# Landing Approach Advisory System for a UAV

Christopher Wilkin [1], Andrew Ross Price [2],

[1] *Aerobotics Group, Dept Electrical and Computer Systems Engineering, Monash University, Melbourne ,Victoria, 3800 Australia*
[2] *Aerobotics Group, Dept Electrical and Computer Systems Engineering, Monash University, Melbourne ,Victoria, 3800 Australia. Andrew.price@eng.monash.edu.au*

**Summary:** With the expanding domestic and military application of Unmanned Aerial Vehicles the list of people using these systems becomes very diverse. While some UAV operators may be highly skilled pilots, either of manned aircraft or remote piloted vehicles, the diversity of application, and the remote nature of many fields of operation may mean that an experienced pilot is prohibitively expensive. This places any UAV at great risk particularly during the critical time of landing the aircraft. This paper describes a simple, low-cost, reconfigurable landing approach advisory system that offers a measure of support for aircraft during the last few critical seconds of approach. The system uses commercial off the shelf video cameras and a conventional PC to capture video of the aircraft in real time. The operator is provided with real-time altitude and groundspeed information in the last few critical seconds of landing approach. The progression of this system is to provide a novice operator with an economical, fully autonomous UAV recovery system able to be deployed in any field of operation. This research was completed as part of an undergraduate thesis project at Monash University.

**Keywords:** UAV, landing approach system, recovery, safety.

## Introduction

Unmanned Aerial Vehicles (UAV's) are slowly gaining acceptance as tools in various industries, both civil and military. Many UAV systems are expensive and require substantial amounts of personnel and equipment on the ground to support any mission. Other UAV's can be nothing much more than remote control aircraft with some fairly sophisticated on board hardware. In any case, the deployment of a UAV involves risks. These risks include damage to the airframe, particularly during take off and landing, damage to the flight control systems and damage to the mission payload. Damage of any kind to the flying hardware is naturally undesirable, however when the UAV is deployed in a remote location, damage can completely nullify any advantage in deploying UAV's in the first place. If, after the first flight, damage on landing prevents the UAV from performing further missions, UAV's become a liability. Risks on landing can be reduced by the use of experienced operators, with knowledge of the aircraft and landing techniques. Unfortunately there may not be an experienced pilot around when you need one, and keeping them 'on-sight' in a remote and potentially hazardous location may be prohibitively expensive.

In order to improve the profile of UAV's as versatile, cost effective tools for remote sensing and surveillance, it is desirable to lower the complexity of their deployment, specifically to minimize the risk of damage during the critical phase of UAV recovery. This research aims toward a 'set and forget' approach to UAV deployment, where the operator is primarily interested in the mission destination, and the results that are obtained, with only minimal interest in the operation of the UAV platform. The platform itself should support the end user by being as safe and simple to operate as possible with minimal risk of damage. We have focussed on the particular area of UAV recovery. In so doing we have devised a simple, passive, landing approach system based on stereo vision. The system is able to assess the characteristics of a UAV as it approaches to land, including altitude and ground speed. At present variable tones indicate to the pilot what state the aircraft is in, and whether or not a landing should be attempted. The progression of this research is to close the loop and have a fully autonomous landing system. Results of field trials of the system, its deployment and accuracy are included.

## System Design

It has been often said that commercial pilots earn their money in the first three minutes and the last three minutes of every flight. One possible and fairly obvious reason for this view is the dramatically increased proximity of the ground at such times. UAV's though unmanned, are generally not disposable items, particularly in domestic or commercial applications. In the process of testing various UAV's airframes at Monash University it was observed that substantial amounts of time, money and effort went into the design and construction of a UAV airframe and its payload, but only seconds were required to destroy everything. Even highly experience pilots have bad days, or the weather conditions are not favourable, or simply that too many things are happening at once. The need for assistance in such critical moments was determined.

The system we have devised consists of 3 main components: - the video camera hardware, the capture hardware and the software. Each of the components was designed in such a way that would allow easy deployment in the field. With this in mind, the hardware chosen consists of low-cost cameras and video capture cards. Lenses were chosen which gave a wide enough field of view for the landing zone to be visible, whist not being too fish-eyed as to introduce significant non-linear effects. To this avail 8 mm lenses were fitted to colour CCD video cameras which output a video signal in the PAL format. Such cameras are cheap and readily available, and operate from 12 volt supplies. The video capture hardware consists of low-cost PCI TV capture cards, allowing the video stream to be accessed by the landing aid software operating on a typical PC. The capture cards met the requirement of being able to capture full 640x480 resolution video frames at a rate of 25 frames per second. Linux was selected as the operating system, providing a platform which is quite portable and requires minimal hardware to operate. The communication layer between the capture hardware and the landing aid software was the video4linux libraries. Captured image data is available via a set of library functions. ( Fig 1).

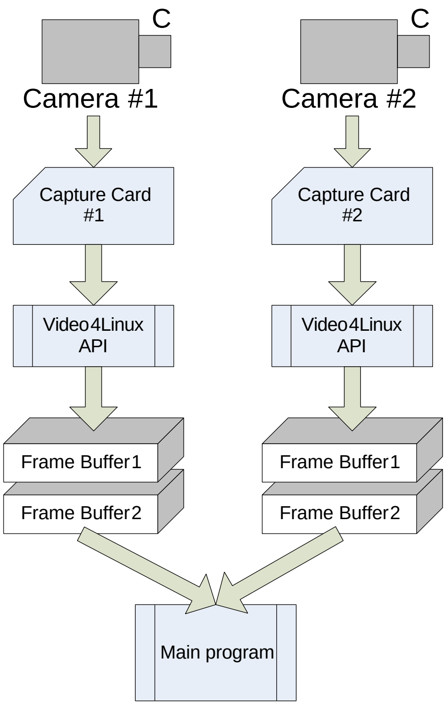


*Fig. 1: Hardware/Software Information Flow*

## Theory of Operation

The goal of this system is to be able to ascertain the x, y and z position the UAV on approach. Triangulation is used to determine these factors and is implemented in a passive system. The UAV is detected in each of the camera images and then triangulated to determine the world coordinates. The system must be calibrated for each potential landing zone, but is not dependent on characteristics of any particular landing zone.

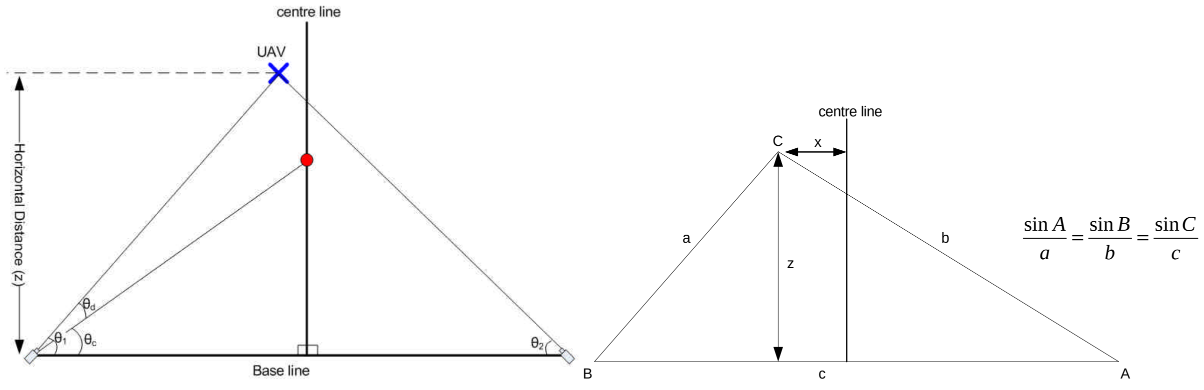


*Fig. 2: Camera Layout*

Figure 2 shows the camera layout and how triangulation is possible from the two camera angles. With the three distances known it is possible to calculate the required angles:

$$q_c = \tan^{-1}\left(\frac{CAL\_DIST\_1}{CAM\_DIST/2}\right) \quad (1)$$

$$q_1 = q_c + q_d \quad (2)$$

By converting the pixel position of the UAV into the deviation angle ($?_d$) then the angle between UAV and camera is thus known, effectively allowing triangulation using a sine rule:

$$z = \frac{\sin A \times \sin B \times c}{\sin C} \quad (3)$$

Altitude is similarly calculated after the horizontal distance is known.

### The Landing Aid Software

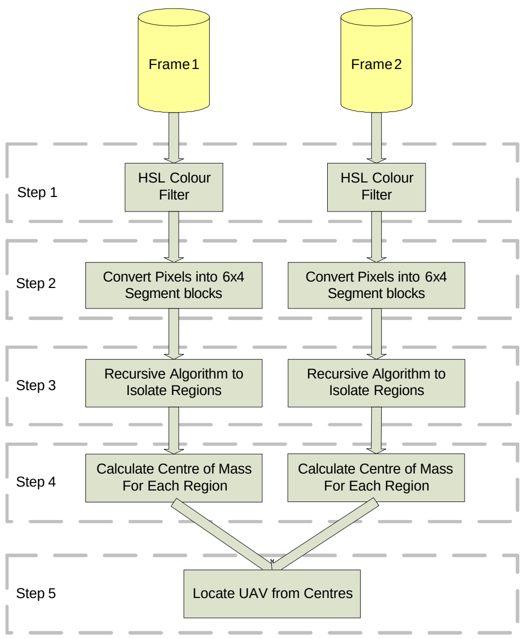


*Fig 3. Software Flowchart*

The UAV is isolated in software from the environment through HSL colour filtering and recursive searching algorithms to ascertain the colour of each wing and the tail (Figure 3). This requires the UAV to be colour coded but does not require active signally. Lighting conditions must be reasonable however alternative approaches could just as easily be implemented such as an active lighting system for night time usage. The recursive algorithm [5] implemented grouped areas of like-coloured regions into neighbourhoods which were to be considered as the wings or body of the UAV. From this, a centre of mass calculation over these areas produced a final centre position of the UAV itself. A single point output for each frame corresponding to the UAV was the result of this, which could then be used in the triangulation equations described above.

## Results

Field testing of the system showed some positive results being produced. Shown below are some typical observations from the system. Results show averages of two trials.

| Actual Range (cm) | Measured Rage (cm) |
|---|---|
| 2100 | 2091 |
| 2000 | 2001 |
| 1900 | 1894 |
| 1800 | 1792 |
| 1700 | 1694 |
| 1600 | 1597 |
| 1500 | 1501 |
| 1400 | 1395 |
| 1300 | 1290 |
| 1200 | 1198 |
| 1100 | 1101 |
| 1000 | 996 |
| 900 | 890 |
| 800 | 793 |
| 700 | 696 |
| 600 | 596 |
| 500 | 500 |
| | |

*Table 1: Horizontal Range Results*

| Actual (cm) | Result |
|---|---|
| 50 | 47.8 |
| 100 | 99.2 |
| 150 | 146.38 |
| 200 | 196.8 |
| 250 | 253.14 |
| 300 | 305.52 |

*Table 2: Altitude Results*

The results gathered demonstrated the landing advisory system is sufficiently accurate to be used as a landing system for smaller aircraft (under 5kg). The landing zone is functional over a region of 20m x 4m x 4m in size. During testing an auditable tone was emitted that relayed useful information back to the pilot. Altitude for example, was chosen to emit a tone between 100 and 1000Hz as the model UAV travelled downwards. These results will largely reflect the accuracy to which the system has been calibrated. Results will vary slightly depending on the accuracy of calibration, thus trials were conducted to ensure errors were minimal.

## Limitations and Future Work

There are numerous aspects of this work that could be persued further, primarily that involving the way in which the UAV is localised. Dual camera systems that could focus on two areas at once would dramatically increase accuracy of the system over a longer range. In addition, providing a closed loop feedback circuit to the UAV for self-guided landings would also be highly beneficial to remove any human errors introduced in the landing process. The system is functional and useful for small UAV systems however to be more broadly applied to UAV's of larger size and greater landing speed it is necessary to expand the area of coverage of the system. A further enhancement is to avoid the use of color entirely and operate on the shape and posture of the aircraft in flight.

## Conclusions

Compact and affordable vision systems are somewhat under utilised in UAV landing aid systems. However some of the ideas brought forward here show this task can be done using low-cost hardware and low processing overhead requirements. Field tests showed the system to be functional, and generally accurate to within 10cm over a 20 meter range. As a landing aid, the system operates in real-time and currently provides a basis for allowing human pilots to respond faster to possible landing problems.

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