Unmanned aerial vehicle of bits pilani

Unmanned Aerial Vehicle of BITS, Pilani-Dubai Campus for the International Aerial Robotics Competition 2011 Saurabh Ladha, Deepan Kishore Kumar, Robin Singh , Pavitra Bhalla, Anant Mittal, Aditya Jain, Anshul Upreti, Prof. Dr. R. K. Mittal, Dr Anand Kumar Birla Institute ofTechnologyandScience, Pilani-Dubai Campus, Dubai, UAE ABSTRACT The Intelligent Flying Object for Reconnaissance (IFOR) is an autonomous aerial vehicle that has been developed by BITS Pilani Dubai Campus students.

The vehicle is capable of localizing itself using the SLAM algorithm, stabilize its attitude (pitch, roll and yaw) and altitude using PID controllers, plan paths around obstacles and navigate an unknown indoorenvironmentwith wall following guidance. In addition, it has been designed to be capable of pattern recognition which would enable it to recognize images and signs. These features enable the IFOR to execute the 6th mission of the International Aerial Robotics Competition, which involves scanning an unknown indoor arena protected by laser barriers and cameras, bestrewn with obstacles, in the search for a flash drive. 1.

INTRODUCTION The field of robotics is witnessing a paradigm shift in the operation and use of robots. With robots becoming autonomous and intelligent day by day, their application and use has increased tremendously. Aerial robots specifically have an edge over other autonomous vehicles due to its higher degrees of freedom in motion and agile maneuverability. To tap these features and advance the applications and versatility of the quadrotor is the aim of the team. 1. 1 Problem Statement The 6th mission of the IARC requires teams to infiltrate a military facility from which a flash drive has to be retrieved and replaced by a decoy.

This flash drive is placed in the ‘ Office of the Chief of Security’, identifiable by a unique Arabic pattern. To reach this room, a vehicle must explore a ‘ maze’ of rooms avoiding randomly placed obstacles along its path. In addition it must also avoid detection by a camera and laser barriers placed within the arena. Once the target pen drive is found it must retrieve the object after dropping a decoy in its place, the entire mission must be performed in under 10 minutes. 1. 2 Conceptual Solution Team IFOR will be using a quadrotor as its aerial vehicle to execute the 6th mission.

The vehicle will use wall following guidance to explore the maze, whilst a path planning system shall continuosly scan the environment to plan optimum paths around obstacles. Localization in a global frame can be accomplished using the SLAM algorithm, the output of which can be used by a Drift Control system to Page 1 of 10 correct unintentional drift. The Image processing routine runs in parallel to find recognizable patterns in its surrounding. Ground Station Wi-? Fi 2. 4 GHz Hokuyo scanning laser range finder Camera Guidance, Navigation, Control -? Mission planner -? Wall following guidance -? Path planning ? Target retrieval -? Pattern matching CoreExpress breakout board Intel Atom Z530 Image recognition Analog 72 MHz Safety Pilot Inertial Measurement Unit -? MEMS gyro sensors -? 3D magnetic compass -? 3 axis accelerometer ARM7 Microprocessor Stability Augmentation System -? Altitude hold -? Attitude hold Motors Sonar Altimeter Figure of Overall system architecture 1. 3 Yearly Milestones In the second year of the 6th Mission, Team IFOR intends to fly autonomously, navigate through the arena, and implement drift control, path planning and image processing(limited to recognition of the pen drive and signboards).

SLAM will serve as a base system for the IFOR to successfully run all other systems that are directly dependent on the localized coordinates. Flash drive retrieval mechanism will be developed in the following year. Page 2 of 10 2. Air vehicle The team is using an off the shelf quadrotor from Ascending Technologies, the Asctec Pelican Quadrotor. The Pelican weighs about 980 g and has a payload capacity of 500 g, ideally suited for covert missions. The Asctec Pelican quadrotor and the propeller action. 2. 1 Propulsion and lift system The quadrotor is a Vertical Takeoff and Landing (VTOL) rotorcraft which is propelled by four rotors.

By appropriately changing the rotor speeds the quadrotor can pitch, roll or yaw. Each of the four propellers produces a downward thrust about the centre of the blades and a torque about the arm of the quadrotor. The quadrotor can be flown either in diamond configuration where the pitch axis is the diagonal of the quadrotor or in square configuration where the axis of the pitch is parallel to two adjacent propellers. If all the four propellers spun in identical directions and speeds, the quadrotor would yaw about its centre of mass.

To stabilize this yaw, the two sets of propellers spin in opposite directions and balance the angular momentum generated by the other two propellers. Pitch, in a square configuration, is achieved by reducing the speeds of two propellers (A and B) and increasing the speeds of the two propellers (C and D), this pitches the quadrotor in the direction of A and B. Roll is achieved in a similar way, by increasing speeds of propellers A and D and reducing the speeds of B and D, this rolls the quadrotor in the direction of B and D. 2. 2

Guidance Navigation and Control Control The quadrotor, by nature, is an aerodynamically unstable system.

It hence demands to be one that is mechatronic in nature with its dynamics being controlled by PID generated control signals. This automatically calls for the Page 3 of 10 implementation of a feedback system to monitor the quads' deviations from the desired response. The Asctec Pelican already has a PID controller implemented to control the attitude (pitch, roll and yaw). The Inertial Measurement Unit(IMU) readings are used as inputs for these loops, in addition, yaw control also uses the inputs generated by the magentometer. 2. Stability Augmentation systems The instability of the quadrotor arises from the fact that the aerial vehicles dynamics are electronically varied, which leads to a delay for the mechanical system to respond due to inertial reasons. The commanded attitude is delivered by use of the PID loops already described. In addition we have also implemented an altitude PID controller which can be described as below: Altitude Output = Kc ? # + 1&' ? # () +*(() ? +) ?- is the difference between the desired altitude and actual altitude . The MaxSonar LV sonar altimeter is used to for readings on the altitude.

A drift control mechanism is also required since milligram imbalances in weight apart from other factors cause a quadrotor to drift unintentionally, the drift control is accomplished via a separate set of loops which can be described as follows: Pitch Output Roll Output = Kc ? + + 1;' ? + () +*(() ? + = Kc ?. + 1&' ?. () +*(() ?.) ?/ is the difference between desired pitch and actual pitch ? 0 is the difference between desired roll and actual roll Kc is the controller parameter, from which Kp (Kc * 1), Ki (Kc / Ti) and Kd (Kc **) values are obtained.

The require the Zeigler Nicholls Tuning method was used to generate optimum values for Kp Ki and Kd. R(s) + - Controller Gc(s) Measured Output System Input Process Gp (s) Control Output Sensor H (s) s: transfer function parameter Figure of control system architecture Page 4 of 10 The three loops described in this section are implemented on the Intel Atom board which is on board the vehicle. 2. 4 Navigation The quadrotor begins ascending and finds the window opening using feature detection. Once the window has been detected, the arena is infiltrated after checking whether the camera is on or off.

Once inside the arena, the quadrotor moves close to the right wall and performs right wall following algorithm to explore the indoor arena. SLAM forms the base upon which the quadrotor extracts its local coordinates for adjusting drift of movement and also aligns itself with the wall to continue its navigation. The mission planner sets the direction in which the vehicle must move. 2. 5 SLAM The term SLAM is an acronym for Simultaneous Localization and Mapping. SLAM is concerned with the problem of building a map of an unknown environment by a mobile robot while at the same time navigating the environment using the map.

SLAM consists of multiple parts; Landmark extraction, data association, state estimation, state update and landmark update. The team has developed a program that extracts data directly from the laser sensor and implements SLAM real-time using CoreSLAM libraries. CoreSLAM is a fully developed simple and efficient algorithm, which can perform SLAM using data just from a laser sensor. Due to its computational simplicity, it can easily be used on-board the vehicle. It integrates laser information in its localization subsystem based on particle filter, using two main functions: • • The scan o map distance function, which acts as the likelihood function used to test each state position hypothesis (particle) in the filter. The map update function, used to build the map as the robot is going forward. It uses a very simple Monte-Carlo algorithm to match the current scan with the map to get the updated (x, y) coordinates of the robot position estimate at all times during the mission. This localization is then provided to other higher-level modules such as drift control, path planning and mission planning. Page 5 of 10 2. Flight Termination System The quadrotor though autonomous in its flight can also be manually commanded to abort the flight.

A safety kill switch mechanism has been developed in order to attain this safety feature. The kill switch will override all other running programs in the quadrotor and gradually reduce the throttle to zero so that the quadrotor can land safely. The Pelican has a built in termination system in which, the vehicle lands the moment the transmitter falls out of range. This feature is used for Flight termination via a kill switch which shuts the transmitter off and hence causes the vehicle to land. . Payload 3. 1 Sensor suite 3. 1. 1 GNC Sensor Asctec 3D MAG is a triple axis magnetometer that determines the vehicles heading by measuring the earth’s magnetic field. A Hokuyo-Light Detection and Ranging Device is used to scan the environment for SLAM, navigation and obstacle avoidance. A SONAR altimeter is used to measure the altitude of the quadrotor. The quadrotor’s sensory system includes an Inertial Measurement Unit comprising of a Triple axis accelerometer and a

MEMS gyrometers. Each of these electronic components perform crucial role in the flight stability, control and navigation. . 2 Mission sensor 3. 2. 1Target identification The image processing module of the quadrotor is capable of detecting the blue LED which indicates whether the camera is on or off, this is accomplished via blob detection. In addition, it is also capable of detecting signboards using Optical Character Recognition. 3. 2. 2 Obstacle detection and Avoidance The threat avoidance system of the quadrotor is directly a subroutine of the Path planning module. This sub routine identifies obstacles, classifies them as threat if they are in the intended path of travel.

On finding an obstacle in the scan, the algorithm proceeds to suitably finding a path that would avoid the obstacle with the minimum possible deviation from the original path. We define a safe distance(the safe distance is contingent on the aerial vehicle's kinematics) from an obstacle and a minimum clearance width, a scanning range of ? degrees in front of the quadrotor is calculated to be sufficient to identify the existence of an obstacle. If in this scanning angle range, a point is found to be too close to the quadrotor it is declared as an Page 6 of 0 obstacle. This is the point at which the " growth algorithm" takes over the navigation of the quadrotor. The growth algorithm and path planning are represented as follows: Reduce each scan by ? , thereby 'growing 'every obstacle If adajecent points lie too close then reduce by secondary factor ? Considering the quadrotor to be a point calculate the longest free path Assign imporatnce factor to di? erent clear paths based on of deviaRon from original path and total length Yaw towards the set path and pitch forward Repeat unRl no obstacles are found 3. Communications The vehicle communicates with a base computer via an

Xbee module over the Zigbee protocol in order to deliver telemetry data. The othercommunicationlinks include a WiFi link to deliver real time video to the base station. Both of these links operate at 2. 4 Ghz. Finally, a safety pilot can take control over the vehicle at any time using a Futaba radio controller operating at 72 Mhz. 3. 4 Power system The quadrotor is powered by an 11. 1V Lithium Polymer Battery. A power board is used to distribute power and communication lines to all motor controllers and other systems on board.

This power board comprises of a switching power regulator to generate a stable Page 7 of 10 6V supply for the Auto Pilot board and a high power MosFET to switch current ON and OFF. 4. Operation 4. 1 Flight preparation Each flight test is performed with utmost precaution following the mentioned safety procedure which ensures a safe and smooth flight of the quadrotor. 4. 2 Checklist 1. Double Check LiPo battery voltage using voltmeter. 2. Examine the propellers, safety mounts, nuts and screws for any damage. 3. Test communication link between the quadrotor and the Ground station 4.

Enable safety pilot and check kill switch action before flight. 5. Check status LED’s 4. 3 Man/Machine interface The Intel atom board which is on board the vehicle can be accessed via an LVDS display, this also allows other HMI devices like a mouse/keyboard to be connected. 5. Risk reduction 5. 1 Vehicle status Two status LEDs allow for a check on certain critical vehicle states. The Red LED blinking indicates that the sensors are being initialized and calibrated. Once the sensors are calibrated a green LED blinks rapidly indicating the flight control software is running. In case the battery voltage drops below under 9. volts a loud tone is emitted, with the beeping becoming faster as the voltage drops. 5. 2 Shock / Vibration isolation The Asctec

Pelican is built on a carbon fiber frame which has a large value of Ultimate Tensile Strength; that is it can withstand a large amount of impact without necking. The quadrotor is also fitted with soft cushioning pads below the arms to ensure that any impact is cushioned. EMI/RFI Solutions Page 8 of 10 The quadrotor's vital components that do not communicate wirelessly are wrapped with aluminum foil paper, which does not allow for Electromagnetic interference from the wireless devices.

This simple solution is based on the principle of a Faraday's cage. Sensitive components like these are also placed above all other devices. RFI is less in the vehicle as all the computation happens on board. Safety The IFOR is equipped with landing gear designed in a manner to deflect shock from the electronic system. The propellers are also covered, which ensures safety to both bystanders and the vehicle in case of a mishap. The ON/OFF switch on board is designed active low, so if for some reason the mechanical switch breaks or looses connection the vehicle will remain ON.

However this mechanism is overridden by the safety kill switch. Modeling and Simulation The intelligence of the quadrotor was extensively tested for robustness before and after burning the codes onto the on board processor. Image processing was developed from scratch to meet the requirements of the competition. The PID controllers were tested on Lab View. Testing Device / Routine HOKUYO LIDAR SLAM Cameras Drift Control Conclusion BITS Pilani Dubai Campus had developed IFOR to become a fully autonomous quadrotor that will be able to successfully accomplish the tasks of the IARC.

The IFOR's intelligence system comprises of Simultaneous Localization and Mapping algorithm for the bot to get localize itself in its environment, achieve drift control using a simple PID controller on each of the pitch, roll and altitude controls, this ensures that the flight operation to be steady without considerable oscillating variations. The navigation of the quadrotor is dependent on the wall following algorithm along with the mission planner. Obstacle avoidance ensures that indoor environments can be explored regardless of the Page 9 of 10 Testing Tested while running the intelligence software.

Real time execution and experimentally determined accuracy of localization. Pre flight and On Flight testing for image processing Onboard as well off board testing for suitability to tuning presence of obstacles. Finally, image processing enables the quadrotor to scan for patterns, edges and symbols and make corresponding control outputs to maneuver the quadrotor to reach its target room with the flash drive. References 1) Johnson, E. N. and Schrage, D. P. , “ System Integration and Operation of a Research Unmanned Aerial Vehicle,” AIAA Journal of Aerospace Computing, Information and Communication, Vol. 1, No. 1, Jan 2004, pp. –18. Durrant-Whyte, H. ; Bailey, T. (2006). " Simultaneous Localization and Mapping (SLAM): Part I The Essential Algorithms". Robotics and Automation Magazine 13 (2): 99–110. Andrew J. Davison. Real-time simultaneous localization and mapping with International Conference on Computer V i s i o n (I C C V ’ 0 3) - V o l u m e 2 , 2003. a single camera. Ninth IEEE 2) 3) 4) Chowdhary, G. V. and Johnson, E. N. , “ Theory and Flight Test Validation of Long Term Learning A d a p t i v e F l i g h t Controller,” Proceedings of the AIAA Guidance Navigation and Control Conference, Honolulu, HI, 2008. 5) 6) Michelson, R. Rules for the International Aerial Robotics Competition 6th Mission, http://iarc. angelstrike.

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