Application of Autonomous Multi-Drone Systems to Large Structure Inspections

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1. Introduction

Use of Autonomous drones and robots are being widely deployed in inspection of large structures such as bridges, buildings, ships, wind turbines and aircrafts, as it is a hard task for the inspector to perform. The inspection is of critical importance since missing details could affect the performance and integrity of the structure. But as important as inspection is, it is also dangerous, time consuming and expensive as in most cases, scaffolding is required to inspect these large structures. The flight time of a UAV is short compared to the time needed to perform complete structural inspection of large structures, and therefore the use of a single UAV is under question and we need to use multi-drone systems to reliably inspect these structures. Inspection missions usually involve: Coverage Path Planning, Model Reconstruction and the Actual inspection of the structure. Coverage Path Planning (CPP) is the task of determining a path that passes over all points of an area or volume of interest while avoiding obstacles. Extensive research and development has taken place in single drone path planning and data integration to reconstruct the models for inspection. In this project, we would be developing the algorithms and methodologies for a Multi-drone system to inspect large structures such as ships or offshore oil installations.

2. Background Research

Visual inspection strategies for large bridges using Unmanned Aerial Vehicles:

Norman Hallermann & Guido Morgenthal of the Bauhaus-Universität Weimar [1] has discussed methods of visual inspection based on airborne photos and video taken by Unmanned Aerial Vehicles. Some of the features included in the setup was a "come home function" which guarantees a safe landing when the connection between the ground station and the flight system is interrupted. A GPS based Matrix system helps in flying at a constant distant to the structure and the feature called Point of Interest (POI) allows flying around a structure in a constant distant to the object with a continuous orientation of the flight system and the camera towards the center of the object.

A survey on inspecting structures using robotic systems:

In this article review[2], they have put together recent work in the field of coverage path planning and model reconstruction. Coverage path planning generates an optimized path that guarantees the complete coverage of the structure of interest in order to gather highly accurate information

to be used for shape/model reconstruction. Majority of existing approaches attempt to reduce the computational cost (time need to compute and execute the inspection mission), avoid collision with the structure of interest and gather information with sufficient resolution for anomaly detection.
Discrete CPP algorithms divide the planning problem into two steps: Viewpoints generation to generate a discrete set of viewpoints and optimal path generation using multi-goal planning to connect the viewpoints. Continuous CPP is mainly focused on following a trajectory while perceiving sensed information continuously.

3. Objectives and Methodology

The main objective of the proposed research work is to develop, implement and validate a methodology to use multi-drone systems for inspection of large structures. To developing a Coverage Path Planning methodology, Lissajous curves are used.

Lissajous curve:

Lissajous figures are patterns produced by the intersection of two sinusoidal curves the axes of which are at right angles to each other. The main objective of choosing such curves is that under specific conditions, they cover the entire surface at infinity time. The parametric equations that produce the curve is given as:

$$\mathrm{x} = \mathrm{A}\ \sin(\mathrm{a}t + \phi)$$
$$\mathrm{y} = \mathrm{B}\ \sin(\mathrm{b}t)$$

A and B represent amplitudes in the x and y directions ϕ is the phase angle. Depending on the values of a and b we can determines the number of horizontally aligned "lobes.[a]nd the number of vertically aligned lobes respectively. Rational ratios produce closed or still figures, while irrational ratios produce figures that appear to rotate.
Multiple Lissajous patterns were considered and is the one suitable for coverage path planning is chosen based on the number of way points from where visual data would be collected.

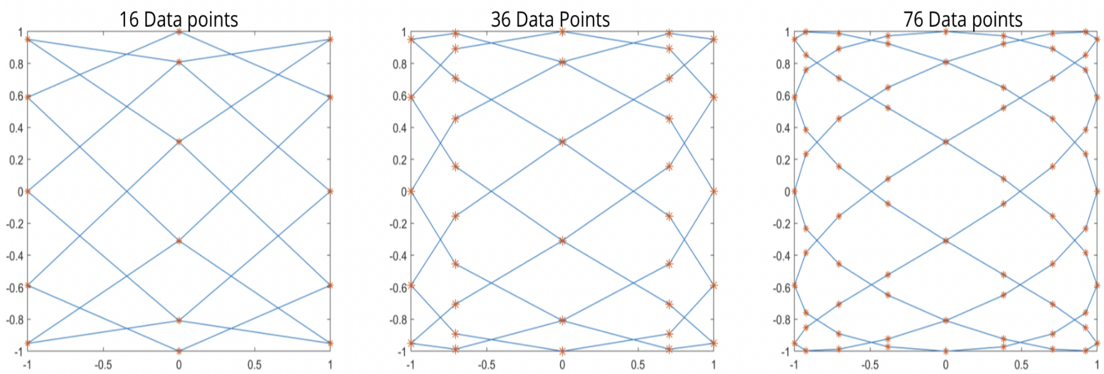

Fig. 1: Lissajous curves with different number of data-points

As Lissajous curves are on a two-dimensional plane, in order to carry out a three-dimensional CPP problem, we transform the way-points from a rectangle to a cylinder whose length and height correspond.

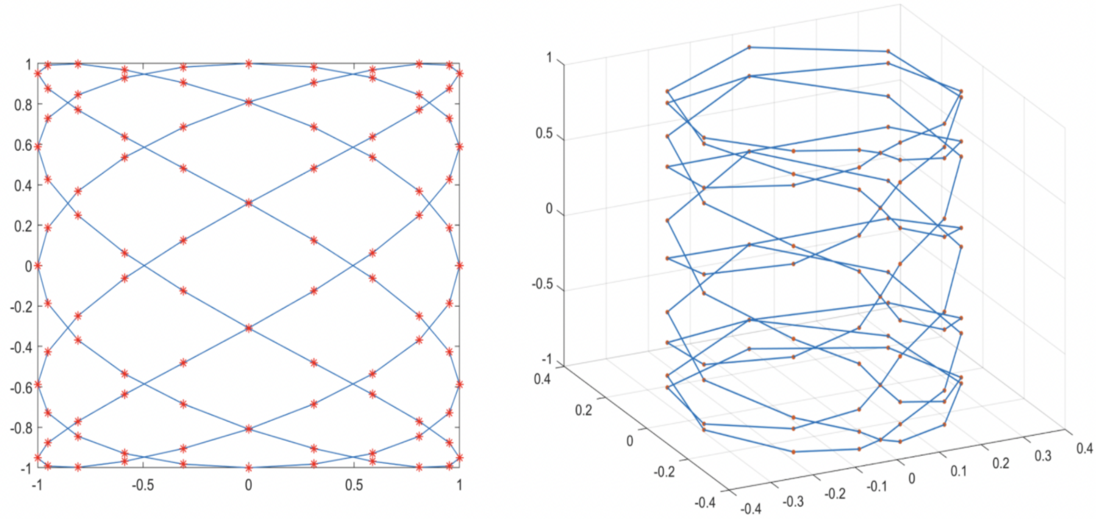

Fig. 2: Lissajous curves transformed to the surface of a 3-dimensional cylinder

The path illustrated in Fig.(2) can be carried out either completely using one drone or my multiple drones. The various simulations in the ROS-Gazebo environment, in order to carry out the coverage path planning problem with the way points generated using Lissajous curves, is elucidated in the next section.

Simulations:

Initially a two-dimensional on-ground simulation was carried out, where apart from control, a provision for stopping, turning to the structure and collecting data at each way-point was included. The simulation was carried out using Turtlebot3 and structure was cube on 1m side length.

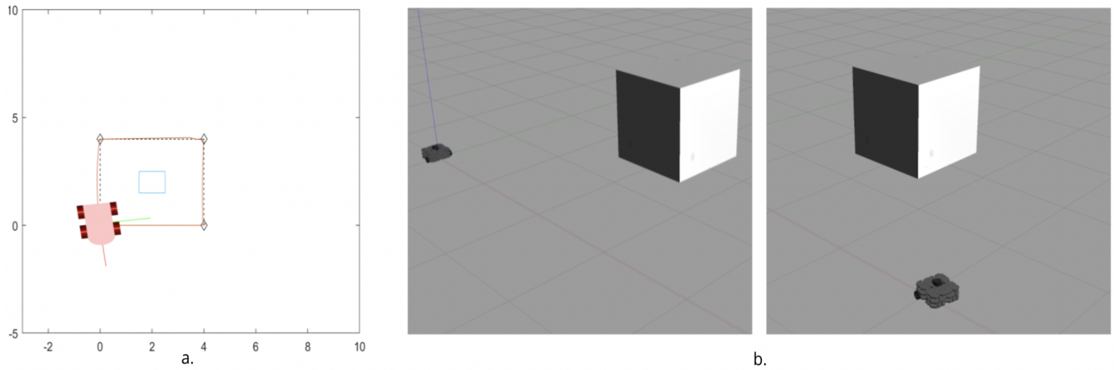

Fig. 3: (a) The trajectory followed by the turtlebot. (b) The Gazebo shots captured at the first corner during data collection.

The data is collected after the number of pixels of the cube inside a generated bounding box in real-time is in a desired range. This makes sure that the distance of the turtlebot from the structure is in a desired range as well. The same depth perception concept can be adopted in 3D data gathering problems to ensure uniformity in collected images.

Fig. 4: Images saved in the 2D path following problem at each way point.

The 3-dimensional coverage Path planning problem is implemented using a drone simulation. The tum_simulator is controlled and made to follow the trajectory using PD controllers for both position and altitude. The different trajectories the drone was made to follow is shown below.

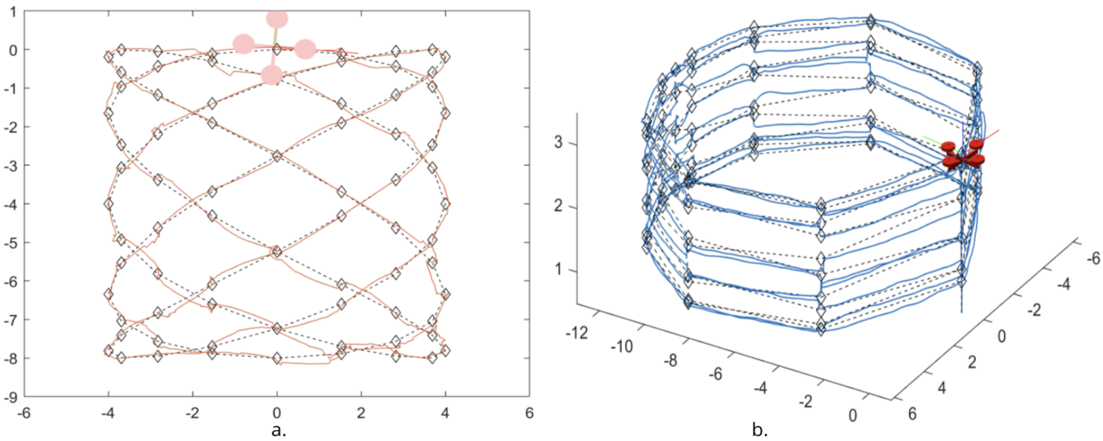

Fig. 5: The trajectory followed by the ARdrone 2.0 drone in (a) 2D along the Lissajous curve. (b) in 3D along the transformed cylindrical surface

Finally, as performed in the case of the turtlebot simulation, the drone is made to face the structure at each of the way-points and collect visual data. Though out the process the drone is stabilized at the altitude using a PD controller. The structure was a large cuboid with 3mx3mx6m dimensions.

The trajectory generated by the Lissajous curves are able to cover the entire curves surface are and at the same time they can be easily split into multiple drones operations. The division is done such the Lissajous curve time series are not disrupted and hence it is a very convenient way to plan multi-drone paths.

4. Conclusion

Through this project, a new solution to the Coverage Path Planning is proposed and implemented. Simulation carried out show the validity of this method. The use of Lissajous patterns to generate way points and trajectory gives us a relatively simple and computationally less extensive method to carry out the desired tasks. The simulation are carried out using ROS-Gazebo using

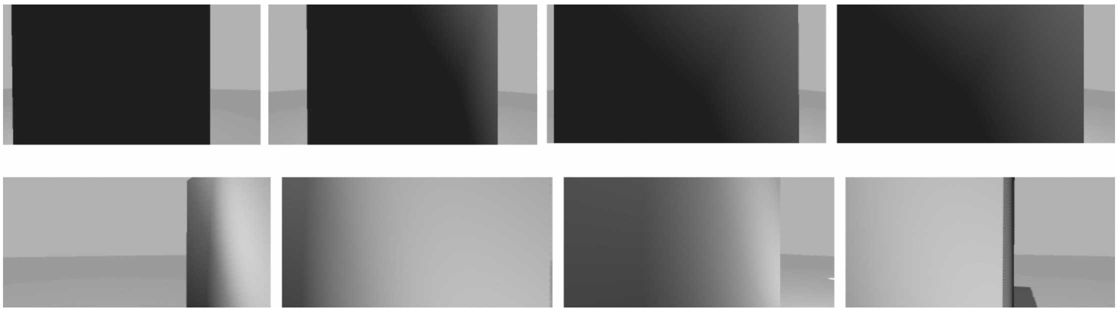

Fig. 6: 8 of 105 Images collected in simulation using MTALAB Desktop Prototyping

Tum_simulator as ARdrone and Turtlebot as the drive-robot. In the future, optimisation of the path with respective to energy expenditure or time, and inclusion of multiple drones to carry out the structural inspection could be implemented to improve the current set up. Moreover, the radius of the surface of cylinder used to create the 3D Lissajous curves can be varied to with time and height to be closer to towering structures. The challenge of way-points moving closer to each other needs to be mitigated by reducing the number of way-points with decrease in radius. With these improvements, the above presented methodology can be used for cases which do not require mapping and blueprints of structures.

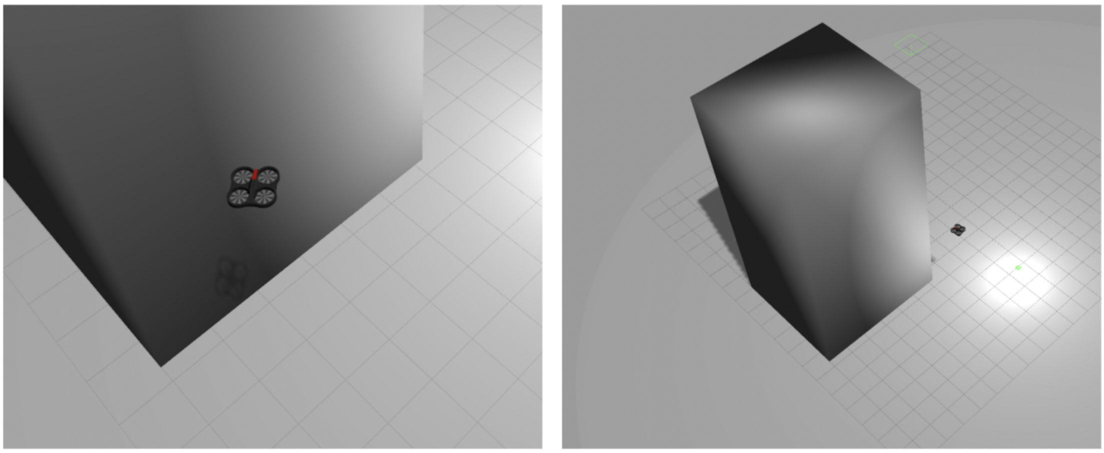

Fig. 7: The ARdrone 2.0 drone in 3D during simulation.

References

1. Norman Hallermann & Guido Morgenthal : Visual inspection strategies for large bridges using Unmanned Aerial Vehicles (UAV) July 2014, DOI:10.1201/b17063-96

2. Randa Almadhoun, Tarek Taha, Lakmal Seneviratne, Jorge Dias, Guowei Cai : A survey on inspecting structures using robotic systems.

3. Borkar, A., Sinha, A., Vachhani, L., Arya, H. (2016). Collision-free trajectory planning on

Lissajous curves for repeated multi-agent coverage and target detection. 2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS). doi:10.1109/iros.2016.7759231

4. Borkar, A.V., Sinha, A., Vachhani, L. et al. Application of Lissajous curves in trajectory planning of multiple agents. Auton Robot 44, 233–250 (2020). https://doi.org/10.1007/s10514-019-09888-7.

5. Milan Erdelj, Osamah Saif, Enrico Natalizio and Isabelle Fantoni : UAVs that Fly Forever: Uninterrupted Structural Inspection through Automatic UAV Replacement.

6. Englot B and Hover F.: Sampling-based coverage path planning for inspection of complex structures. In: Icaps 2012, pp. 29–37.

7. Borkar, A. V., Hangal, S., Arya, H., Sinha, A., Vachhani, L. (2020). Reconfigurable formations of quadrotors on Lissajous curves for surveillance applications. European Journal of Control. doi:10.1016/j.ejcon.2020.03.00