Primary Level UAV for Tunnel Inspection: the PLUTO project

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***Abstract*—The PLUTO project is aimed at the construction and testing of a drone, capable of carrying out autonomous inspection of railway tunnels. The project is fully implemented by the innovative Italian S.M.E. WPWEB, in response to a challenge proposed by the French railway company SNCF. The system: carries out the inspection of confined spaces where communication with the outside is absent; creates a 3D mapping to be used for monitoring the explored environment; automatically detects deteriorations through a neural network.**

Keywords—Service robotics, Flying robots, Tunnel inspection, Neural networks

I. Introduction

Inspection and maintenance of tunnels are key functions in maintaining safe and effective facilities in the construction sector, in which a rise in passenger and freight traffic means reduced access time for inspection and repair. The requirement is for a robotic system that can inspect current rail tunnels, identify areas that need repair in order to speed up possible interventions.

Interventions of maintenance operators inside tunnels of subways and raw inspections after infrastructure incidents are time-consuming operations. The access to these deep tunnels are inside the urban space and offer serious problems for maintenance people: parking difficulties, tools supply difficulties. Once inside the tunnel, walking is hard, walking between the sleepers is risky, limited space between the tracks, low lighting and hard work conditions (humidity, dust, etc.)

The key task for the robot is to automatically travel to the Point of Intervention from the docking station and, once there, to inspect (visually) the complete volume of the tunnel with many possible viewpoints, in order to report, as fast as possible, the causes of the malfunction or tunnel impairments. In response to this robotic challenge introduced by the French railway company SNCF, WPWEB proposed an autonomous system based on an aerial robot.

II. Project Objectives

PLUTO will demonstrate the autonomous inspection of railway tunnels. The challenges that can arise in such environment are related to a number of factors including localization and mapping, path planning, navigation to the goal position while avoiding collisions, usage of limited knowledge about the environment generated from on-board sensors. Moreover, the environment in which the agent flies, it poses many constraints over the type of sensors and the kind of algorithms employed for the localization and path planning. For example, in confined cluttered spaces, GPS/GNSS is not available for localization and cameras cannot be effectively used in low/varying lighting conditions.

The technical challenges are numerous:

- Inherent weight constraints
- Lack of communication and GNSS signal
- Designing controllers for a consistent navigation
- The issue of collision avoidance which is of crucial importance for flying systems
- Severely limited energy autonomy

In order to deliver the envisioned solution, the PLUTO project will address a couple of objectives:

A. *Implementation of an autonomous navigation system*

Piloting a drone manually requires specific piloting skills and constant concentration by the pilot. Within a confined space this operation is often impossible, both due to the difficulty of manually maneuvering inside a restricted space, and to the lack of communication between the pilot and the mobile robot. There is therefore a strong scientific interest in developing solutions that allow drones to fly independently, without the constant supervision of a human.

B. *Identification of deterioration through a neural network for inspection purposes*

The use of deep learning for the purposes of automatic deterioration recognition is a recent method. Our goal will be to target the results currently obtained in the best international literature.

III. The PLUTO Approach

The obstacles that have prevented the automatic inspection of tunnels with robotic systems so far are:

- Lack of communication that doesn't allow a human to pilot the robot inside the tunnel
- Difficulties in manually piloting a robot in cluttered environment

To overcome these obstacles, we are not proposing an automatic approach, but an autonomous one. That means the UAV doesn't follow a pre-defined path inside a tunnel, but it is able to accomplish an inspection mission inside the tunnel perceiving the environment, thus sensing and avoiding unexpected obstacles and autonomously generating 3D inspection paths to move the UAV along, in order to inspect a target structure.

A. *Scheduling system and mission planning*

In robotics there are several models on decision making processes, for building up a kind of "deliberative layer". Our solution is inspired by a hybrid deliberative/reactive robot architecture[1] and adopts one of the most widespread deliberative system: namely the "state machine". In particular, through the SMACH package [2], which is part of the ROS operating system, the implemented state machine can be hierarchical, because each state can contain within it a hierarchy of other nested states.

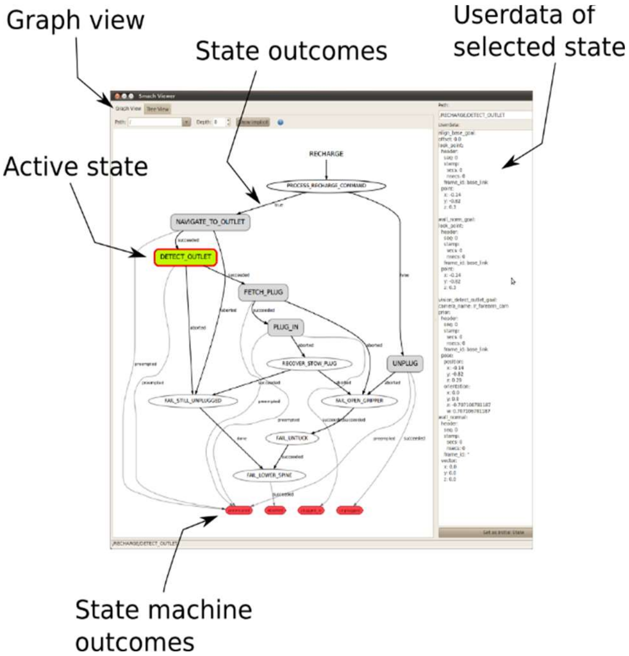

Fig. 1. SMACH graph view

The entire system, once started, can be, at a given time *t*, only in one of the expected states. Events or commands, execute transitions, which, if they are valid, will move the system to the next state. Each state provides one or more outcomes that determine the direction (transition) to the next state. From transition to transition, the system reaches the end of the mission or its eventual interruption.

B. *Autonomous localisation, navigation and obstacle avoidance*

At the time of writing, we are experimenting two different possible solutions:

- a navigation based on PX4 [3] firmware, and the avoidance module, for the Pixhawk flight controller for waypoints navigation
- a custom navigation algorithm

We obtain the position of the drone, in both solutions, implementing a SLAM and using lidar, accelerometer and gyroscope.

In the first solution the navigation is based on PX4 firmware and an obstacle-avoidance module that uses 3DVFH* algorithm [4] (a 3D version of VFH*) [5]. This algorithm combines the advantage of the A* planning algorithm with the local properties of the VFH+ algorithm. A look-ahead tree is built where at every node the VFH+ algorithm is executed to find feasible directions. The tree is then searched for the best path using the A* algorithm. Before the take-off, we can create a list of waypoints along the central axis of the tunnel for the outward and the return. The PX4 optimizes any approximation of waypoints by finding the safest trajectory, keeping the drone away from walls and obstacles. The navigation system, is aware at any time of reaching a waypoint. In this way it can perform any activity related to that waypoint, or the route between it and the next one (for example, video recording of tunnel sections). The local planner node runs the local planner algorithm and handles the communication to the other nodes. It receives the vehicle state information from the Mavros node and the 3D point-cloud from the Lidar node. The planner algorithm then calculates the next waypoints and publishes them such that the Mavros node can send them to the PX4 autopilot.

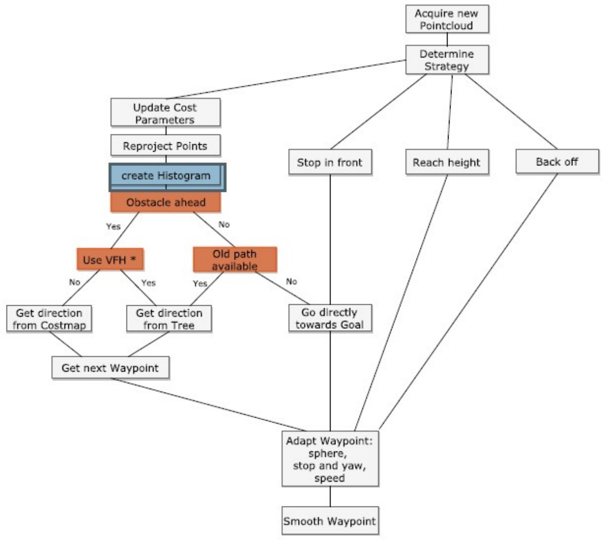

Fig. 2. PX4 Waypoints navigation and obstacle avoidance algorithm

The second solution involves the use of a custom algorithm whose purpose is to keep the drone in the center of the tunnel and make it go back and forth. In this case the waypoint is not a point defined in space by its coordinates (x,y,z) and its rotation (r,p,y), but only by the distance from the starting point. As in the previous solution, the mission is configured by giving a list of waypoints to be reached with the distance from the origin of the mission. The custom algorithm implements a centered navigation with the help of LIDAR. A complementary algorithm implements anti-collision by intervening on the navigation to avoid obstacles. The distance travelled is computed using the laser-inertial SLAM. The propulsive thrust is sent to the flight controller through speed commands managed by a PID controller implemented in the custom navigation algorithm.

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