Autonomous Guidance for Unmanned Aerial Vehicles

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Rotor powered unmanned aerial vehicles (UAVs) are inherently unstable systems that are prone to turbulence and sensor error. Feedback control algorithms can be implemented to measure and correct these sources of instability, resulting in a stable, versatile, and efficient platform. Navigation algorithms can then be implemented on this now stable UAV to enable particular flight paths, such as the 2D raster pattern needed for the UAV Synthetic Aperture Radar (SAR) Project.

What's the Hype with UAVs?

An estimated that 1 million unmanned aerial vehicles (UAVs) were sold during the 2015 holiday season alone. These holiday gifts will likely serve as the next robotic cameramen, do-it-yourself projects, and children's toys. While the common UAV is a fun-to-fly toy, this technology is here to stay. UAVs are fast, agile, and easy to deploy, giving them serious commercial and military applications. These include search and rescue, military reconnaissance, event security, and disaster relief.

Case Study: Synthetic Aperture Radar

One application in particular that benefits from UAV technology is Synthetic Aperture Radar (SAR). In SAR, a small radar antenna is equipped on a vehicle. Radar images are taken at numerous places along the vehicles trajectory and stitched together to create a high resolution radar image. The resolution of this stitched-together image is far higher than could be achieved with one radar image alone. Typical applications for SAR imaging are disaster and exploration mapping or military reconnaissance.

However, constraints in size, weight, and power have traditionally limited SAR platforms to large aircraft and spacecraft. The prohibitive cost and size of these platforms in turn limits who can create SAR images and where they can be created.

Recent technological advances have miniaturized radar antennas. These new low cost, low power antennas can be equipped to smaller platforms. In the case of the UAV SAR Project, the Blue Team is using an UAV as our SAR platform. UAVs offer key improvements over traditional SAR platforms because they are agile, easily deployable, and low cost. They therefore have the potential to dramatically increase the accessibility and applicability of SAR technology.

There are of course many technical obstacles to overcome in order to create usable SAR images from a UAV platform. Positional accuracy is crucial in forming coherent SAR images, but UAVs are inherently

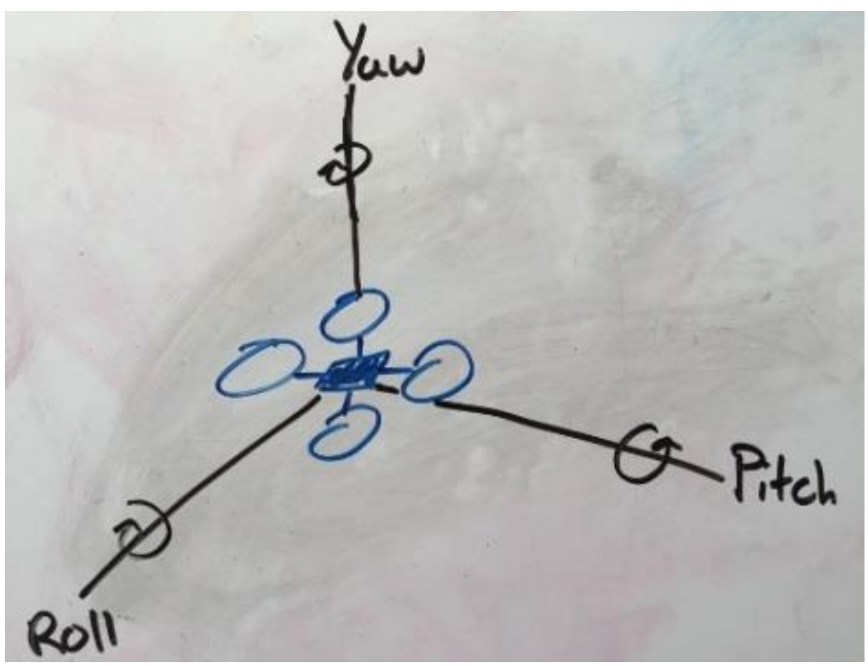

Figure 1: Diagram of Roll / Pitch / Yaw

unstable platforms. The image errors that originate from these positional inaccuracies can be compensated for with post-processing autofocus algorithms, as discussed in *Synthetic Aperture Radar (SAR) Autofocus Techniques* by Blue Team member Josh Psofi. Aperture flight paths also need to be addressed, touching upon the issue of autonomous navigation and sensing. Sensors used in for autonomous guidance, navigation, and control (GN&C) are discussed in the *Role of Sensors in Autonomous Navigation* by Blue Team member Aaron Forest. The remainder of this note is concerned with the algorithms behind GN&C and how they are best adapted for use with the UAV SAR Project.

Autonomous Navigation

Feedback Control

In open loop control, rotor UAVs are unstable platforms (Bristeau, 2011). They require embedded control systems to enable stability and ease of flight for the operator. These feedback control algorithms take user input and information from onboard sensors. This information is then processed and low level commands are issued to the rotors to control attitude, roll, pitch, and yaw (Bristeau, 2011).

Guidance, Navigation, and Control (GN&C) Algorithms

Once control and stability for the UAV itself has been achieved, navigation throughout an environment can be considered. These GN&C techniques are inherently optimization algorithms. Based upon a given environment and user input, they aim to find the optimal path between a given starting and ending location. In the case of the SAR Project, we require an algorithm to allow our UAV to traverse a 2D raster pattern. This will sweep out our ideal synthetic aperture.

Two types of path planning algorithms are used to identify the one best suited for the SAR Project. They are grid-based navigation and virtual force field path planning. Both are described below.

Grid Based Navigation

Most path planning algorithms partition the flight area into a grid, where each object is assigned an x, y, and z coordinate (Borenstein, 1989). The advantage of the grid is that it allows for simple integration from various sources, such as sonar, vision, and user input (Borenstein, 1989). The UAV maps objects to the grid either in real-time (a prevalent research topic), or based upon a prior mapping.

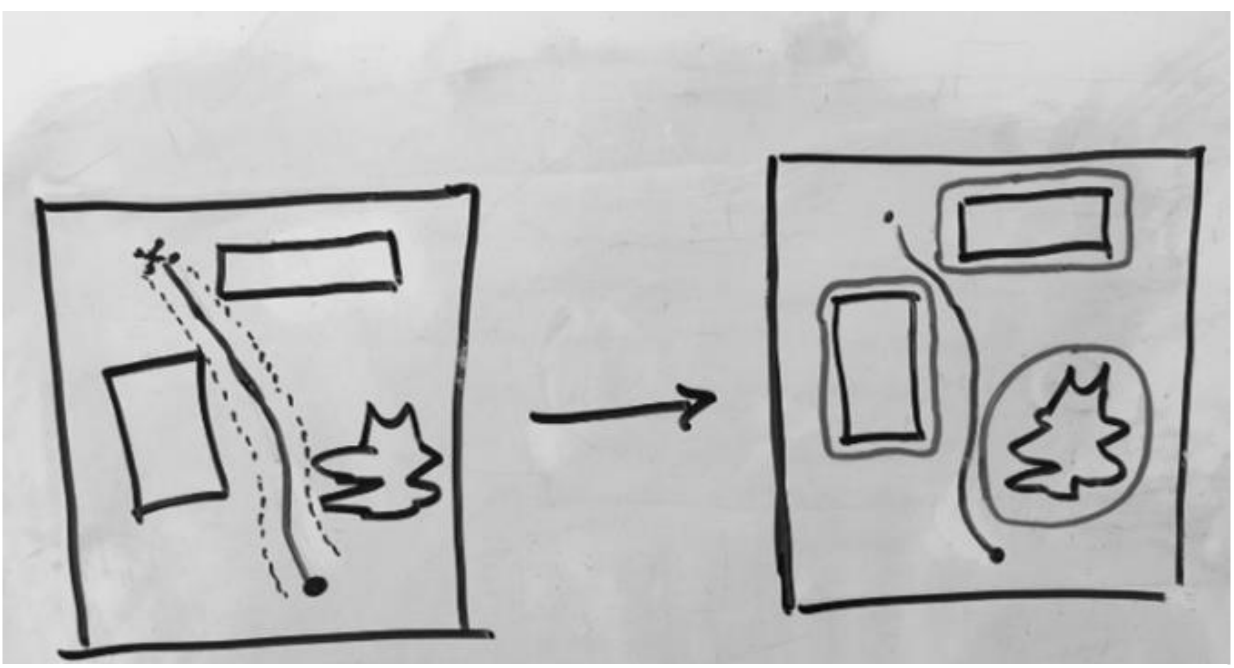

Figure 2: Two path planning sequences. Left: the vehicle is surrounded by a bounding ball. Right: the vehicle is a single point and a buffer radius has been applied to every obstacle.

To properly navigate without incident, either in real time or with a predetermined trajectory, the vehicle must be modeled within the map. The easiest modeling method is to represent the vehicle as a single point. However, because the single point does not take the vehicle's size into account, the point vehicle is most often fit inside a bounding ball. This ball can take on either two or three dimensions (it is 3D for modeling UAVs) and has dimensions similar to that of the actual vehicle. Figure 2 illustrates how the bounding ball is used for trajectory planning. There are two simulation methods. Either the vehicle can remain bounded by the bounding ball, or the vehicle can be represented by a single point. If the vehicle is represented by a single point, every obstacle in the world space is expanded by the radius of the bounding ball. This buffer space ensures that the UAV will never collide with any object in the map.

Virtual Force Field Path Planning

The Virtual Force Field (VFF) translates every object in the world map into attractive and repulsive forces (Figure 3). This forms a gradient that points away from all obstacles and towards the target. A gradient descent algorithm then allows the robot to find the optimal path through this gradient space (Goerzen, 2010).

While this is an effective algorithm, it is prone to several issues. The first is being caught in local minima (Goerzen, 2010). This can occur if the UAV becomes trapped with a U-shaped obstacle or if it rotates more than 90 degrees away from the target. In order to recover from these local minima, the UAV can revert to a simple line following algorithm. The second issue with VFF is that it can cause oscillatory motion in the UAV as it travels towards and away from an obstacle. To remedy these oscillations, force and speed dampening must be applied. This effectively smoothens the trajectory (Borenstein, 1989).

Adaptation for the SAR Project

As described above, UAVs are a promising platform for SAR. They are easy to deploy, low cost, and adept at navigating through challenging terrain. In order to produce viable SAR images, the UAV must travel in a crisp raster pattern, as shown in Figure 4. The navigation algorithms described above can achieve this.

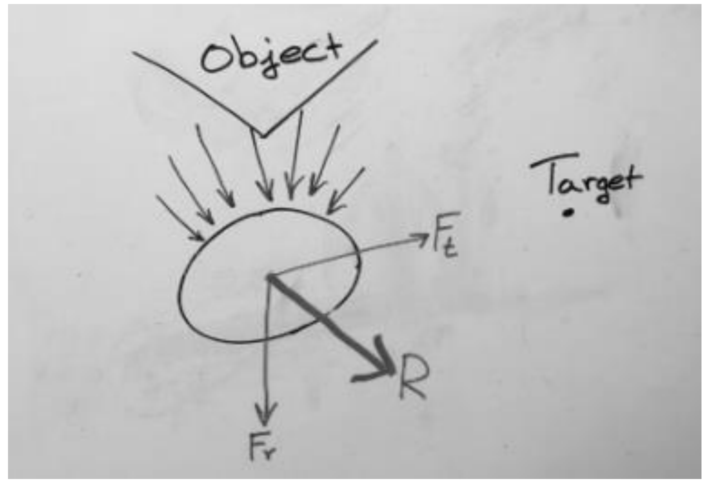

Figure 3. Diagram of the Virtual Force Field algorithm. The object exerts a force on the vehicle, preventing a collision. F_r represents this repulsive force, F_t represents the attractive force to the target, and R is the resultant force.

Our project implements a combination of grid-based navigation and virtual force field path planning. Most flight paths can be pre-planned using existing area mappings. GPS waypoints can be placed throughout this mapping in any desired pattern, a raster pattern for our project, and the grid-based algorithm will program

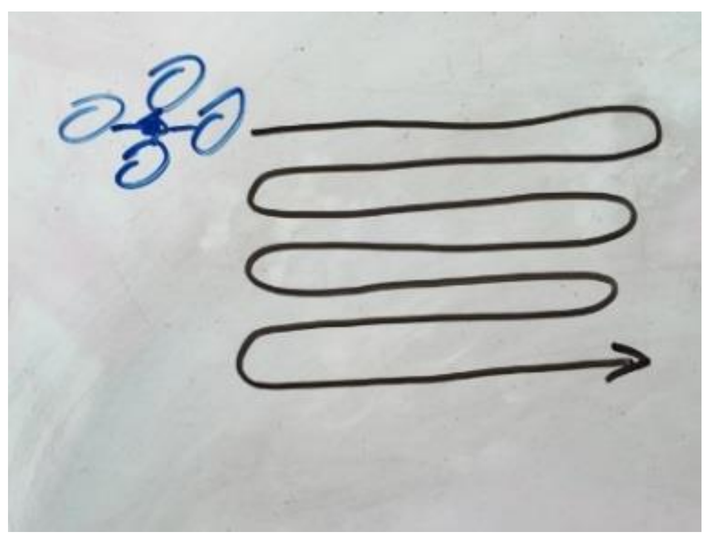

Figure 4. Optimal UAV flight path. This raster patter allows the UAV to sweep a rectangular aperture.

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trajectory that avoids any known obstacles. There is a chance, however, that the planning trajectory will intersect unknown obstacles. This is where on-board sensors (The Role of Sensors in Autonomous Navigation) and the virtual force field algorithm take over. If sensors detect an imminent collision, the VFF will be able to slow the UAV and guide it around the object. The raster pattern would be slightly compromised. However, as long as the UAV position is accurately measured during this course change, image quality will not be compromised.

References

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