UAV for target placement in buildings for retrofitting purposes

Kepa Iturralde[a], Wenlan Shen[a], Tao Ma[a], Soroush Fazeli[a], Weihang Li[a], Hünkar Suci[a], Runfeng Lyu[a], Jui Wen Yeh[a], Phillip Hübner[a], Nikhita Kurupakulu Venkat[a], Thomas Bock[a]

[a] Chair of Building Realization and Robotics, School of Engineering and Design, Technical University of Munich, Germany

E-mail: kepa.iturralde@br2.ar.tum.de

Abstract

The use of UAVs in the construction industry is a rather novel concept whose applications are not widespread yet. This research aims to develop a UAV with an end effector used to fix targets on a building façade. With the use of this application, the use of manual force and cranes can be eliminated. The UAV also can reach places with complicated geometry and greater heights which is difficult to be performed manually. The finite element analysis was performed before manufacturing and the flight simulation was performed using ROS. Results are still ongoing but promising.

Keywords –

UAV, end effector, simulation, ROS

1 Introduction

The use of drones in various industries has been on the rise in recent years, and the technology is continuing to evolve and improve. One area of drone technology that has seen significant advancements is the use of 3D printing in the manufacturing of drones. The ability to 3D print drones allows for greater customization, faster production times, and cost savings. The traditional approach used for synthesizing, implementing, and validating a flight control system in [1], [2] for manned aircrafts is time consuming and resource intensive. Applying the same techniques to the small UAVs is not realistic. To reduce the cost and time to market, small UAV systems make use of low cost commercial-off-the-shelf autopilots [3]. These autopilots are often classical Proportional–integral–derivative (PID) controllers and ad-hoc methods are used to tune the controller gains in flight [4]. In this research article, a UAV with an end effector is developed and manufactured. The components of the UAV are manufactured using 3D printing with PLA. The hardware is assembled, and flight simulations is done using ROS. This research is part of the ENSNARE project [5].

2 Research Gaps

UAVs are still not prominently used in the construction industry. This research aims to tackle the following Research Gaps (RGs):

- To place the targets, a heavy operating machine like a crane should be employed, but with the use of a UAV, this can be eliminated. In principle, the UAV is planned to perform with lightweight targets.
- Using a UAV is also time and cost effective than using heavy machinery. According to first simulations, the placement of a target would take about 20 seconds, while with the use of a mobile platform and operators, this would take much longer.

The Apriltag needs to be stuck to the building. We have used a double side tape that performs correctly in the preliminary phases. The rest of this paper aims to provide a solution to develop an unarmed aerial vehicle (UAV) that tackles the above-mentioned RGs.

3 Approach and Results

The UAV was designed with an end effector which is used to place AprilTags on building façades. UAV was designed to be compact, light and have a stable center of gravity. Finite Element Analysis was performed on the body to make sure the material does not undergo fracture during its collision with the building façade as shown in Table 1.

Table 1. Displacement simulation results at various velocities

Velocity (m/s)	Force (N)	Maximum displacement (mm)
1	0.4	0.01668
2	0.8	0.0325
5	2	0.0814

Moreover, in the preliminary studies, the weight of the end-effector was balanced with the weight of the hardware devices of the UAV, mainly with the battery. This aspect should be further considered in the next steps.

The UAV was manufactured using 3D printing [6]–[9] with PLA [10] as shown in Figure 1. The UAV hardware consists of a battery, brushless motors, rotos, raspberry pi 4 and a Navio2 Flight Controller.

Figure 1. Right, Manufactured UAV model.

Various tests were performed on the end effector to ensure it is efficient in attaching targets on building facades. Tests were also performed to calibrate the hardware of the drone in order to attain a stable center of gravity.

3.1 Flight control

The flight control can be divided into three divisions: Software, Middleware, and hardware.

The main Component of software structure is the controller as seen in Figure 2. To be able to make the drone stable during flight, its necessary to use a controller. As it can be seen in the figure the controller has two inputs, Desired state which comes from a human side with RC controller or from a mission planner, that calculates the desired state in order to accomplish the mission autonomously. On the other hand, Controller tries to calculate the errors and decide required actions that needs to be taken. In our case, controller sends the calculated rpm (rotations per minute) to motors. During flight testing we tried three different controllers:

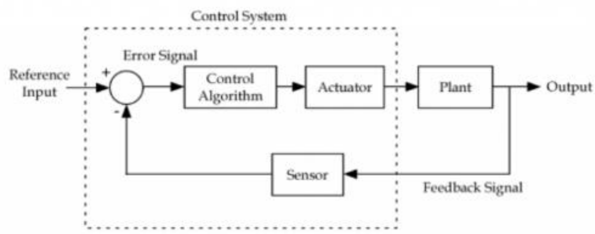

Figure 2. A general flight controller

- **Geometric Controller:** This controller as seen in Figure 3 for the quadrotor is generally based on the principle of solving control problems with the geometry of the state space.

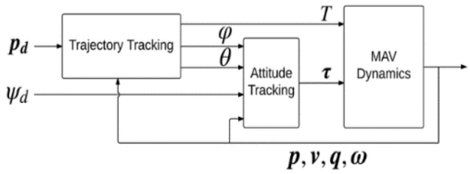

Figure 3. A geometric controller

- **PID Controller:** A proportional–integral–derivative controller (PID controller or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control systems and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value e(t) as the difference between a desired setpoint (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively). Figure 4shows the framework of a PID controller

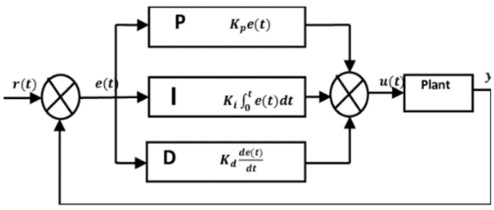

Figure 4. A PID controller

- **ArduPilot**: ArduPilot is an open source, unmanned vehicle Autopilot Software Suite, capable of controlling autonomous drones. The ArduPilot software suite consists of navigation software (typically referred to as firmware when it is compiled to binary form for microcontroller hardware targets) running on the vehicle (either Copter, Plane, Rover, AntennaTracker, or Sub), along with ground station controlling software including Mission Planner, APM Planner, QGroundControl.

Robot Operating System (ROS) is an open-source robotics middleware suite. Although ROS is not an operating system (OS) but a set of software frameworks for robot software development, it provides services designed for a heterogeneous computer cluster such as hardware abstraction, low-level device control, implementation of commonly used functionality, message-passing between processes, and package management. Figure 4 shows the framework of ROS.

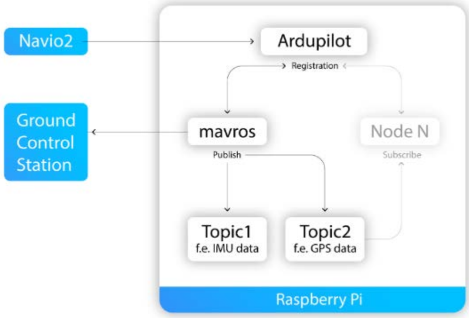

Figure 5. ROS framework

ROS makes communication processes, known as nodes, extremely easy using ROS topics which can be published and subscribed to. Each topic has a certain message type that tells the publisher or subscriber what kind of data can be sent and received from over a topic. In this case it would be possible for the software to communicate with the hardware components such actuators and sensors.

3.2 Hardware

Every drone has essential hardware components in order to fly, such as flight controller, on-board computer, ESC, Motors, Propellers and Battery.

Flight Controller: The main function of the Flight Controller is to provide control for the Electronic Speed Controller (ESC) to direct the rpm of motors based on inputs from the on-board computer. It has sensors on the board so it can understand how the craft is moving. Using the data provided by these sensors, the FC uses algorithms to calculate how fast each motor should be spinning for the craft to behave

- **On-Board Computer**: Raspberry Pi is a micro-computer at the size of an average credit card for data processing. With the General-Purpose Input Output (GPIO) pins, the Raspberry Pi has high processing capability to run functions like flying a drone. All the algorithms and middleware software are implemented on raspberry pi. Also, on-board computer is connected to flight controller in order to getting the sensor data and sending commands.
- **ESC**: An ESC is a device that interprets signals from the flight controller and translates those signals into phased electrical pulses to determine the speed of a brushless motor. The ESC is graded with the maximum amount of current that it allows to pass through. In this project, a 4-in-1 ESC has been used. A 4 in 1 brushless ESC allows you to move ESCs from the arms of your quadcopter into the center stack with your flight controller. Compact builds can benefit, as they make wiring a lot simpler, removing the need for a power distribution board and separate BEC in some cases.
- **Motors**: The motors are the main drain of battery power on your quad, therefore getting an efficient combination of propeller and motor is very important. Motor speed is rated in kV, generally a lower kV motor will produce more torque and a higher kV will spin faster
- **Propellers**: Propellers for Drones and UAVs. Propellers are devices that transform rotary motion into linear thrust. Drone propellers provide lift for the aircraft by spinning and creating an airflow, which results in a pressure difference between the top and bottom surfaces of the propeller.
- **Battery**: LiPo batteries are the power sources of the quadcopters. LiPo is used because of the high energy density and high discharge rate. LiPo batteries are rated by their nominal voltage (3.7V per cell), cell count in series, capacity in mAh (ie.1300mAh) and discharge rate (ie. 75C).

3.3 Simulation

The simulation software aims to reproduce the idea we want to realize in the real world with real UAV. The code designing principles follow the idea from [11]. Figure 6 depicts the simulated building with targets on ROS. Figure 7 is the framework of UAV functions.

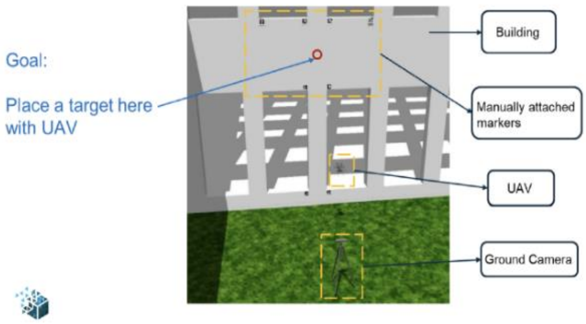

Figure 6. Simulated TUM building with placed target

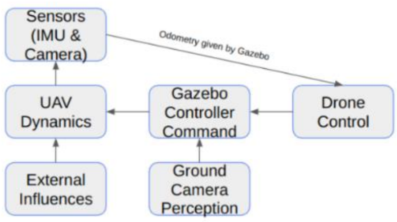

Figure 7. Framework of the UAV functions

The flight simulation on ROS is performed in the following steps.

1. Simulated TUM building environment with placed target.
2. Simulated UAV with the same physical property with design team.
3. Fine-tuned geometry controller to stabilize the drone to a specific position.
4. AprilTag detection algorithm [12] with real-time localization ability.
5. Simulated ground camera with possible extension for accurate target localization.
6. Simulated with real-world joystick.

It was observed through flight simulation that the drone remained stable under various flight conditions.

4 Conclusion

This research paper presents the development of an unmanned aerial vehicle (UAV) with an end effector specifically designed for use in the construction industry. The UAV is equipped with an advanced manipulator arm, which allows for the precise handling of the targets. The UAV and end effector were tested under various scenarios and the end effector has been effective in attaching the targets. The flight control has been calibrated to obtain a good precision. Using the FEM method and 3D printing for the parts has optimized the capabilities of the UAV.

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