An Algorithm for Landing a Quadrotor Unmanned Aerial Vehicle on an Oscillating Surface

Paul Infant Teenu Mohan Das, Suraj Swami and James M. Conrad
University of North Carolina at Charlotte, Charlotte, NC, USA
{pmohanda, sswami, jmconrad}@uncc.edu

Abstract— **In many applications of a Quadrotor Unmanned Aerial Vehicle (UAV), it is necessary for it to land on a moving surface. In this experiment four simple PING))) ultrasonic sensors are used to create a landing algorithm that changes the orientation of the quadrotor during landing depending on the orientation of the landing surface. The control structure changes the roll, pitch, yaw, and throttle parameters of the quadrotor in real time to provide the softest possible landing. This is very important when the quadrotor is carrying a delicate payload. The same algorithm can also be used to land a quadrotor on an inclined surface.**

Keywords-Quadrotor, oscillating, landing, UAV

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) were initially designed in military application to save human lives. However, improvement in sensor fabrication and automation made it possible to design smaller UAVs which could not only be used for military application but indoor application as well. Figure 1 [1] differentiates different UAVs based on features like the flying principle and the propulsion mode. The major categories of aircraft are the Motorized type, with well known examples like commercial and military airplanes and helicopters. Quadrotors are an UAV that are being increasingly used for research in the last decade.

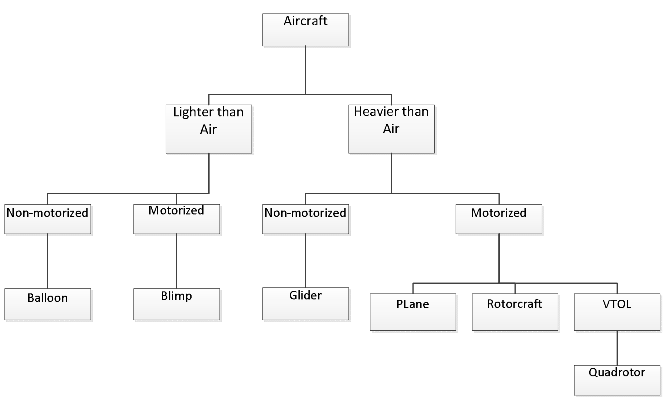

Fig.1. Aircraft classification based on flying principle and propulsion mode

Among these UAVs, quadrotors provides an advantage on maneuverability over conventional UAVs due to their Vertical Take Off and Landing (VTOL) capabilities. Quadrotors are an underactuated system with four inputs (throttle of each rotor) and six outputs (translational and rotational motion). General algorithms provide the control system for controlling the motors to stabilize the quadrotor in the air and as well as take-off and landing. Different algorithms [1 – 8] were implemented depending upon various factors like the configuration of motor (plus and cross configuration) and the required task to be performed. Various algorithms for Mapping, Simultaneous Localization and Mapping (SLAM) [11-13] could be possible since the quadrotor could also hold various sensors like laser scanners and stereo cameras on them.

Most of the experiments only emphasize landing of the quadrotor on a flat surface. However, in certain situations such as landing on a ship's deck, it is required for the quadrotor to land on an oscillating surface. In most cases, the quadrotors are load bearing and to ensure safety of the load, landing has to be as soft as possible. This paper focuses on testing the algorithm for landing the quadrotor on an oscillating surface. Section 2 provides background details on quadrotors and various experiments performed on them. Section 3 describes the design of the quadrotor to perform landing on an oscillating surface. In Section 4 we describe the control loop applied on the quadrotor to make it land, Section 5 includes the experimental observations and finally we conclude with future work possible.

II. BACKGROUND

The field of UAV and VTOL systems provides various research areas for further development. The major advantage of a quadrotor over a traditional helicopter is the fixed rotor propulsion mode. The roll, pitch and yaw of a quadrotor change depending on the throttle in each rotor. The four rotors are aligned such that, the rotors at opposite ends rotate in the same direction and the other two in the opposite direction.

In order for the quadrotor to move about the roll axis, the throttles of the other side rotors (right or left) are increased, while reducing the same side rotor throttles. For movement about the pitch axis, the front or back rotors are increased or reduced in the same way as for roll. In case of movement about the yaw axis, the counter-clockwise rotating rotors throttles are increased for rotation of the vehicle in counter-clockwise direction and the same holds good for clockwise rotation as well.

The vehicle has two different configuration in which it can be flown, the ‘X’ configuration and the ‘+’ configuration. Figure 2 shows both the configurations. The experiments described in this paper were based on an X-configuration quadrotor as they are more stable compared to the + configuration, which is a more acrobatic configuration.

There has been work done on quadrotors in areas like control systems [1 – 9], which apply different control algorithms on a quadrotor in order to stabilize it. There have also been journals which describe the complete control mechanism and the different sensors used [8].

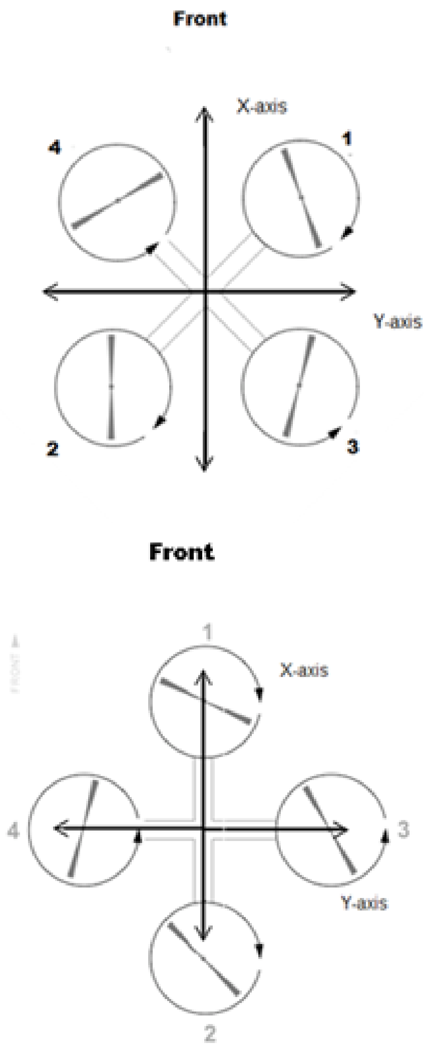

Fig 2. X-configuration and + - configuration

Papers can be found on designing large quadrotors which have load bearing capacity [9]. There has been research in various other aspects of a quadrotor like vision-based systems [10-12] and Multi-Agent systems [13-16].

In all the above experiments, the quadrotor landed on a flat surface, where the only way for landing in all the systems was to reduce the throttles of all motors gradually at the same time. Hence, in this paper a different algorithm for landing of a quadrotor on an oscillating surface is developed.

III. DESIGN

As explained in the introduction a quadrotor has four rotors that interact to produce lift. An open-source quadrotor from Aeroquad [17] was used for the experiments related to this article. It consists of four brushless motor DC motors of high RPM which were controlled using the Arduino Mega 2560 micro controller board. It also incorporated a 6-DOF inertial measurement unit (IMU) containing an accelerometer and a gyroscope along the x, y, and z axis. These motors are controlled through Electronic Speed Controllers (ESC), using Pulse Width Modulated signals (PWM). The quadrotor could be controlled using a RF remote controller. Figure 3 shows the quadrotor with all the sensors. The PING))) sensors near each rotor are specific to the experiment and algorithm execution.

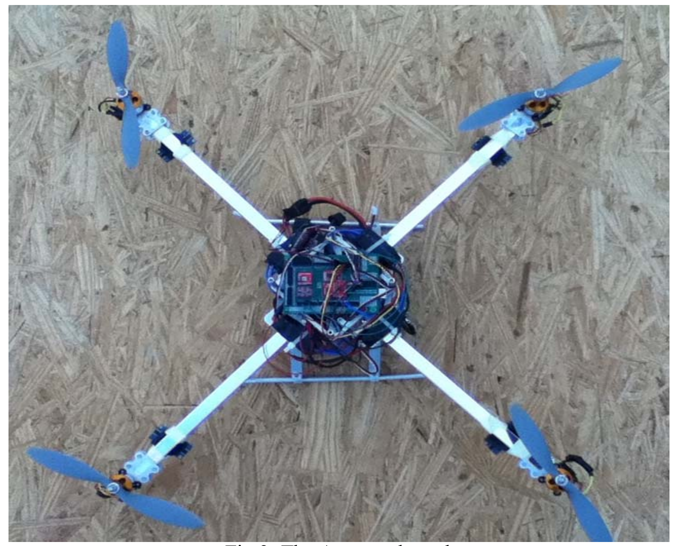

Fig.3. The Aeroquad quadrotor

The original design of the open-sourced quadrotor lacked the capabilities to be controlled by the PC. Hence, for this study a Xbee Pro 802.15.4 module was incorporated which communicated control commands from the PC to the quadrotor and received sensor data for analysis from quadrotor to PC using the XBEE module.

To calculate the ground distance for the algorithm, four PING))) ultrasonic sensors were installed facing the ground (Fig 3). The PING))) sensors used in these experiments had a range 20-300 cm. These sensors helped in detection of a landing surface and its orientation.

The original code was modified to have an autonomous take-off and landing on a stationary surface. The new code could also modify different parameters of the quadrotor like roll, pitch and yaw depending on the command transmitted from the PC via Xbee communication. Further, the code was improvised such that, on receiving a landing command, the quadrotor could land even on an oscillating surface.

IV. CONTROL SYSTEM

The control system used on the quadrotor may vary from a PID system [2-4] to more complex systems like Backstepping and Neural networks [5-7]. The effective control that complex control systems produce, like Backstepping and Neural networks, comes at the cost of computation time and resources. Complex control systems are used when the maneuvers that the quadrotor needs to perform are also complex. However, for our experiments a simple PID system which consumes less time and computation power was sufficient.

The PID control system was taken from the open-source aeroquad project and was in the form of software. It is important that proper PID tuning is done as it might cause instability during flight. For example, a high proportionality constant might give rise to oscillations that need damping time to stabilize.

V. LANDING ALGORITHM

The major advantage of this algorithm is that it uses low-cost PING))) sensors in order to land safely. The algorithm to land the quadrotor is presented as a flowchart in Figure 4. When the landing command is received, the algorithm gradually starts reducing the throttles of all the motors simultaneously. The rate at which the throttle is reduced depends on individual quadrotor characteristics like weight and dimensions. At the same time, the algorithm estimates the distance from the ground using the PING))) sensors. The landing algorithm starts only when the quadrotor is at a height of 1 m (or less) above the landing surface, which is calculated by taking the average of the four PING))) sensor readings.

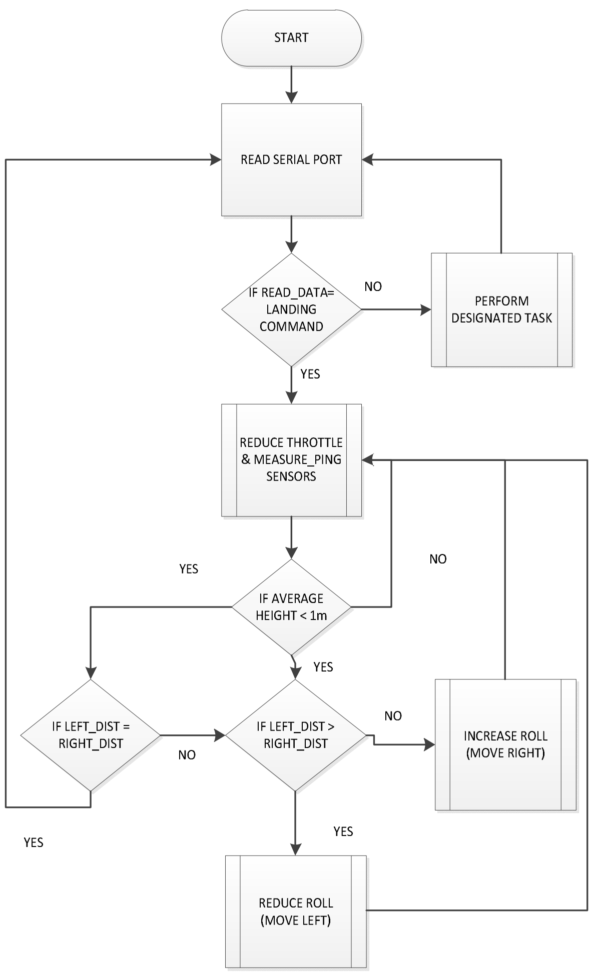

Fig. 4 The algorithm for instruction receive and landing

When the quadrotor is at a height of less than 1 meter from the ground, the algorithm continues to reduce the throttle value and at the same time detects the orientation of the landing surface using the four PING))) sensors which are placed under each rotor of the quadrotor. Assume the surface is tilted along the roll axis; in that case, the average distance of the two sensors on the left side of the rotor will be different from the average on the right. In order to align the quadrotor with the landing surface, the algorithm changes the roll in small steps until the distances on both sides of the quadrotor are the same, i.e. the quadrotor is aligned to the landing surface. The reduction in throttle and the working of the PING))) sensor simultaneously, ensures that the quadrotor lands on the landing surface while changing its orientation.

The major application and the motivation for this landing feature was the case of a quadrotor landing on a ship's deck. Even though a quadrotor is a VTOL and the space required for it to land is small, the damage that could occur on its landing gear could be substantial, especially if the quadrotor is large or carrying considerable payload.

VI. EXPERIMENT

Experiments had to be conducted in different stages in order to reach the final result. Initially, code supporting RC control was utilized to test the quadrotor's flight. After satisfactory flight performance the Xbee module was integrated with the quadrotor.

The Xbee module has a low baud rate as it is equivalent to a wireless serial connection. Hence, to ensure proper reception of commands, the commands were made of single alphabets, for example,'t' stood for takeoff and 'l' for landing. These commands were tested with the propellers detached from the quadrotor for safety purposes. Eventually, commands to control all the degrees of freedom (roll, pitch, yaw, and throttle) were verified even with the propellers on the quadrotor.

The next stage of testing was to control only the roll axis of the quadrotor when the landing command is given. This phase assumed that oscillations only happen along the roll axis. Once this was verified, the same was done for the pitch axis separately. These experiments were first conducted without the propeller on the quadrotor. After satisfactory results were obtained, the quadrotor was taken outside to do the test in flight.

Fig. 5 The experiment to verify the algorithm

The final phase involved testing of oscillations in both axes. Due to instability problems in the quadrotor's flight, for the safety of the people participating in the experiment the quadrotor was suspended from a string to restrict it from drifting away. The throttle was increased and a wooden surface of size 4'x 4' was brought under it and tilted on the quadrotor's roll axis. Figure 5 shows a scene from one of the tests that were conducted in which the tilting surface has a slope at the right side of the quadrotor and the quadrotor is inclined in order to orient itself to the landing surface.

After the landing command was given the quadrotor was observed to be moving according to the landing surface and the algorithm responded satisfactorily. During the experiment different rates of oscillations were given and the response of the quadrotor was observed. Even though the quadrotor responded to the landing surface there are improvements that still need to be made in order to ensure safe landing

VII. Conclusion

The landing was observed to be highly dependent on the rate of tilting/oscillation of the landing surface. At lower frequency the quadrotor was observed to drift away from the landing platform, due to its inherent property of moving in a direction of tilt.

In order to counter this problem, more sensors need to be mounted which may vary from GPS to Image processing cameras, which detect the landing surface and restrict the quadrotor from flying away from it.

References

[1] S.Bouabdallah, P. Murrieri and R. Siegwart, "Design and Control of an Indoor Micro Quadrotor", pp 4393-4398, New Orleans, *Proceedings of IEEE International Conference on Robotics and Automation,* April 2004.

[2] S.Bouabdallah, A. Noth, R.Siegwart, "PID VS LQ Control Techniques Applied to an Indoor Micro Quadrotor", pp.2451-2456, Sendal, *Proceedings of IEEE International Conference on Intelligent Robots and Systems,* October 2004.

[3] B. Erginer and E. Altuğ, "Modeling and PD Control of a Quadrotor VTOL Vehicle", pp 894-899, Istanbul, *Proceedings of IEEE Intelligent Vehicle Symposium,* June 2007.

[4] A.Tayebi and S. McGilvary, "Attitude Stabilization of a VTOL Quadrotor Aircraft", Vol. 14, No.3 pp. 562-571, *IEEE Transactions on Control Systems Technology,* May 2006.

[5] S.Bouabdallah and R.Siegwart, "Backstepping and Sliding-mode Techniques Applied to an Indoor Micro Quadrotor", pp 2247-2252, Barcelona, *Proceedings of IEEE International Conference on Robotics and Automation*, April 2005.

[6] J. Dunfied, M. Tarbouchi and G. Labonte, "Neural Network Based Control of a Four Rotor Helicopter", pp 1543-1548, *Proceedings of IEEE International Conference on Industrial Technology,* December 2004.

[7] T. Madani and A. Benallegue, " Backstepping Control for a Quadrotor Helicopter", pp 3255-3260, *Proceedings of IEEE International Conference on Intelligent Robotics and Systems,* October 2006.

[8] Bouabdallah, S.; Siegwart, R.; "Full control of a quadrotor," *Intelligent Robots and Systems, 2007. IROS 2007. IEEE/RSJ International Conference on* , vol., no., pp.153-158, Oct. 292007-Nov.22007doi: 10.1109/IROS.2007.4399042

[9] P. Ponds and R. Mahony, "Design Principles of Large Quadrotors for Practical Applications", pp 3265-3270, Kobe, *Proceedings of IEEE International Conference on Robotics and Automation,* May 2009.

[10] A.Tsourdos, S. Jeyaraman, M. Shanmugavel, B.A. White and R. Żbikowski, "A Formal Model Approach for the Analysis and Validation of the Cooperative Path Planning of a UAV Team", pp 69-73, Proceedings of IEEE seminar on Autonomous Agents in Control, May 2005

[11] D.H. Shim and S. Sastry, " An Evasive Maneuvering Algorithm for UAVs in See-and-Avoid Situations", pp 3886-3891, New York City, Proceedings of IEEE American Control Conference, July 2007

[12] M. Achtelik, T. Zhang, K. Kühnlenz and M. Buss, "Visual Tracking and Control of a Quadcopter Using a Stereo Camera System and Interial Sensors", *Proceedings of IEEE International onference on Mechatronics and Automation,* August 2009.

[13] A. Benallegue, A. Mokhtari and L. Fridman, "Feedback Linearization and High Order Sliding Mode Observer For A Quadrotor UAV", pp 365-372, Alghero, *Proceedings of IEEE International Workshop on Variable Structure Systems,* June 2006.

[14] S. L. Waslander, G. M. Hoffmann, J. S. Jang and C. J. Tomlin," Multi-Agent Quadrotor Testbed Control Design: Integral Sliding Mode vs. Reinforcement Learning", pp 3712-3717, IEEE *Proceedings of International Conference on Intelligent Robotics and Systems,* August 2005.

[15] G. Hoffmann, D. G. Rajnarayan, S. L. Waslander, D. Dostal, J. S. Jang and C. J. Tomlin, "The Stanford Testbed of Autonomous Rotorcraft for Multi-Agent Control (STARMAC)", Vol. 2, pp12.E.4 – 1-10*, Proceedings of IEEE Digital Avionics Systems Conference,* October 2004.

[16] Nathan, P.T.; Almurib, H.A.F.; Kumar, T.N.; , "A review of autonomous multi-agent quad-rotor control techniques and applications," *Mechatronics (ICOM), 2011 4th International Conference On* , vol., no., pp.1-7, 17-19 May 2011 doi:10.1109/ICOM.2011.5937132

[17] www.aeroquad.com