Autonomous Navigation in Indoor Environment: Design, Implementation and testing

Achal D Arvind
B.N.M. Institute of Technology

Amogh Akshintala
B.N.M. Institute of Technology

Swaroop Narayan
B.N.M. Institute of Technology

Shashank Raghu
B.N.M. Institute of Technology

Shashanka L
B.N.M. Institute of Technology

Abstract

This paper deals with the autonomous navigation and control of an unmanned aerial vehicle (UAV) in an indoor (GPS denied) environment without any external aid. The presented solution splits the problem of indoor navigation into 3 modules, Stabilisation, Path planning and Image processing. These three processes are performed asynchronously and simultaneously to achieve indoor flight.

INTRODUCTION

Navigation in indoor environments is made difficult by the fact that most modern UAV's extensively use GPS to navigate. We present a solution that involves a mix of using the magnetometer for heading and SLAM algorithms for navigation. Indoor navigation can be extremely useful in search and rescue operation and surveying of dangerous areas that humans do not have access to. Aerial platforms can also be deployed quickly and are able to traverse various terrains that would not be possible with conventional land robots.

Statement of the problem

The 6th Mission requires a completely autonomous aerial robot to:

1. Enter a building through a 1m x 1m opening.
2. Scan the area for a flash disk.
3. Retrieve the flash disk.
4. Replace with duplicate flash disk.
5. Exit the building.

The above should be completed in less than 10 minutes and without triggering any alarm or landing even for the briefest period of time.

Conceptual solution to solve the problem

The primary air vehicle is a quadrotor, with motor to motor length of about 60cm. The sensor suite includes the following:

1. 3 axis accelerometer, 3 axis gyroscope constituting a 6 DOF IMU.
2. 3 axis magnetometer to dictate the heading hold.
3. Sonar module to indicate altitude hold.
4. LIDAR module for path planning and mapping.
5. 2 Cameras for detection of laser barrier, flash disk and to process signs.

The vehicle has a robotic arm to pick up the flash disk. The stabilisation is done using a microcontroller and the higher level processing i.e. path planning, localization etc. is done onboard using a microprocessor. A serial link has been established between the processor and the microcontroller. An Xbee module has been connected to the lower level controller to facilitate the kill switch and a manual override has been incorporated to prevent danger of the robot going out of control.

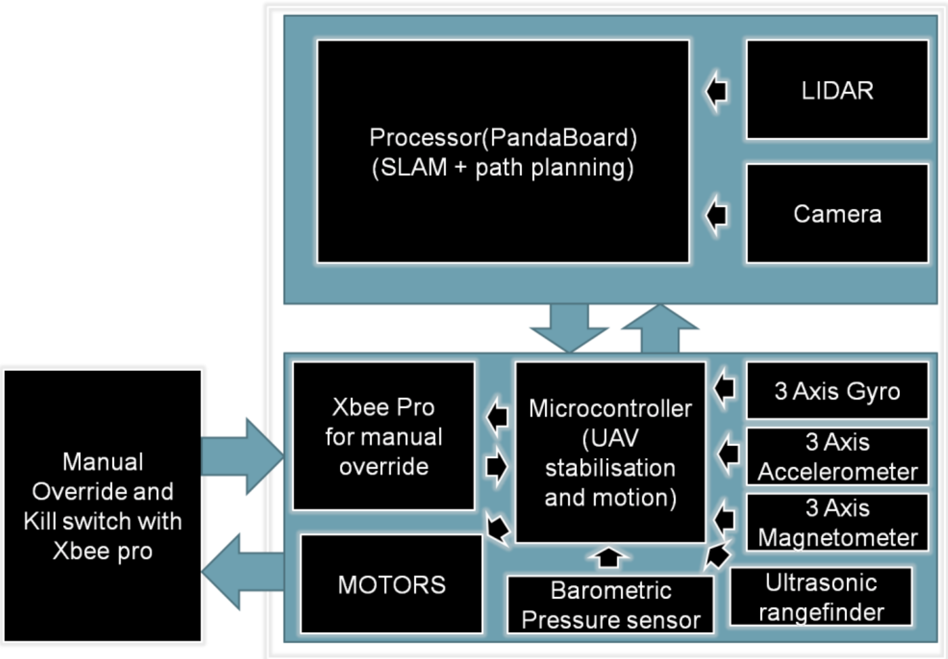

Figure1. Overall system architecture

AIR VEHICLE

Propulsion and Lift System

The propulsion system consists of four brushless motors (ROBBE ROXY 2827-35) paired with EPP 1047 propellers. The motors were chosen for their low power consumption and kV (760 rpm/V) and the propellers for their light weight and efficiency. Each motor has a separate motor control board from Mikrokopter BL ctrl 2.0 interfaced to the flight control board through the I2C bus. 8-bit resolution of motor speed coupled with a high update rate, due to I2C, allows for precise control of the quadcopter.

Guidance, Nav., and Control

The system uses a LIDAR to map its surroundings and this information is also used for avoiding obstacles. The LIDAR data gives a very high degree of accuracy of 720 points over 240 degrees with an error of ±3% over a distance of 1000mm and allows the quadcopter to traverse through confined places with ease. Along with the LIDAR, we have the Camera system that apart from parsing the various sign boards and detecting the LED and Laser gates, also provides feature data that is used in SLAM. The camera system also allows us to calculate the height of various obstacles in the area and allows us to send altitude adjustments to the MC in order to circumvent these obstacles.

We use an ICP based (P.J. Besl, 1992) SLAM approach that allows us to use the LIDAR scanner data and very accurately keep track of the system's current position in the environment. We use the open source MRPT (Mobile Robotics Programming Toolkit) to provide the basic algorithms as per our requirements. Also this information affords us a very accurate map of the space and improves reconnaissance abilities.

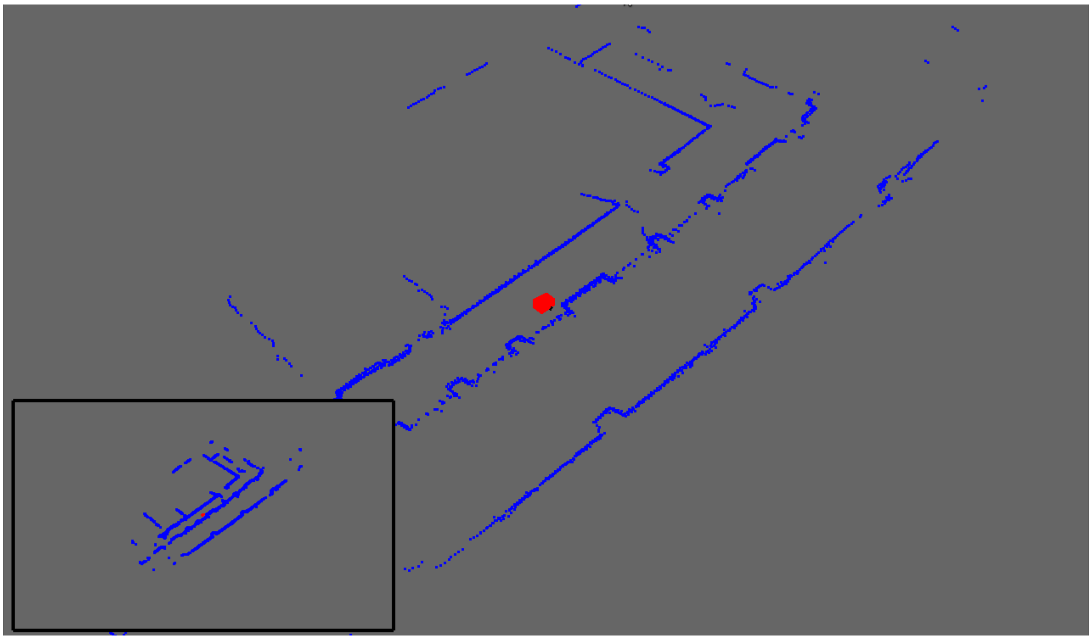

Figure 2. Map of corridor generated by ICP slam on raw data from LIDAR scanner

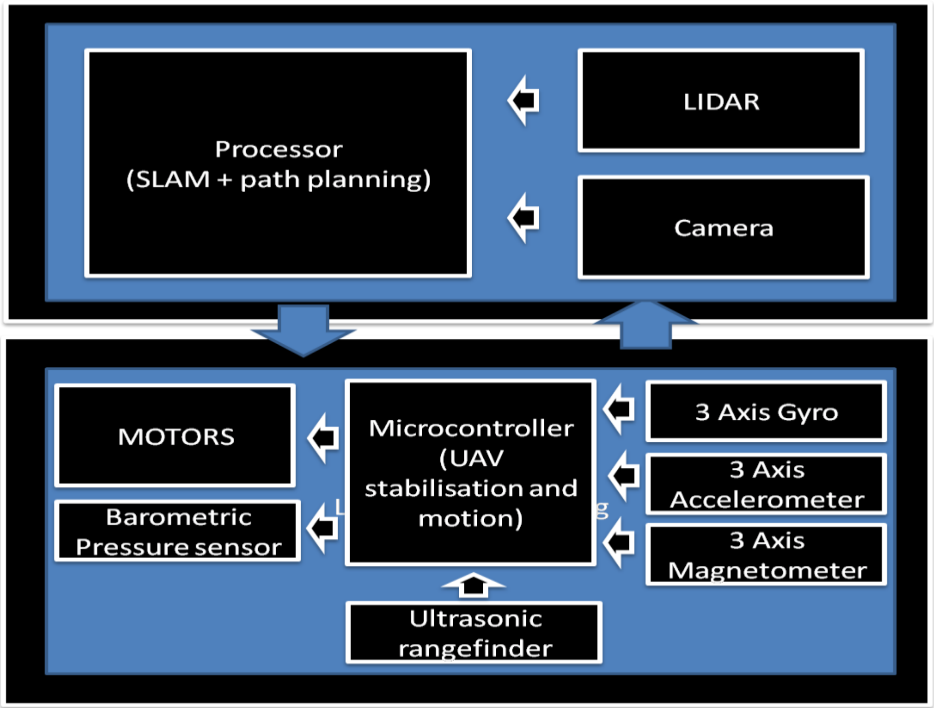

Figure 3. Block Diagram of control system architecture

Flight Termination System

2 Xbee pro modules and the flight termination switch constitute the flight termination system. One Xbee module is connected to the flight stabilizing microcontroller and the other module is connected to the flight termination switch which consists of a simple switch interfaced to a microcontroller. Activating the flight termination switch causes a flight termination signal to be sent to the quadcopter. The quadcopter enters flight termination mode. Its stops all processes and lowers power until it lands, beeping continuously until it does so.

PAYLOAD

Systems

The main processing is performed by the Panda board which uses an OMAP 4430 comprising of a Dual-core Arm Cortex processor having each core clocked at 1 GHz and a graphics accelerator for floating point instructions with 1GB of DDR2 RAM. A custom version of Linux is ported onto the panda board providing the backbone operating system. The panda board is connected to the Atmega microcontroller through a Serial line and sends commands to the MC based on a reference bit-frame which allows transmission of Altitude, heading and other adjustments. This is an economical and very fast alternative to having the Quad copter connected via Wi-Fi which brings a lot of power and data loss problems. This approach allows the system to be completely independent on the field and work without the hassle of being connected to a command hub/cluster for processing and analysis of data.

To make sure that the onboard processing restrictions are carefully met, we have restricted the speed of the quad to ensure that the amount of data that the system receives from both the Cameras and the LIDAR does not overwhelm the processor and ensures that the system has adequate time to finish all computations.

GNC Sensors

A 9 Degree of freedom inertial measurement unit constituting of a 3 axis accelerometer, a 3 axis gyroscope and a 3 axis magnetometer is used for the stabilization and control of the quadcopter. The accelerometers help counter gyro drift and the magnetometer gives a north reference for heading hold. A LIDAR module, Hokuyo URG-04LX-UG01, is used to provide point data to enable Simultaneous Localisation and Mapping of the quadcopter in an unknown environment. Two cameras, one facing the front and the other attached at the bottom for an orthogonal view, are used for parsing the signs, finding the flash disk, for safe entry i.e. when the blue LED is off, to detect the laser barrier and for obstacle avoidance.

Target Identification

Object detection is done by detecting the key points of the sample and matching it with the reference. For an object or an image, the key points of the object can be extracted to provide a feature description of the object. This description, extracted from the image, can be used to identify the object in a sample containing many other objects. The object recognition can be made more reliable if the extracted features are detectable even under change in image scale, noise and illumination. Such features can be found in high contrast regions of the object such as the edges. The relative position between the features must remain constant in the original image and the sample. As mentioned in (Lowe, 1999), SIFT's key features are obtained using the following steps.

1. Construction of scale space using gauss kernel
2. Taking difference of Gaussians(DOG)
3. Locating the extrema of the DOG
4. Sub pixel localization
5. Filter edge and low pass contrast responses
6. Assign key point orientation
7. Build key point descriptor

Feature matching

The sift features are computed for the reference and the target images. The distances and the distance ratios among the features are computed. It is considered as a feature match only if the distance is less than the distance ratio times the distance to the second closest match.

Threat Avoidance

Threats are detected and avoided by using a combination of input from the LIDAR, the cameras and sonar. These detected threats are then mitigated by adjusting the quadcopter suitably. Most threats can be thwarted either by moving over or under them or by moving away from them. The laser barrier presents a major threat and we intend to have the quadcopter attempt to disable it but if that fails, it will fly between the lasers so as to avoid triggering it.

Communication

The higher level processing is done on the ARM A9 powered Panda Board whereas the stabilisation and control of the quadcopter is done via the Atmega microcontroller. We communicate between processes running on the Panda Board via IPC and between the Panda Board and the Microcontroller using a serial link on which data is sent with predefined headers indicating what the data represents. The only external communication required is for the manual override and the kill switch. This is done using a Zigbee module. Zigbee was chosen for its light weight, long range and simple implementation. Sensor data is transmitted to a computer for testing and debugging. The flight control board communicates with the motor control board using the I2C bus. The motor controllers each have a unique address using which commands are sent from the flight control board.

The various peripherals (LIDAR, Camera) are attached to the Panda Board using USB. The accelerometer, gyroscope and magnetometer communicate with the microcontroller using the I2c bus. The sonar sensor used has an analogue output and is interfaced with the microcontroller via the ADC.

The quadcopter is an isolated independent agent and doesn't communicate with any other system.

Power Management System

The Brushless motors controllers constantly monitor the battery levels and the power consumption and transmit data via the I2C bus on sending the read signal. Based on this the flight time can be calculated and when the the charge level falls below a threshold, the quadcopter automatically lands.

OPERATIONS

Flight Preparations

Before each flight the battery levels are checked. The propellers are inspected for signs of wear and tear. Also the quad is inspected for signs of damage. The wireless links is tested. The motor mounting screws and the screws attaching the propeller to the quadcopter are tightened.

Checklist

1. If all screws are tightened.
2. If the propellers and motors are mounted securely.
3. If the propeller guards are secured tightly.
4. If all the connectors are in place and oriented right.
5. If the battery is completely charged.
6. If the remote link, manual override and kill switch are functioning.
7. If the quadcopter is perfectly level for the sensors to calibrate.

Man/Machine Interface

The man machine interface is in the form of a zigbee link between the computer and the quadrotor. Using this link the quadcopter control can be overridden. Also an option has been provided for ppm input from a receiver (for control using hobby RC transmitter.).

Risk Reduction

Each propeller is surrounded by a propeller guard to prevent the propeller from coming in contact with any external material. Also the LIDAR prevents the quadcopter from flying too close to any object. In the rare event of the quadcopter flying too close to any object/person, control can be overridden and taken over by a human. Also in the case of an emergency the kill switch can be used and the quadcopter disabled.

Vehicle Status

The vehicle status information is transmitted wirelessly using the zigbee module. Odometry data, battery level, motor rpm, motor amp draw, errors etc are constantly transmitted. These parameters are monitored constantly to keep track of the quadcopter's progress.

Shock/Vibration Isolation

All the PCB's are mounted on rubber mounts to decouple them from the motor vibrations. The quadcopter arms are mounted to the center plate using rubber bushes to reduce vibration.

EMI/RFI Solutions

The PCB's are placed in a magnetically shielded compartment to prevent the electromagnetic fields produced by the motors interfering with the system.

Safety

The propellers are shielded to prevent any harm to bystanders and the quadcopter has a robust obstacle avoidance system to prevent it from colliding with anything or anyone.

Modeling

A 3D model of the quadcopter was made to aid in the optimal placement of parts and for clean wiring. It also helped with making the quadcopter from the least amount of material. The 3D model was used to shrink the size of the quadcopter as far as possible.

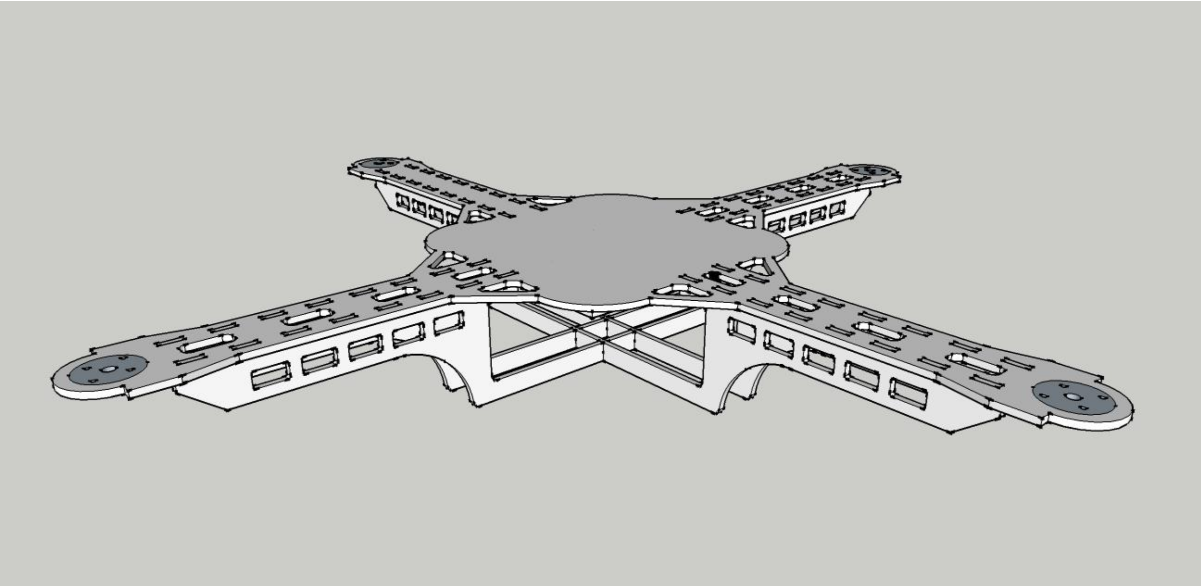

Figure 4. 3D model of the Quad Copter Frame

Testing

Various motors were tested for efficiency and thrust. A graph was plotted and using this graph the ROBBE ROXY 2827-35 was chosen as it gave the highest thrust at the least power consumption.

Conclusion

A quadcopter was built with the ability to traverse autonomously in indoor environments for search and retrieve operations. SLAM algorithms were implemented. Also image processing

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