2014 5th International Conference on Information and Communication Systems (ICICS)

Obstacle Avoidance and Navigation in Robotic Systems: A Land and Aerial Robots Study

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***Abstract*—Autonomous airborne systems have generated a lot of interest in civilian and military applications. The operation of such systems involves routing and navigation toward targets and obstacle avoidance. In this paper, these problems were tackled and solutions were applied to land-based robots as well as a quad-rotor aerial system. The quad-rotor flight path navigation and routing was programmed based on GPS and on-board measurement data. Obstacle avoidance was implemented based on an algorithm that relies on the idea of Virtual Potential field. Kalman filters were implemented to improve the accuracy of the measured data. While 3D visualization was used to visually identify obstacles. In the case of in-building reconnaissance, where GPS signals are very weak and largely useless, we rely on laser sensors and data aggregation from proximity feeds to identify obstacles and the shape of the surrounding environment.**

I. Introduction

Robots have long attracted human interest. Intelligent robot development is a long-running wide-ranging research area. In the past few years, unmanned aerial vehicles (UAVs), or drones, have increased in prominence due to the number of possible civilian and military applications. Just recently, Amazon has announced that it will be using UAVs to deliver packages to customers in the next few years pending proper usage regulations by the United States government [1]. Moreover, the US have recently announced a set of six test sites all around the country with the goal of developing proper safety and operational regulations, advancing the UAV technology, and testing commercial usage [2].

Aviation technology has become ubiquitous, reliable, and cheap enough to allow for the development of sophisticated applications with relative ease. The majority of the complex flight control and avionic functionalities are readily available so as the road is paved for innovation. Quad-rotor also known as a quad-rotor helicopter did made the research area wide open because of the features that came with these type of UAVs. Military and security applications such as close range recognisance, agricultural applications, and commercial delivery are some of the major applications attracting great attention.

The unpredictability of the deployment environments makes obstacle avoidance one of the major problems in using unmanned vehicles. Achieving deployment goals relies on autonomous navigation and avoiding the obstacles in the environment. Autonomy is needed to deal with sudden appearance of different types of obstacles and to make on-site decisions. Moreover, it is requires in cases were the decisions need to be made in prompt real-time situations to avoid errors caused by the slow human decision-making process.

In this paper, we tackle the navigation, routing, and obstacle avoidance problems associated with UAV deployment. To conserve resources, we initially applied all algorithm to a land-based robot, the Pioneer 3DX [10], as a test vehicle. Only when the algorithms are fully verified and the implementation checked, we moved to the quad-rotor testing. For the UAV, we employed the Asctec Pelican quad-rotor [3].

Routing functionalities were programmed and relayed to the quad-rotor and the land robot using wireless connections. A map of the deployment area is fed to the system from Google Maps [4]. The flight path is then fed to the UAV as a set of points, which will be traversed in a certain order. The crux of the work involves obstacle avoidance, which will be detailed in the remainder of the paper.

To achieve obstacle avoidance from on-board sensor proximity values, we applied 2D planner algorithms in 3D. The 2D planner of choice is based on the Virtual Potential Field (VPF) approach. Much like magnetic fields, VPF treats targets and obstacles as charged particles that attract and repulse the UAV respectively. By establishing potential fields around obstacles and targets, we can simulate this effect and navigate the robot around obstacles and toward the targets. An attractive field surrounds the target. The potential field is defined across the entire free space. In each time step, we measure the potential field around the robot position. Then, calculate the induced force by this field and the robot will move according to this force. We calculate the relative distance between the robot and the target, the the required force is applied to drive the robot to the target and away from the obstacle.

The remainder of this paper is organized as follows. Section III discusses obstacle avoidance in land-based robots. Some background into the importance of the subject along with related work is presented in section II. Section IV details the various components of the quad rotor data analysis and filtration, routing, and obstacle avoidance. This section also shows the various algorithms we used to tackle these issues. We conclude in section V.

II. Background and Related Work

Multiple flight solutions are commercially available with reasonably cheap cost. We give details of two aspects related to our contribution; 1. Avionic technology and capabilities, and 2. Applications.

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A. Avionic Technology and Capabilities

Current small-scale flying solutions offer a very high thrust to weight ratio, a varying number of rotors (4, 6, or 8), and great onboard capabilities (GPS, 3D campus, ARM7, Intel Atom Processor, laser depth sensors, night vision). Moreover some of these solutions are made from carbon fiber material, which is ultra light weight material.

Capabilities [3]:

- Number of rotors: The large numbers of available rotors (up to 8) provides high lift capabilities and fault tolerance.
- GPS: For location awareness and navigation, this is possible by the on-board 3D campus.
- Laser depth sensors. This provides highly valuable information for obstacle avoidance programs.
- Night vision, thermal, and daytime cameras: Provide excellent monitoring and surveillance tools
- The ARM7 and Atom processors: provide us with great processing power to create and program sophisticated applications.

B. Applications

There are many situations that present a hazard for humans to venture into (e.g., building collapse, radiation, fire, etc.). For example, when the crane at the Jordan Gate project collapsed [5], it was left dangerously hanging pending rescue crew intervention, dismantling, and maintenance.

Traditionally, remote-controlled land-based robots equipped with cameras were used to explore hazardous areas and objects [6]. Such systems have achieved a great deal of success in dealing with search and rescue missions. However, there are conditions were such systems are hindered by debris, natural obstacles, mobility, heat, and many other natural factors impeding the movement of land-based objects. Such missions require high agility, maneuverability, and obstacle avoidance capabilities. Land-based robots lack in this regards. Moreover, the robots need to have a degree of autonomous capabilities in order to react to external circumstances.

Once provided with cheap, versatile aerial solutions. The door opens for a great number of applications are of use to the local community, a few of these include:

- Reconnaissance and monitoring; Future application scenarios include robotic security guards that can rapidly react to a triggered alarm by autonomously providing surveillance of a specific site or area. Other tasks center around autonomous border patrol and perimeter search. See Figure 2.
- Firefighting [7].
- Agricultural [8].
- Environmental.[9].
- Rescue Operations [6].

III. Obstacle Avoidance in Land Robots

As a starting point all algorithms were implemented and tested on the Pioneer 3DX robot [10]. This robot has on-board cameras as well as a sonar-based proximity sensor. It also features remote control and guidance capabilities.

We employed Alg. 1 for obstacle avoidance, which is based on the Virtual Potential Field (VPF) idea as mentioned earlier. In this algorithm, if the object is moving in the field of the target then it will start decreasing its speed (line 0.8), and if it is outside the target's field then it will move in a speed proportional to the power of the target's field. Once it reaches the target then it will stop. As for the obstacle, if the moving object is inside the obstacle's potential field then it will slow down and change its direction and orientation. Hence, the negative sign in the equation at line 0.16. Moreover, if the moving object is not within the range of the obstacle's field then no change is applied.

Figs. 1 and 2 show the Matlab simulation using the one stationary and two moving obstacles respectively. It clearly shows the effectiveness of the approach in avoiding obstacles. The algorithm was also implemented to work with the P3DX robot. Fig. 3 shows video snapshots of the robot moving toward the target while avoiding obstacles in the lab. Fig. 4 shows the same experiment from the live feed from the robot's camera along with a map of the location.

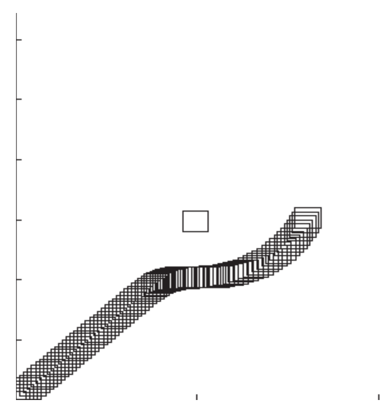

Fig. 1. Matlab simulation with one stationary obstacle.

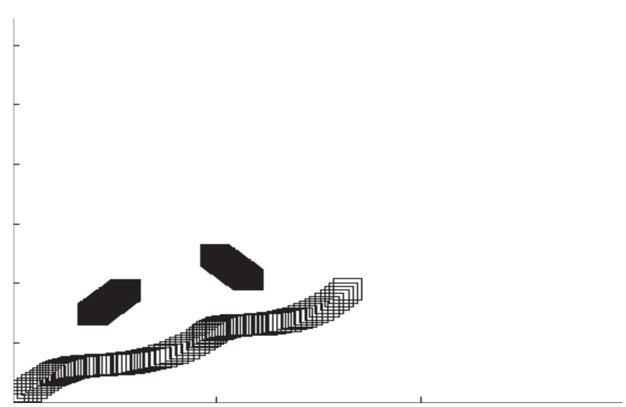

Fig. 2. Matlab simulation with two moving obstacles.

Data: d_t : Distance to target `// The cartesian distance`
r : virtual field radius around target
$Q_t : atan2(x, y)$ `// The arc tangent of the difference in coordinates between robot and target`
d_o : Distance to obstacle
r_o : virtual field radious around obstacle
$Q_o : atan2(x, y)$ `// The arc tangent of the difference in coordinates between robot and obstacle`

0.1 Assume initial robot position $(x = 0, y = 0)$
0.2 Calculate distance to obstacle
0.3 Calculate the angle between obstacle and robot
0.4 Calculate the distance between the robot and target along with the angle
`/* Target check */`
0.5 **if** $d_t > r$ **then**
0.6 $x\_to\_target = 0, y\_to\_target = 0$
0.7 **end**
0.8 **if** $(d_t < r \text{ AND } d_t + speed\_factor < d_t)$ **then**
`// Start decreasing speed of robot`
0.9 $x\_to\_target = factor \times (d_t - r) \times \cos(Q_t)$
0.10 $y\_to\_target = factor \times (d_t - r) \times sin(Q_t)$
0.11 **else**
`// Move full speed to target`
0.12 $x\_to\_target = factor \times \cos(Q_t)$
0.13 $y\_to\_target = factor \times sin(Q_t)$
0.14 **end**
`/* Obstacle check */`
0.15 **if** $(d_o < r_o)$ **then**
$x\_to\_obstacle = -factor \times \cos(Q_o)$
0.16 $y\_to\_obstacle = -factor \times sin(Q_o)$;
`/* else if too close to obstacle the slow down and reverse direction */`
0.17 **else if** $(d_o > r \text{ AND } d_o < (r + speed\_factor))$ **then**
0.18 $x\_to\_obstacle = -\beta \times (factor + r - d_o) \times \cos(Q_o)$
0.19 $y\_to\_obstacle = -\beta \times (factor + r - d_o) \times sin(Q_o)$
0.20 **else**
`// collision with obstacle`
0.21 $x\_to\_obstacle = 0$
0.22 $y\_to\_obstacle = 0$
0.23 **end**
0.24 $x = x\_to\_obstacle + x\_to\_target$
0.25 $y = y\_to\_obstacle + y\_to\_target$
0.26 Go to step 0.2

Algorithm 1: Virtual potential field algorithm.

IV. Obstacle Avoidance and Navigation in Quad Rotor Aerial Robot

Once the majority of the algorithms were implemented and tested on the P3DX, we moved into the quad-rotor deployment. However, the transition is not straight forward. We have encountered several issues mainly regarding obstacle representation. Fig. 5 shows the Xcontrol interface [3], which displays various flight parameters like location altitude, GPS data, rotor altitude, battery levels, speed, yaw, etc. This data is collected by the rotor's Inertial Measurement Unit (IMU) and presents the operator with a live feed of information from the on-board sensors. This same set of data can be used to program autonomous navigation and obstacle avoidance. Fig. 6 shows the interface used to program the flight path. Based on Google Earth maps [4] (or any other mapping service), the flight path is entered as a set of points to be traversed by the rotor in a predetermined order. The figure shows a path that instructs the rotor to follow the perimeter of a rectangular area.

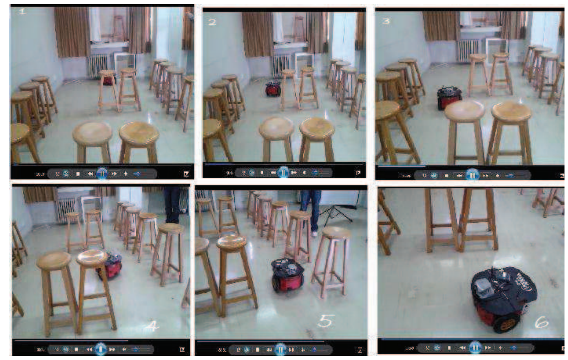

Fig. 3. The robot navigating around obstacles in the lab.

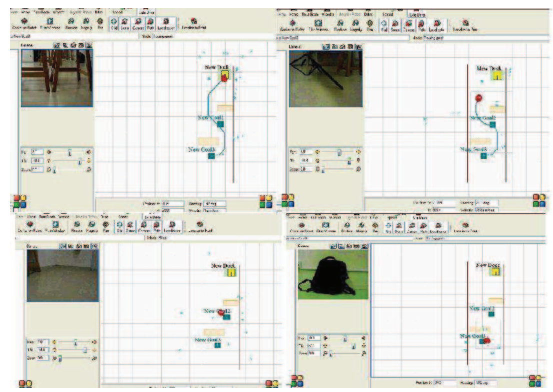

Fig. 4. A live view of the obstacles and the robot based on data feed from the robot.

V. Conclusion

Unmanned Aerial Vehicles have garnered a lot of research interest in the past few years. UAVs have found their way into a lot of civilian and military applications in what is now considered a multibillion dollars industry, and growing. Small UAVs offer cheap solutions along with great flexibility and ease of operation. In addition, these UAVs are increasingly equipped with more sensing, communication, and payload capabilities.

In this paper, we have tackled three issues central to the operation of UAVs and robots in general. Through simulations and experiments, we have implemented and demonstrated routing, navigation, and obstacle avoidance algorithms. In the future work, we will go through the details of our approach to quad-rotor navigation and obstacle avoidance.

The future is bright for Unmanned Aerial Systems; with the technology continuously improving, the costs are coming down, and many applications are finding this type of aerial capabilities useful. Tailoring UAVs to specific missions and applications would be an interesting research direction.

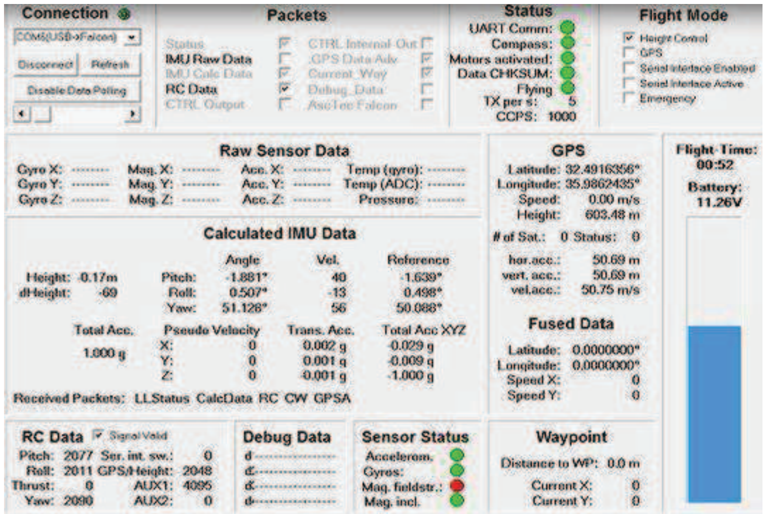

Fig. 5. A screenshot of the X control quad rotor data viewer showing the various parameters.

Fig. 6. The flight path programmed and overlayed on a Google map showing JUST soccer field.

Acknowledgment

We would like to thank Jordan University of Science and Technology (JUST) deanship of research for supporting this work through research grant 20110266. This research was funded in part by King Abdullah Design and Development Bureau (KADDB) in association with King Abdullah II Fund for Development (KAFD) research grant 12/2012.

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