Unmanned helicopter system for miconia weed surveys

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Summary We present the design and evaluation of a system for aerial weed surveys based on a small unmanned helicopter. The system consists of an aircraft, a user interface, and software for flight planning and data visualisation. It is specifically designed for detecting *Miconia calvescens* DC., an invasive tree species threatening the Australian rainforest. The aim of our work is to provide a safer and more cost-effective alternative to traditional methods. The system has been successfully deployed to survey several hundreds of hectares of rainforest near Cairns.

Keywords UAV, aerial survey, *Miconia calvescens*, weed eradication, rainforest.

INTRODUCTION

Miconia calvescens DC (miconia) is a small rainforest tree native to tropical America which was originally brought into Australia for its ornamental values during the 1970s and 1980s. The pest potential of this species was later recognised after receiving reports of its invasiveness from overseas, leading to its classification as a Class 1 species in Queensland in 1996. In 2003, a National Eradication Program commenced with the intention of completely removing miconia from the wet tropical rainforests of North Queensland, and the subtropical rainforests of northern New South Wales.

One of the primary seed dispersal vectors of miconia is frugivorous birds. Dispersal models for miconia have been proposed by Murphy *et al.* 2008. Seed dispersal has been recorded up to 2 km from parent plants. By drawing a dispersal buffer around one plant, this can generate a search area of over 1250 hectares. This area is often dense rainforest within steep terrain which is extremely challenging to cover thoroughly by the use of ground teams only. The National Eradication Program started trialling helicopters manned with spotters in 2007, and has continued to utilise this technique until late 2015. This has been discontinued due to two serious helicopter accidents in the past five years. Long-term monitoring, however, is essential to evaluate the progress of an eradication program (Panetta and Brooks 2008).

The benefits of UAVs (Unmanned Aerial Vehicles) for aerial weed surveys have already been shown (see e.g. Bryson *et al.* 2014 and Dehaan *et al.* 2012). The focus of our work is the automation of unmanned aircraft to enable safe operations in mountainous environments, with minimal human interaction. Moreover, we aim for a seamless integration of all stages of a survey and a solution optimised for detecting miconia trees in the Australian rainforest. The system is generalisable for surveying other weeds.

MATERIALS AND METHODS

Aircraft selection We required an unmanned aircraft which can fly up to 5 km from the launch point, and at up to 1000 m altitude above main sea level under ISA (International Standard Atmosphere) conditions. Moreover, it should require at most two people for operation, and be deployable within one hour of arrival at a survey site. We have considered different options for unmanned aircraft and decided to use a conventional single-rotor helicopter with piston engine (Figure 1). The benefits of such a vehicle include: (1) easy launch and recovery; (2) suitability for flights close to the canopy; (3) a proven record of manned helicopter surveys and existing experience with unmanned helicopters; and (4) longer endurance compared to electric multirotors. A fixed-wing aircraft offers longer range but has launch and recovery limitations, and must fly at higher altitudes over hilly terrain to avoid having

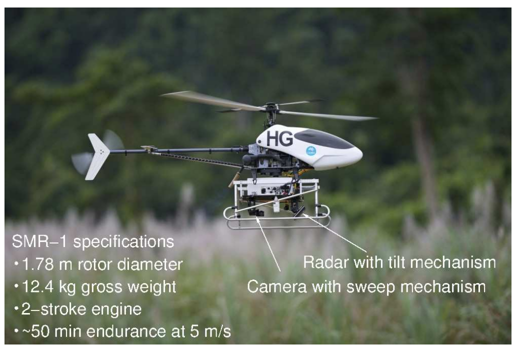

Figure 1. CSIRO SMR-1 helicopter configured for weed survey flights over mountainous rainforest.

to fly aggressive manoeuvres. Flying high increases sensor resolution and stabilisation requirements, limits surveys of narrow gullies, and increases the risk of encountering other air traffic. Additionally, a rotorcraft's ability to hover simplifies certain aspects of the automation.

Sensor selection Miconia is a small tree with large leaves with purple underside and three prominent veins. These features can be seen in high-resolution aerial images, however the view can be obstructed by larger trees, and the purple underside is not always visible. Multiple images from different view angles increases the chance of detecting miconia. To our knowledge, aerial images captured outside the visual spectrum do not improve the detection ability.

We developed an affordable high-resolution wide-angle camera system that is light enough to be mounted on a small unmanned helicopter. The camera system comprises a 5MP camera with global shutter which is triggered by the flight computer, a sweep mechanism, and an image recording computer. The camera is moved to five different sweep angles per second, and images are saved on a removable solid-state drive (SSD). The corresponding camera pose (required for geo-referencing) is stored on a USB stick which is attached to the flight computer. No images are transmitted to the ground.

From experiments with aerial images with various Ground Sample Distance (GSD) values, we determined a maximum GSD of 1.5 cm for detecting miconia trees. The camera is fitted with a 25 mm lens, which limits the distance of the helicopter to the leaves to 109 m. The field of view for one sweep is 80 × 16 degrees. Apart from increasing the field of view, the sweep mechanism allows the capture of images perpendicular to the ridge surface when flying along ridge contours, and to compensate for helicopter roll.

Helicopter automation Our helicopter is designed to be safely operated with minimal human interaction. During flight, the helicopter must perform the duties of a pilot without having to rely on the expertise of a remote pilot. This relaxes requirements on communication links and simplifies the user interface. The helicopter user interface is a small box with two switches: a push button switch with multiple functions depending on the state of the mission (e.g. starting a mission, aborting a mission, invoking an aircraft avoidance manoeuvre), and a toggle switch for terminating a flight in an emergency. Helicopter flight plans are generated with a flight planning tool before the flight. A flight plan is stored on a USB stick which also serves as flight recorder storage. The helicopter also includes a flight termination system which ensures that it stays within a pre-defined area, and under 122 m above ground level (AGL) to comply with Australian aviation safety regulations. The assumption is that in the event of a non-recoverable fault, the helicopter can crash anywhere in the area without causing severe damage to the environment.

Flight plans are generated using commercially available terrain data from aerial LIDAR (Light Detection and Ranging) surveys with an average sample density of two points per square meter. For areas where no LIDAR data is available we use 1 arcsec resolution terrain data from the Shuttle Radar Topography Mission (SRTM) which requires to fly at a higher altitude to accommodate for the lower resolution.

A plan is a sequence of linear and circular curve segments which allow the generation of paths required for low-altitude flight over hilly terrain (Figure 2). Our guidance and control system ensures that the path is followed with less than 5 m control error in winds up to 10 m s^{-1} (if sufficient power is available). The nominal cruise speed is 5 m s^{-1} (ground speed) which may be reduced to stay within the flight envelope and performance limits. Flight control is based on cascaded, decoupled Proportional-Integral-Derivative (PID) control for attitude, velocity, and position. The navigation solution is based on a single-frequency GPS receiver without differential correction, a barometric altimeter, a magnetometer and a MEMS-based (Micro Electromechanical Systems) inertial measurement unit.

We developed a radar-based obstacle avoidance system to accommodate for mapping errors. If the system detects an obstacle it will abort the mission. The radar is also used for landing, aircraft avoidance manoeuvres, barometric altimeter corrections, and in terrain-following flight mode. The latter is engaged when a mission is aborted, returning to base on a direct path whilst staying below 122 m AGL. The aircraft avoidance manoeuvre involves a rapid, safe

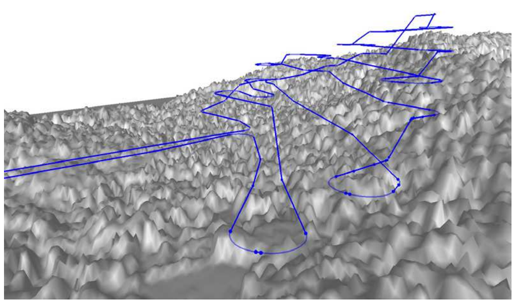

Figure 2. Helicopter flight plan generated by the flight planning tool for the El Arish site.

vertical descent until the radar senses an obstacle. The helicopter will then hover at low but safe altitude above the obstacle (e.g. canopy or ground). When the airspace is clear, the operator pushes the context-sensitive push button switch on the interface box, and the helicopter returns to base. The radar is mounted on a tilt mechanism to accommodate for the multiple radar orientations needed for the different modes of operation.

The helicopter automatically monitors its health, including engine, electric power, sensors, trajectory tracking errors, flight envelope, and mission execution. If it detects a problem, it aborts the mission.

Flight planning The goal of a flight is to capture images covering a given survey area with a given upper bound GSD. Flight plans are complex due to the topography of the terrain and the requirement to fly close to the canopy. An interactive flight planning tool based on the Rapidly Exploring Random Trees (RRT) algorithm was developed for generating plans which both satisfy the GSD constraint and a 30 m safety distance to obstacles. The tool runs on all common operating systems. It requires the survey area boundary, terrain data, a takeoff and landing location, and a 2D map for visualization purposes. The user can also define no-fly zones (e.g. houses) if needed.

In areas with steep slopes which are common for miconia infestations, flight plans typically follow contour lines (Figure 2). This is also a more energy efficient way to survey an area than crossing ridges. The planning process must also consider airspace constraints, however this capability is currently not integrated in the planning tool.

Flight operations Before commencing a flight it must be ensured that: (1) regulatory requirements are met; (2) the aircraft is serviceable; (3) the takeoff and landing area is suitable. The second requirement involves a daily inspection of the aircraft in addition to adhering to the maintenance schedule. For takeoff and landing our helicopter requires an area with approximately 5 m clearance in all directions with a firm approximately levelled surface and good GPS reception. For manual takeoff and landing these requirements can be relaxed.

During flight the operator must ensure separation from other aircraft and that the helicopter does not fly into bad weather. Separation from other aircraft can be achieved with airspace observers who monitor the mission boundaries and invoke the aircraft avoidance manoeuvre if necessary. The observers can also prevent the helicopter from flying into bad weather by aborting the mission.

We fitted our helicopter with a strobe light which significantly increases the visual line-of-sight distance. However, due to tall trees, hilly terrain and low-altitude flight it can be challenging to find locations from where the helicopter can be seen at all times.

Apart from that, the operations are quite simple: fuelling the helicopter, inserting the USB stick and the SSD, connecting the charged batteries of the helicopter and the interface box, waiting for the system self-checks to complete, starting the engine, and pushing the push button switch on the interface box when the launch area is clear. The helicopter will then take off and fly the mission. After landing the system automatically shuts down and the SSD and the USB stick can be removed.

Image analysis Our approach was to develop a method to analyse images which is (at least) comparable to spotting miconia from on-board a helicopter, but in a safer and more comfortable environment. We developed a visualisation tool that allows for easy access of images and geo-referencing of projected terrain points. Apart from the images, it requires flight data from the USB stick, terrain data, and a 2D map. It runs on all common operating systems. The geo-referencing error is less than 10 m which is accurate enough to locate a tagged tree for manual removal.

Images can also be displayed with the terrain data for better orientation in the survey area and to be able to consider topographic information in the analysis. The tool can display all images showing the same feature and enables the comparison of leaf sizes.

RESULTS AND DISCUSSION

To demonstrate the feasibility of the system, we conducted aerial surveys at two sites south of Cairns (Australia) where miconia was found in the past: El Arish and Harvey Creek. We surveyed the first site in May 2014 where we covered 68 ha and logged 1.2 flight hours. The Harvey Creek site was surveyed in October 2015. At this site we covered 293 ha and logged 6.3 flight hours. At the El Arish site, seven miconia plants (range of sizes from 2 to 4 m tall) were found based on the data our helicopter delivered. In comparison, two weeks earlier during a manned helicopter flight with three spotters, only two plants were detected in the same area. No trees have been found at the Harvey Creek site.

All surveys were conducted without incidents and we demonstrated that our system offers a feasible and safer alternative to manned helicopter surveys. Moreover, the images may also be useful for path planning and other surveys.

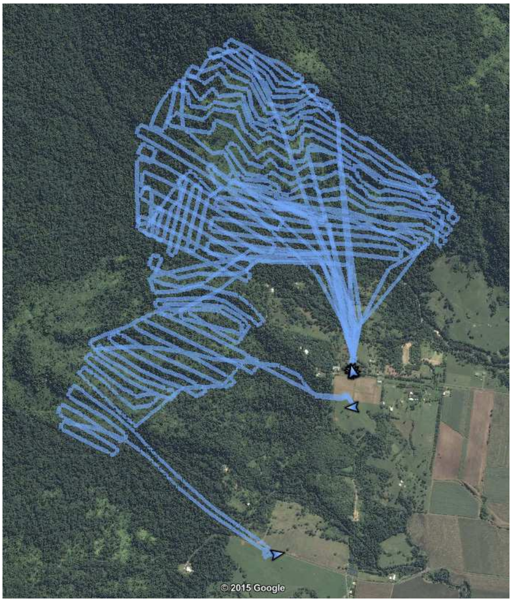

Figure 3. Flight paths of the unmanned helicopter at the Harvey Creek site.

A direct comparison with spotting from on-board a helicopter is difficult. Typically, more time is spent looking at recorded images. This reduces the risk of missing a miconia tree but on-board spotters have a wider field of view and can get more views of a suspicious tree if needed. Geo-referencing of trees is more accurate with our system compared to the position estimates that an on-board spotter can provide.

The system can be much improved by automating the image analysis. For instance, the Harvey Creek survey produced 66,000 images which had to be analysed manually. The development of an automated image analysis solution is challenging due to the small amount of aerial images showing miconia in an Australian environment.

Regulatory restrictions may limit the utilisation of the system. Under the current Australian aviation safety regulations, our helicopter must be operated by a certified pilot within visual line-of-sight. For flights beyond line-of-sight, a certified pilot with instrument rating and an area approval are required. This increases the costs of operations and takes more time.

We are currently planning to survey another 2500 ha of rainforest. As there are more areas for which no LIDAR data is available we will investigate more in depth solutions based on SRTM data. We also plan to work closely together with the aviation safety regulator to find ways to better utilise the potential of our system especially for operations beyond visual line-of-sight.

Figure 4. Image captured by the unmanned helicopter showing a miconia tree.

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