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Testing Unmanned Aerial Vehicle Missions in a Scaled Environment

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Abstract UAV research generally follows a path from computer simulation and lab tests of individual components to full integrated testing in the field. Since realistic environments are difficult to simulate, its hard to predict how control algorithms will react to real world conditions such as varied lighting, weather, and obstacles like trees and wires. This paper introduces a methodic approach to developing UAV missions. A scaled down urban environment provides a facility to perform testing and evaluation (T&E) on control algorithms before flight. A UAV platform and test site allow the tuned control algorithms to be verified and validated (V&V) in real world flights. The resulting design methodology reduces risk in the development of UAV missions.

Keywords First keyword · Second keyword · More

1 Introduction

The robotics community is faced with an ever increasing demand for robots that operate in cluttered outdoor environments. To perform tasks such as search and rescue and surveillance, the robots must operate in unstructured, dynamic environments. The nature of these environments often drives development to focus on sensing and control algorithms.

The current design paradigm begins with laboratory development and testing. Sensors are characterized in sterile, structured environments with the claim that the results are extensible to real life objects and conditions. While it is true that rigorous testing

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Fig. 1 A scaled model environment for testing UAV missions. Things such as trees and unstructured lighting that are difficult to capture in computer simulation are easily incorporated here.

such as that presented in [1] and [2] helps one to understand the limitations of hardware, it is difficult to determine how the sensor and sensing algorithms will perform in unpredictable field conditions.

Similarly, computer simulations aid in the design of control algorithms. As the control code is refined, greater and greater detail can be incorporated into the model to approximate real world conditions. [3] investigated methods for simulating environmental conditions such as wind gusts. Sensors have also been incorporated into computer simulation, as shown in [4]. However, present day computer models are unable to incorporate unstructured environments. In particular, objects such as trees and bushes are exceedingly difficult to accurately integrate into simulation.

Following lab development, the sensing hardware and control software are transferred to the robotic platform in order to perform real world tests. Many times the first test of the integrated sensing hardware and control software occurs in the field during these flights.

This design methodology invites costly, time consuming failures. Errors in programming, unforeseen design challenges, and unpredictable real world conditions lead to catastrophic crashes. To mitigate these risks, we propose a step in between lab development and real world flights where sensing and control can be tested and evaluated without having to fly the robotic platform.

The authors' previous work in this area [5] involved a full scale mock urban environment inside a 6 degree of freedom gantry. Sensor suites attached to the end effector of the gantry could be virtually flown through the environment. The motions of the gantry were governed by a high fidelity math model of the robotic platform. This allowed hardware-in-the-loop testing of the robot's sensing and control algorithms.

This approach proved useful for evaluating the robot's reactions to varying environmental conditions. However, physical limitations confined the testing area to a small slice of the urban environment. This limited testing to low-speed, low altitude maneu-

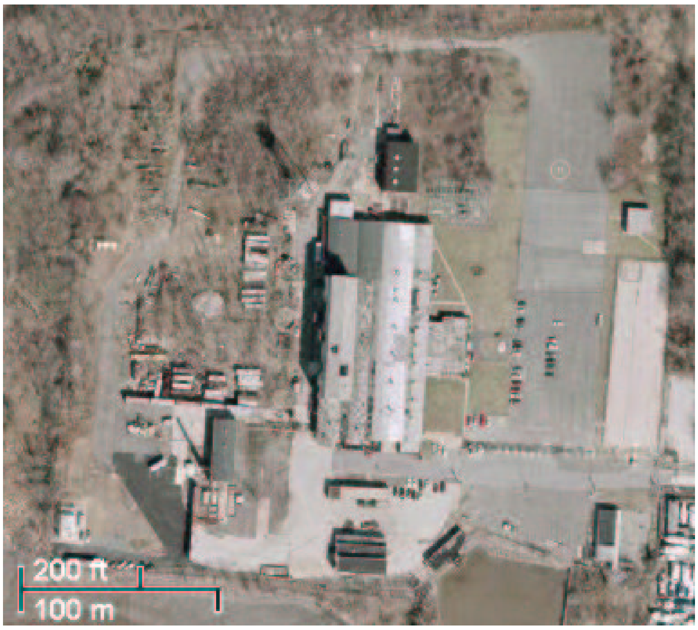

Fig. 2 Satellite image of the helicopter development range at Piasecki Aircraft. The complex contains typical terrain for UAV missions, such as urban and wooded environments. The area spans several hundred meters, allowing ample room for UAV flight tests.

vers. While this technology could be implemented on a larger scale, it was ultimately unfeasible to evaluate entire missions, which could occur over several thousand square meters.

To solve these issues, inspiration was drawn from the early development of flight simulators. As described in [6], some of the first flight simulators utilized scaled models of terrain to provide visual feedback for pilots. These systems provided high fidelity, realistic visual cues for pilots. However, simulations were limited to the area of the models. This approach was abandoned in favor of computer based simulators which provided endless terrain maps, albeit at the sacrifice of realism.

The problem faced by simulation of UAV missions is quite the opposite. Missions are often confined to a defined region such as a town or group of buildings. Computer simulations attempt to model real world effects, but fail to capture the caveats of operating in real world environments. Scaled models such as that shown in Fig. 1 provide a means to test sensors and control algorithms against realistic environments.

This paper presents the design of a testing facility for UAV missions and its use to guide the development of a robotic helicopter. Section 2 describes the facility and its integration into the design process. Section 3 describes the robotic platform. Section 4 describes the mission and algorithms being tested in the facility. Section 5 describes experimental results to date. Finally, conclusions and future work are presented in Section 6.

Table 1 Constraint velocities

Axis	Gantry	Scaled	Mission Required
X	0.012 - 0.61m/s	1.04 - 53.0m/s	4 - 10m/s
Y	0.019 - 0.61m/s	1.65 - 53.0m/s	4 - 10m/s
+Z	0.030 - 0.61m/s	2.61 - 53.0m/s	0 - 3m/s
-Z	0.101 - 0.61m/s	8.79 - 53.0m/s	0 - 1m/s

2 Testing Facility

The goal of this research is to introduce a more sound design methodology to the field of UAV research. Through testing and evaluation (T&E), sensors and control algorithms can be tuned before flight. The refined hardware and software can then go through verification and validation (V&V) on board the actual robotic system. This affords a more robust end product and better management of risk during development. To guide the design of these T&E and V&V setups, the mission profiles must first be defined.

The types of missions under investigation are those typically executed by UAVs on-station after being deployed from a remote location. Such missions include reconnaissance, perch-and-stare and payload delivery. Many of these missions require investigation of more fundamental capabilities such as autonomous mapping and landing zone identification. Areas of interest are typically urban environments containing obstacles such as buildings, poles, trees and thin wires.

Such missions have been investigated in both [7] and [8]. In these experiments, the operational area was as large as $220m$ x $220m$ flown at altitudes in the 10's of meters. The craft in these missions traverse the environment at speeds ranging from $4-10m/s$. Futhermore, the ascent velocity in [7] is limited to $3m/s$ while the descent velocity is limited to $1m/s$. These requirements are compiled in Table 1. From these criteria, the V&V environment selected by the authors was the helicopter development range at Piasecki aircraft. As can be seen in the satellite photo in Fig. 2, the area encompasses several hundred meters. Buildings and wooded regions provide a variety of terrain to test UAVs.

The focus of this design methodology is to create a continuous path from laboratory research to real world flights. The transition from T&E to V&V should therefore be as seamless as possible. As such, the T&E environment was created to closely approximate the Piasecki facility, as shown in Fig. 3. The facility was recreated at 1/87th scale, which is a common modeling scale. This permits access to a wide range of obstacles and terrain features which can be added in the future.

Assessment of UAV control algorithms required a testing facility capable of repeatable and controllable simulation of UAV dynamics and flight paths. The Systems Integrated Sensor Test Rig (SISTR), shown in Fig. 4, is a National Science Foundation funded UAV testing facility that provides this capability. SISTR measures $19ft$ x $18ft$ x $20ft$ enclosing the scaled T&E environment.

As described in [5], the facility is surrounded by a 6 degree-of-freedom (DOF) computer controlled gantry. Using the math model of the UAV and model adaptive control, the gantry can be programmed to mimic the flight of an aerial vehicle. UAV sensor suites can be attached to the end effector of the gantry to provide real-time sensor feedback for testing sensor and control algorithms.

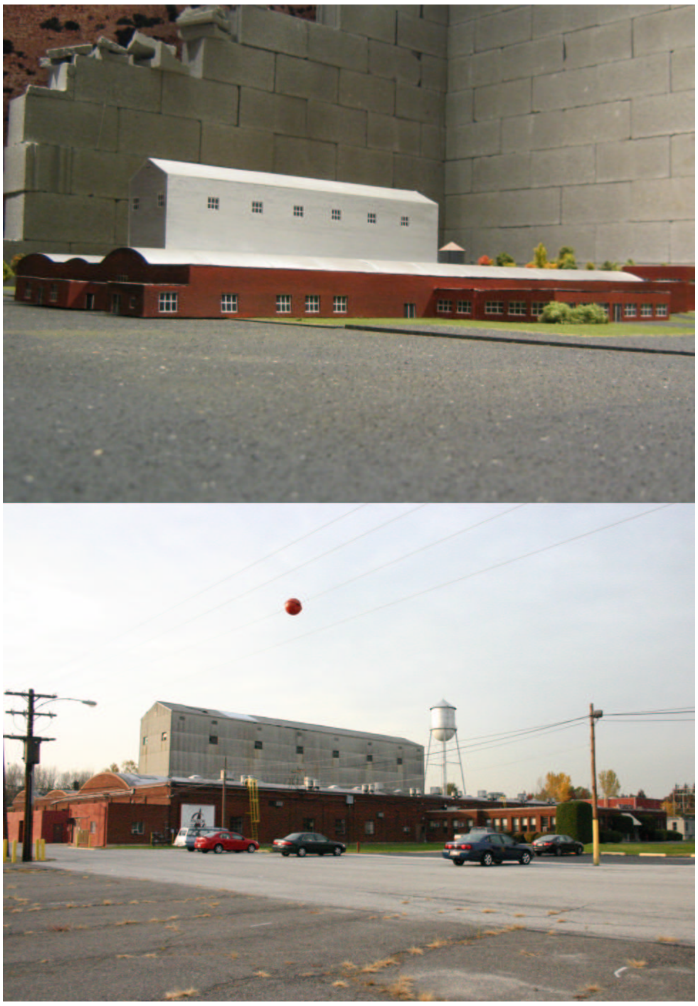

Fig. 3 The V&V environment compared to the 1/87th scale T&E environment. The T&E facility was created to closely approximate the helicopter development range in order to draw a continuous path between laborartory testing and real-world flights.

In mimicking the flight of a UAV, one of the most important design factors is that the velocities of the UAV can be accurately matched in the scaled down model. To accomplish this, the translational motions of the gantry must scale appropriately to fall within the operational velocity ranges of the UAV. Table 1 displays the maximum and minumum velocities achievable by the gantry, the scaled values of those velocities, and the corresponding required mission velocities. As can be seen, the velocity ranges required for the X-axis and Y-axis are easily achieved by the gantry. However, the Z-axis velocities of the gantry are faster than those required by the mission. This issue exists under the current software solution for controlling the gantry. The authors believe the gantry hardware is capable of achieving slower motions. This issue is currently being addressed by the authors.

Fig. 4 Systems integrated sensor test rig (SISTR). SISTR provides a stage for testing and evaluating sensor and control algorithms in a scaled environment. The 6 DOF gantry that comprises SISTR can be programmed through model adaptive control to mimic the flight of UAVs.

Finally, the position in all translational axes of the gantry can be controlled to within $\pm 1cm$. This scales up to a resolution of $\pm 0.87m$. This position accuracy is well within the $\pm 2m$ accuracy of the typical GPS system. This provides a complete facility which can accommodate T&E of sensor and control algorithms for many different UAV platforms. To show the validity of this approach, the authors use a specific robotic system to show the complete design process incorporating T&E and V&V.

3 Robotic Platform

To perform V&V, a Rotomotion SR100 electric UAV helicopter was used, shown in Fig. 5. The SR100 is sold as a fully robotic helicopter capable of performing autonomous take off, landing, and GPS waypoint navigation when controlled from a laptop base station. Control from the base station to the helicopter is routed through an 802.11 wireless network adapter.

The SR100 has a rotor diameter of $2m$ allowing it to carry a payload of up to $8kg$. For these experiments, we outfitted the helicopter with custom landing gear, a custom camera pan/tilt unit, the SICK LMS200, a serial to Ethernet converter, and two $12V$ batteries for payload power. In total we added approximately $7kg$ of payload. This greatly reduces the flight time, which is up to 45 minutes without a payload.

The biggest attraction of this platform, however, is the fact that it is already outfitted with all of the necessary sensors to calculate its pose. Gyros, an inertial measurement unit, and a magnetometer provide the craft's attitude and heading. This information is fused with a Novatel GPS system to provide position data. The position

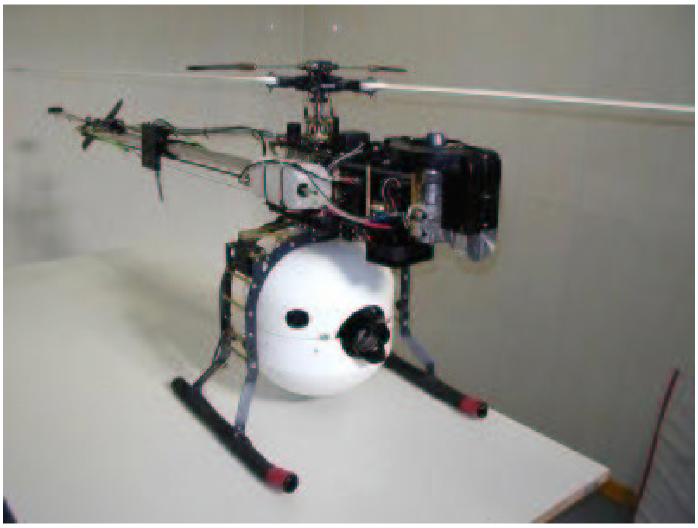

Fig. 5 The SR100 helicopter from Rotomotion, Inc. The SR100 is sold as a fully robotic package capable of automated take off, landing, and GPS waypoint following.

is reported as Cartesian coordinates relative to a global frame, who's origin is at the location where the helicopter was activated.

In selecting hardware to perform initial tests, the authors looked to previous experience designing UAV sensor suites. As a Future Combat Systems (FCS) One team member, the authors have gained extensive experience designing sensor suites for robots flying in near-Earth environments. The FCS Class II program focused on building a UAV to fly missions in areas such as urban terrain and forests. This project identified a few fundamental requirements for these sensor suites.

The sensor must detect a wide range of obstacles. In urban terrain, object size and composition can vary drastically, from buildings to telephone poles to thin wires and clothes lines. In particular, sparse objects such as trees and bushes are troublesome to detect.

The sensor must also be able to detect obstacles from far away and at oblique angles. The speed that a UAV can travel at is directly related to how far away it can detect obstacles. The greater the detection distance, the more time the UAV has to react and plan a new flight path.

These experiences in sensor suite design revealed that scanning laser range finders are the best suited sensor to meet these criteria. Preliminary experiments against the criteria stated above showed them to out perform common sensors such as sonar, computer vision and optic flow.

The biggest attraction of these sensors is their high fidelity and wide field of view. Their range is comparable if not better than many traditional sensors. Laser range finders are also able to clearly detect many different objects including sparse objects such as trees and bushes. Additionally, they are robust to varied lighting conditions, encountering difficulties only in extreme conditions such as direct sunlight measuring over $10,000 lux$.

To illustrate the feasibility of this design methodology, a sensing algorithm must be exhibited on the scaled model, and the results must be replicated in the real world.

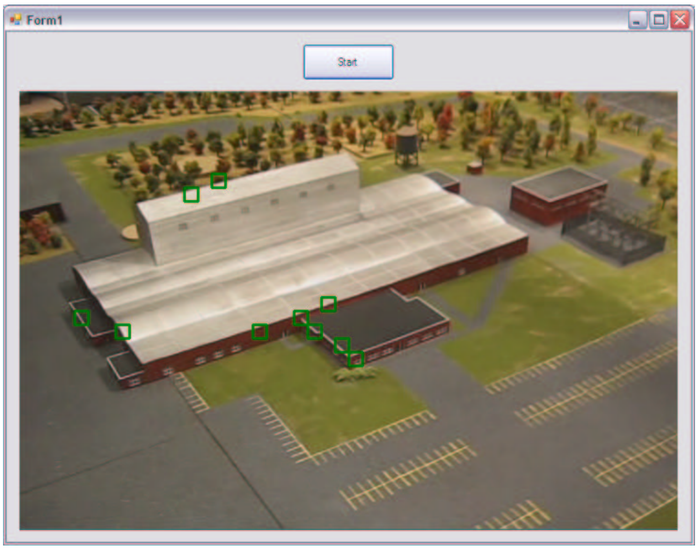

Fig. 6 Kanade Lucas feature detection implemented on video of the scaled T&E environment. The algorithm successfully detected features such as the corner of buildings and windows. These features are consistent between the model and the real world, allowing for a more strict comparison of the scaled and full sized environments.

A sensing algorithm must be utilized that tests the capabilities of the scaled T&E environment.

4 Missions and Algorithms

When selecting which sensors and algorithms to assess, we looked for an application that was highly relevant to most UAVs. One of the most common sensing methods utilized on UAVs is computer vision. Commercial UAVs are equipped with cameras for surveillance. Research UAVs use cameras to accomplish tasks such as autonomous landing, target tracking and obstacle avoidance. This makes computer vision a very attractive problem to investigate.

One of the fundamentals of most computer vision algorithms is feature detection. Techniques such as optic flow, object recognition, and target tracking all rely on detecting features in the image. Feature tracking is therefore a good representative technology for testing the feasibility of scaling UAV missions.

The notional mission we wished to evaluate was a helicopter performing surveillance near a group of buildings. As the helicopter flies past the buildings, a Kanade-Lucas-Tomasi (KLT) feature tracker will process video from an on-board camera. The KLT tracker will find the strongest features in the visible field and track them as the helicopter moves. This scenario would be executed in the scaled T&E environment and in the full sized V&V environment. The features detected and tracked in the scaled flight should match those detected in full sized flight.

5 Experimental Results

Kanade Lucas feature detection was implemented on video taken of the scaled model. Preliminary results are shown in Fig. 6. Boxes drawn around an area represent a feature window containing a detected feature. It can be seen that features such as the corners of buildings and windows were detected.

The features detected on the model were made to closely approximate those of the real world environment. This allows for a consistent comparison between the model and the real world.

6 Conclusions and Future Work

Preliminary results indicate that it will be possible to directly compare the scaled model against the real world setting. In order to make this comparison, the SR100 must be flown through the testing facility at Piasecki Aircraft. This flight must then be duplicated in the scaled environment.

The SR100 is equipped with the correct sensors to localize its position and measure its pose. This allows for the path of the helicopter to be recorded. To use SISTR to trace this path through the scaled environment, the dynamics of the helicopter must be appropriately scaled.

Another issue that must be addressed is distortion of the image because of the camera lens curvature. There are also issues associated with correcting the image for perspective. To make an accurate comparison, these distortions must be removed from the image.

The results from these experiments will provide a measure for closely a scaled environment approximates the real world. The result will be a continuous path from laboratory development to real world implementation.

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