model for object detection. SSD model provides the performance of the Yolo model and accuracy of Region-based object detection models such as Fast-RCNN. A front camera takes a Real-Time image of an object and passes the image to a computer through a Wi-Fi interface. The computer computers the distance and position of the object in real-time and sends the roll, pitch, yaw and altitude values as parameters to the drone. The drone on receiving these values updates its flight information.

Another paper [15] describes object detection using Qualcomm Snapdragon processor 801. This development used PX4 Autopilot open-source software to manage the overall operation of the drone. Robot Operating System (ROS) is deployed on ARM core to provide Linux OS support of real-time object detection. The object tracking method uses a lightweight machine learning model and inertial measurement unit data, global positioning system data to calculate the relative distance between the drone the object in a Coordinate based system.

The ultrawideband beacon used in our project is to monitor the tracking of the autonomous drone that shall be used for the remote locations where GPS coordinates cannot be read from the GPS sensor. There are previous implementations of UWB beacon that was used for various applications. The authors Vincent Mai, Mina Kamel, Matthias Krebs, Andreas Schaffner, Daniel Meier, Liam Paull, and Roland Siegwart(2018) explained the use of UWB sensors integrated with the gyroscope which was used to create an estimator that accurately tracked the position, altitude, linear and angular velocities. “This estimator uses a complete dynamics model, which allows external disturbance estimation. However, it cannot track external forces” and need more strong assumptions for developing hardware and software platforms [12].

Another case study of using UWB technology was the development of a flight system based on the indoor positioning feature. The authors Zhiyuan Shi, Hanbo Li, Hezhi Lin, Lianfen Huang (2018) explains this application. The system was deployed on a Nano quadcopter and indoor navigation was achieved with the help of a UWB indoor positioning system and a flight control scripts. As the author explains, “The accuracy of the UWB indoor positioning system is 10cm which can meet the demands for the nano-quadcopters to perform a formation flight.”[13].The limitation of this system is that it is applicable only for domestic purposes and hobbyists' implementation. In order to develop a system for industrial or any military applications, we need to deploy strong embedded hardware to achieve the goals.

For this project, we are making use of a stereo camera which will provide us with the depth estimation of an object that is in front of the camera. A disparity map is nothing but the difference in the pixels between the left and the right images. The higher the pixel difference, the greater is the distance from the camera. This is due to the fact that the stereo camera has two cameras separated by a distance called baseline just like the humans are able to percept depth because of 2 eyes that create a disparity. The paper [11], formulates a CNN network called Pyramid Stereo Matching Network for generating a disparity map which is quite accurate. It takes into account many different datasets such as KITTI and Scene Flow to evaluate the performance of their network. The architecture proposed by them is as shown below [11]:

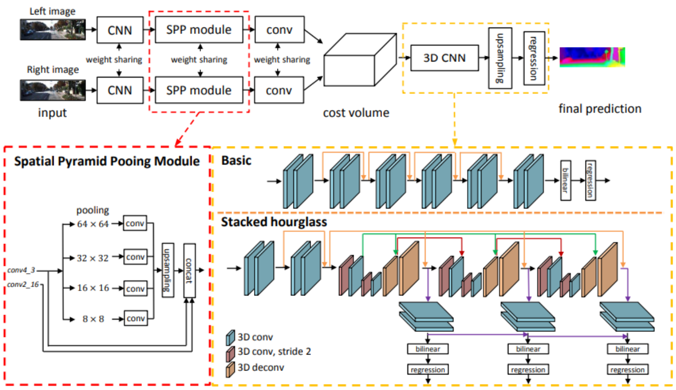

Fig. 1 PSMNet Architecture

The above architecture is obtained from [11, Fig. 1]. “The left and right input stereo images are fed to two weight-sharing pipelines consisting of a CNN for feature maps calculation, an SPP module for feature harvesting by concatenating representations from sub-regions with different sizes, and a convolution layer for feature fusion. The left and right image features are then used to form a 4D cost volume, which is fed into a 3D CNN for cost volume regularization and disparity regression.” [11]. For the KITTI 2012 dataset, the PSMNet gave an error of just 1.89% for the three-pixel-error which is outstanding [11]. Similar accurate readings were obtained from KITTI 2015 and Sceneflow dataset. Thus, we can implement this architecture on our stereo camera for getting an accurate depth of an object.

We are making use of Pixhawk 4 which is an open-source hardware design and it is an advanced autopilot system. It has an STM32F765 processor as its main FMU processor. It has four onboard sensors - Accelerometer/Gyroscope ICM-20689 for motion tracking of system, Accelerometer/Gyroscope BMI055, Magnetometer IST8310, and Barometer MS5611.

NuttX is a Real-Time Operating System (RTOS) developed for 8-bit to 32-bit microcontrollers that are used by Pixhawk. Its design is primarily based on POSIX and ANSI standards, but it includes some of the functionalities of UNIX standards. The main features of NuttX OS are as below.

- POSIX/ANSI-like task controls, named message queues, counting semaphores, clocks/timers, signals, pthreads, robust mutexes, cancellation points, environment variables, filesystem.
- Realtime, deterministic, with support for priority inheritance.
- System logging.
- Realtime, deterministic, with support for priority inheritance.

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