Background and Progress Report

For individual project

Jonas Brami

1 June, 2022

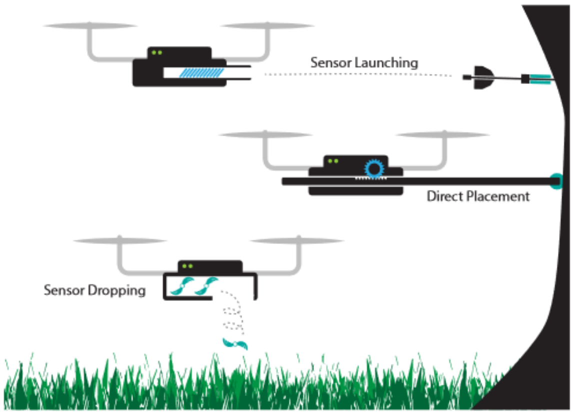
Contents

1. Introduction

The problem we aim to solve during this project is the placement of a sensor on a specific target point on a surface using a fixed manipulator arm mounted on the top of an unmanned quadcopter (helicopter with four rotors). Sensor placement of surfaces using UAVs (Unmanned Aerial Vehicles) is an active field of research and we will propose a solution based on velocity fields. A velocity field is a function taking as input 3d coordinates and time and returning a 3d velocity vector. Since our environment is static (obstacle and goal are not moving), we will always use velocity field constant in time. Diverse ways of placing sensors sensor using UAVs have been explored in the past, including but not limited to:

- Direct Placement: Using a fixed arm manipulator on an UAV, we use the force exerted by the thrust of the UAV to provide enough pressure on the tip of the arm to place the sensor on the target point
- Sensor Launching: Using the energy stored in a spring, the UAV ejects the sensor at the desired velocity to reach and attach to the target (Unmanned Aerial Sensor Placement for Cluttered Environments). This strategy is very useful when it is not physically possible for a mounted arm to reach the target however it suffers from small payload capacity.
- Drop from flight: We simply drop the sensor above the target point. When target accuracy is not a priority, we are aiming at an non vertical surface and there is no occlusion above the target, this sensor placement strategy is the most effective.

We decided to go throught with the Direct Placement strategy because despite its simplicity, it provides good accuracy and is able to place a large variety of payloads. The solution we will propose can be divided in 3 parts: The first is environment mapping where we perform surface and obstacle recognition using live depth sensor feed. The second part is designing a potential based velocity field to perform path-planning by guiding the UAV from the start point to the target point. The third and last part is designing a velocity field around the target point to apply the desired force amplitude. In this part, we will use the passive velocity field controller (PVFC) to optimize our energy consumption.



	Direct [7]	Drop [2]	Launch [i]
Accuracy	±0.025 m	±4 m	±0.1 m
Safety distance	0 m	>10 m	4 m
Payload	1.85 kg	10 kg [ii]	0.65 kg
Sensor number	single	multiple	expandable

Figure 1: Unmanned Aerial Sensor Placement for Cluttered Environments

2. Literature Review and Theory

1- PVFC 2- Potential field 3- Asl Narikiyo ? no countour so no need?

2.1. Velocity field path-planning for single and multiple unmanned aerial vehicles

In the paper "Velocity field path-planning for single and multiple unmanned aerial vehicles", the author presents a path-planning technique based on Velocity Fields generated from potentials solution of Laplace's equation. Two different type of solution to the Laplace

$$\nabla^2 V = 0$$
$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} = 0 \tag{1}$$

equation are presented in this paper: Type 1 are irrotational solutions to generate sink and source fields and Type 2 solution are used to build solenoidal fields.

$$V_1 = Q_1 \ln\Big((x_1 - \tilde{x_1})^2 + (x_2 - \tilde{x_2})^2\Big) \tag{2}$$
$$V_2 = Q_2 \arctan\left(\frac{(x_2 - \tilde{x_2})}{(x_1 - \tilde{x_1})}\right) \tag{3}$$

(x_1, x_2) is the position of the UAV
$(\tilde{x_1}, \tilde{x_2})$ is the position of the obstacle
V_1 and V_2 are respectively type 1 solution (source field) and type 2 solution (vortex field).
The author justifies the use of Laplace solution for building the velocity field for multiple reasons:

- The use of Laplace solution for potential guaranties the uniqueness of minimum in the field. Specifically, the use of vortex function built from shaping function to circle around obstacle will. This ensures that only the goal point will be a minimum and that the UAV will not get stuck at some local minimum. As the author states, we can do an analogy with a famous strategy to find the exit of a maze: By keeping a hand on a wall of the maze and walking while always touching the wall, we are ensured to find the end of the maze. This is far from being an optimal solution, however, by using vortex function to circle around obstacle, we can provide the guaranty that the goal will be reached. As a result, those solenoidal fields based on vortex function also provides active collision avoidance.

- Scalar shaping functions are at the base of these methodology because by crafting them to match the shape of the obstacles, we are able to generate corresponding vortex functions for obstacles of any shape. Since the vortex field is defined for each obstacle, it would be easy to reevaluate the field add/removal of an obstacle.

- Finally, irrotational solutions of the Laplace equation allows us the define an exclusion radius around obstacles (source field) and to direct ourself in direction of the target point (sink field). The exclusion radius is encoded using the amplitude Q_1 of the irrotational field.

We can leverage these both types of potentials to derive a velocity field that will guide the UAV to the contact point without colliding with the surface. For example we could define the exclusion radius to be the distance between the centre of mass (CoM) of the quadcopter and its most distant part on the quadcopter. We will still be able to make contact because the distance between the tip of the arm and the CoM will be longer than this exclusion radius.

2.2. Spherical field to maintain desired force

When contact has been made, we suppose that the surface static friction coefficient is high enough to maintain the contact. Since the arm has a fixed size and does not move, this part will describe a partial sphere around the target point with a radius defined by the distance between the CoM of the quadcopter and the tip of the arm. First we need to compute the feasible position of the CoM to apply the desired force. We know that this position is unique because there is only one vertically stable pitch for a given desired force amplitude. We can either compute this position analytically or we can use machine learning techniques such as regression to compute the feasible pitch in function of the desired force. The latter option would require collecting training data from simulations on gazebo. Now we can generate the velocity field on the surface of the sphere to point on the tangent direction of the sphere in the direction of the stable pitch position with an amplitude proportional to the distance from this point. Finally, we use the Passive Velocity Field Control to follow this field

2.3. PVFC

2.4. Asl Narikiyo coutour

normal + tangeant ? talk about it despite not doing countour

3. Technical Experimentation

In this section, we will present the field we previously described with illustrations. The field in

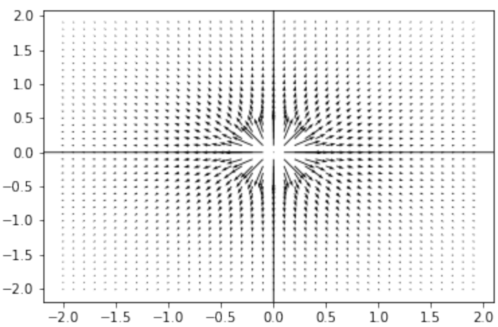


Figure 2: Simple Type 1 irrotational source

figure 2 was drawn by computing the gradient of V_1 with $(\tilde{x_1}, \tilde{x_2}) = (0, 0)$

The field in figure 3 is a sink field at $(0, 1)$, it is similar to the source field in figure 2 but with opposite sign.

The field in figure 4 has been generated by computing the gradient of the shaping function of a superquadratic: $F = \frac{1}{1+(\frac{1}{L}H^{\frac{1}{n}})^m}$ As stated in the paper, when $m >> 1$ the edge of the shaping function gets more thin and the higher n is the more quadriatic and the less circular the shape will be.

Both these fields are type 1 irrotational solutions of the Laplace equation.

By adding the irrotational sink from figure 3 and the irrotational field from shaping function in figure 4 we obtain a good representation (figure 5)

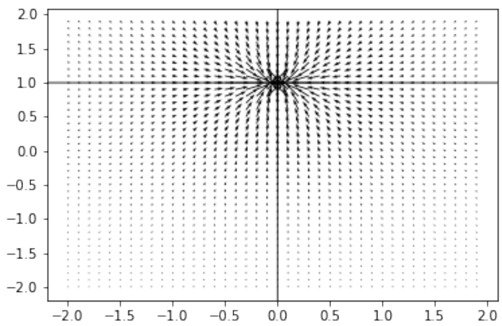


Figure 3: Simple Type 1 irrotational sink

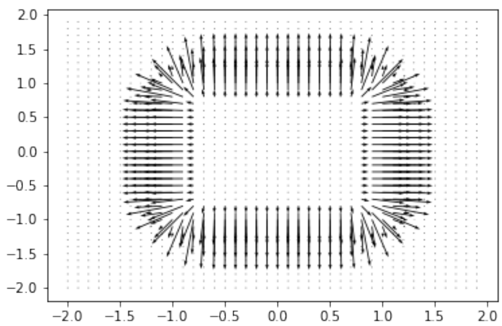


Figure 4: irrotational field from shaping

of what the velocity field will look like when close to the target point.

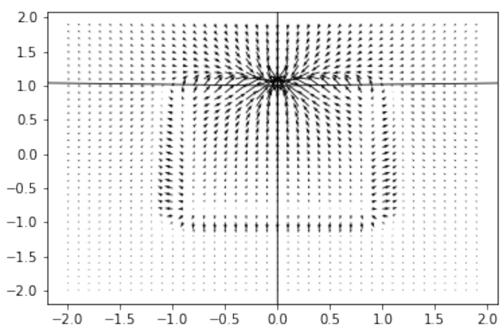


Figure 5: irrotational field from shaping with sink

The shaping function is mainly used to generate a vortex field around an obstacle, as explained in the paper, it is given by: $v_2 = -\frac{\partial F}{\partial x_2} e_1 + \frac{\partial F}{\partial x_1} e_2$ We can see in figure 5 an example of vortex field around a super quadriatic

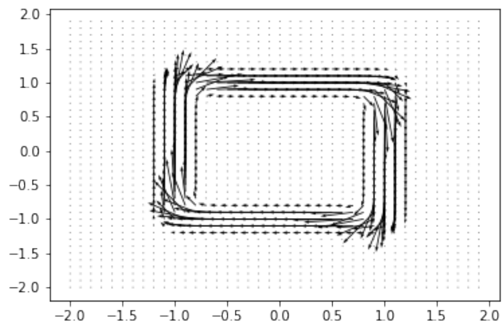


Figure 6: Solenoidale field from shaping function

4. Project Plan

5. References