Visual Determination of UAV Attitude In-Flight

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Summary: Unmanned Aerial Vehicles (UAV's) are finding increased application in both domestic and military applications. Most end users of UAV's are not particularly interested in the flying platform itself, but rather in the destination, the timing, the cost and objectives of a particular mission. Many end users have very little training in aircraft flight, including model or remote controlled aircraft. The idea of a UAV that can be used in a 'set and forget' manner is very appealing, particularly in applications where the user is in a remote location such as outback Australia or the Antarctic. In such cases, having an experienced pilot on standby may be prohibitively expensive. Unfortunately there are substantial risks involved in both launching and landing a UAV. Any damage to the airframe or to sensitive payload equipment may make the use of UAV's in such applications prohibitively expensive.
This research examines the use of a typical domestic video camera and Commercial off-the-shelf video capture hardware for determining the attitude of a small, under 5kg UAV, while in flight. This research was completed as part of an undergraduate thesis project at Monash University.

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

Introduction

A major hazard for new model pilots in learning to fly their aircraft is a phenomenon that occurs when pilots are viewing their aircraft in flight, at altitude and speed. It is sometimes very difficult to determine if the aircraft is actually flying towards the pilot or away. That split second of uncertainty, often following a turn or manoeuvre of some sort may fool the pilot into an inappropriate control adjustment. Depending on whether the aircraft is flying towards the pilot or away from the pilot, the controls appear reversed. Instead of stabilizing the plane the pilot may be adding to its instability and driving it into an unrecoverable attitude.
UAV operators may not have an interest in the flying platform itself. For that reason the platform should be simple to fly, take off, and land. Ideally UAVs should be a 'set and forget' system. Mission objectives, payload and power resources should be simple to load and configure. The airframe itself should be simple to launch and easily recovered. To aid this process we have devised a ground based, single camera vision system that is able to determine the attitude of a small, 5kg UAV in flight. Using a conventional video camera, low resolution capture board and a PC, our system is able to determine the yaw, pitch and roll of the airframe in real time. The aim of this research is to provide an aid system that will allow critical flight information to be determined and provided to either a pilot in the process of landing a UAV, or ultimately to a closed loop feedback system which will allow the UAV to land at a designated point, simply by observing it in a video image. It is hoped this will greatly reduce

the dependence on both experienced pilots and the need for sophisticated and ultimately heavy 'on board' sensor system. While auto landing systems are in design and use, it may not be possible to land at the pre-designated location. The system we are developing allows some measure of control, but without the need for sophisticated piloting skills.
In this paper we present results of our attitude determination system including testing on a model airframe. Yaw, pitch and roll status is determined in real time and the results are displayed via means of an artificial horizon indicator.

System Design

In order to keep the system simple and cost effective a basic set of system components were utilised. In particular, a GoVideo CCS-C81 CCD Camera was interfaced to a PC via a LifeView FlyTV 3000 PCI Video Capture Card. The listed hardware was implemented in conjunction with the Video4Linux API in order to capture and access live video under Linux. The video format utilized was PAL and was captured at a resolution of 640x480 at 25 frames per second.

To determine the attitude of an in-flight UAV the attitude determination system required a means of identifying the UAV and its orientation. A reasonably simple method of identifying the UAV was sought in order for the system to operate at a full 25 frames per second. The attitude determination system utilizes color as the primary feature extraction method. The UAV itself is painted with three different colored markings. Two markings identify the two wings, whilst the third marking identifies the tail, see Fig. 1.

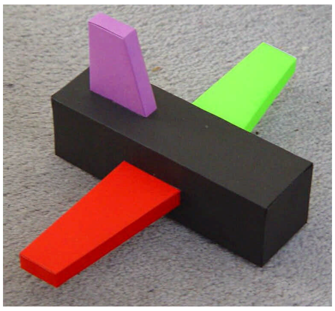

Figure 1: A Simple Model

The use of color filtering as a segmentation technique has known issues [1], particularly in dynamic lighting conditions. However, in order for the system to operate in real-time, color filtering was implemented in order to extract the colored markings on the wings and tail. The effect of dynamic lighting was minimized through the use of the HSV color-space [2] and also spatial information in conjunction with pixel point data. Each captured frame was essentially segmented into a grid. If a grid cell contained a sufficient concentration of a marking color, the cell was considered as a candidate for a part of that marker. Once all candidate cells were processed, separate objects could be determined. This was achieved by an edge tracing algorithm [3] depicted in Fig. 2. This algorithm traced the edge of a binary segment, post-color filtering.

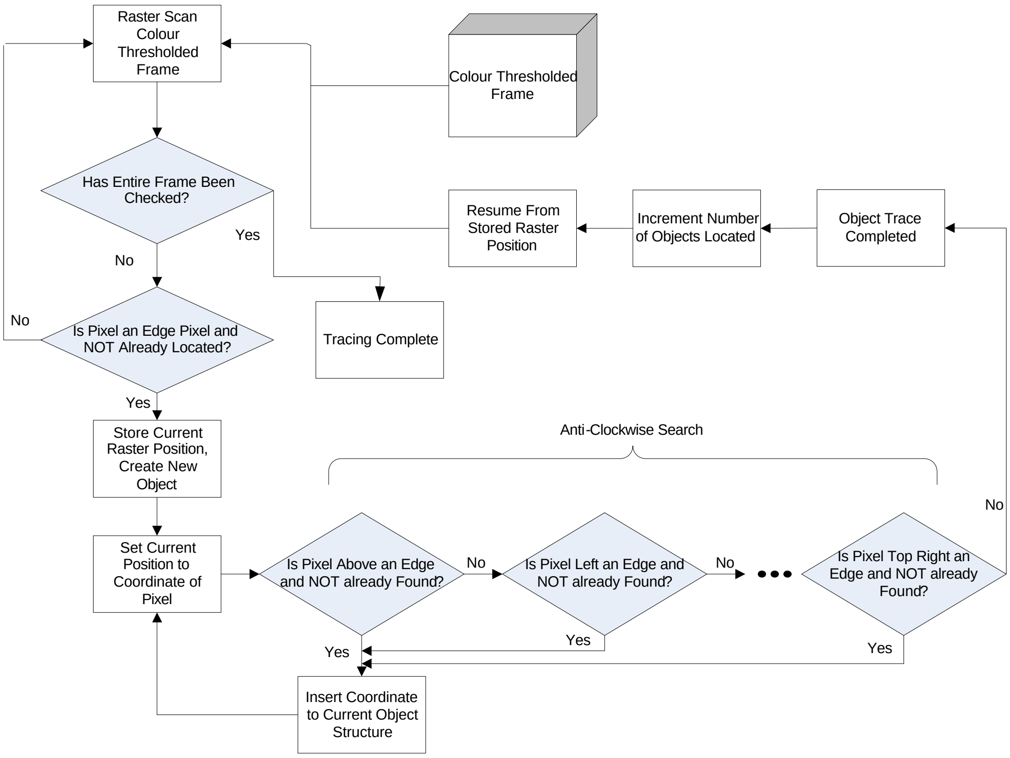

Figure 2: Edge Tracing Algorithm

Several geometric parameters of each candidate object were determined. These parameters included the centre of mass, width to height ratio, minimum moment of inertia [4] and area. These parameters were then utilized to correlate against a set of known parameters for every possible orientation of the UAV in 15 degree increments of pitch, roll and yaw. The known parameters were stored in a table that was generated from a 3D model of the UAV. The attitude determination system provides functionality to easily construct a 3D model of the UAV under surveillance. This model is utilized to form a correlation between the extracted colour segments and a possible orientation of the UAV. The model is constructed from user provided dimensions.

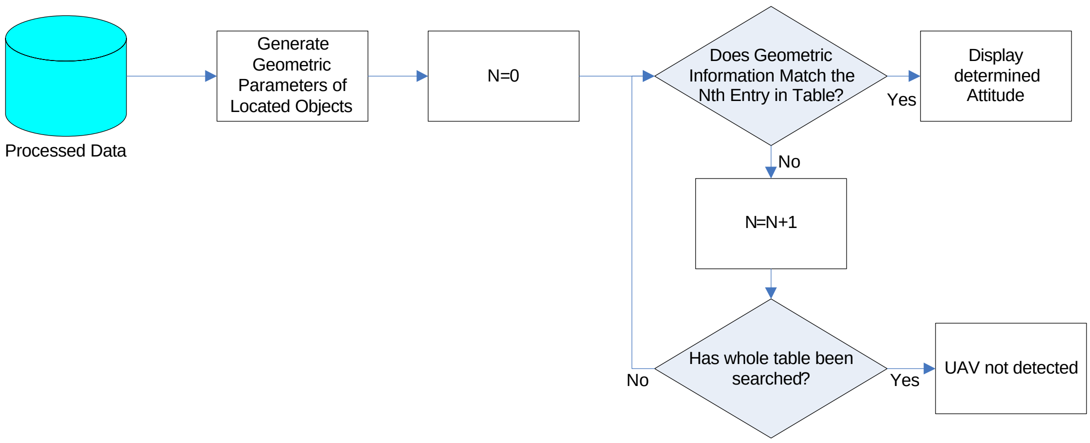

Figure 3: Correlation Algorithm

If the system determines that the current set of candidate objects correlate closely with a possible orientation, the interpreted pitch, roll and yaw are output by the system. The system provides several methods of information output. A text based output is provided to display the actual pitch, roll and yaw angles, whilst a graphical artificial horizon is also provided. Additionally, a speech synthesizer is utilized to alert the pilot of a dangerous attitude with useful instructions such as ‘pull up’.

Results

Figure 4: UAV Identification

Fig 4. depicts the attitude determination system correctly identifying the wings and tail of the model airframe. The lines originating from the centre of each wing/tail represent the minimum moment of inertia of the respective wing/tail. This parameter is crucial in determining the width to height ratio of each marker object. The system was found to be able to identify each wing/tail under most lighting conditions (assuming no other object of the same color became more significant inside the viewing frame).

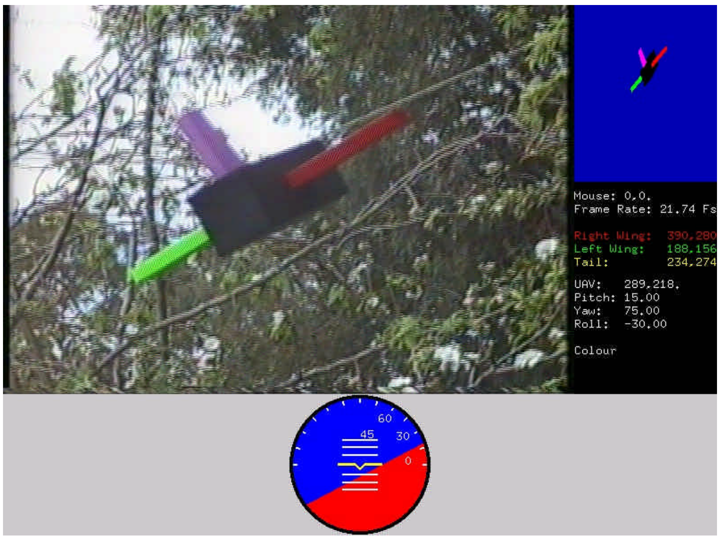

Figure 5: Artificial Horizon

The artificial horizon depicted in Fig. 5 provides the pilot with a visual indication of the UAV's attitude. This is similar to the instrument found on most manned aircraft, providing information to the pilot regarding the pitch and roll. The top left part of Fig. 5 depicts the original footage before processing whilst the top right of Fig 5. displays the system interpretation of the UAV orientation.

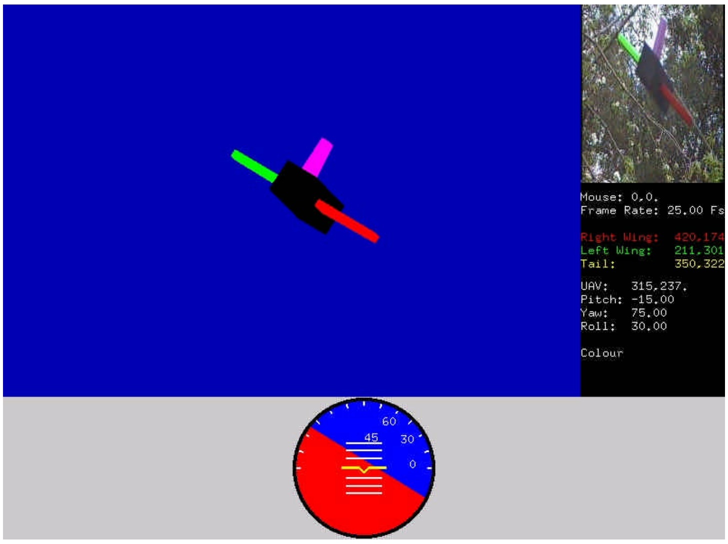

Figure 6: 3D Model and Artificial Horizon

Potential Limitations and Practical Considerations

Whilst the attitude determination system is able to determine the attitude of the UAV within 15 degrees of pitch, roll and yaw at a success rate of 90%, these results are limited to favorable lighting conditions. It is proposed that the system be extended by the use of frequency encoded, high power LEDs to overcome the sensitivity to dynamic lighting conditions.

Our system, while demonstrable, does have practical limitations, primarily due to the use of color. In the design of the system we began by specifically targeting natural outdoor lighting conditions and occlusions with objects such as trees, buildings and vehicles. Our efforts have yielded a system which can work and is a valuable tool towards UAV flight control by video. The use of color is not a long term advantage as the appearance of color is far too dependant on lighting conditions. The use of active beacons placed on the aircraft may be one solution. While several different approaches including active beacons, shape recognition and color recognition have their advantages, it is likely that a reliable fly by video system will be a hybrid approach able to adapt as conditions change during the flight.

There are also practical considerations in the method of determining the position and attitude of the camera. As the range of the aircraft increases it is possible to zoom in on the plane itself however this leads to an increased sensitivity on the positioning of the camera and a potential quantization error in the camera attitude measurement.

Conclusions

UAVs are at their most vulnerable when under manual pilot control in poor viewing conditions. The attitude determination system provides a highly useful training utility and also an aid for experienced pilots in unfavourable conditions. Additionally, the system has promise as a closed loop controller and landing system. It requires no substantial system on the ground. The software may be implemented on a much smaller dedicated system attached directly to the ground camera. While not being the most sophisticated or precise system available, it is ultimately simple and functional.

We have presented a vision based attitude determination system based on highly economical capture hardware. The system successfully determines the attitude of an in-flight UAV and operates in real-time at a full 25 frames per second on a standard PC. Field results have shown promising performance under favourable lighting conditions. High intensity LEDs have been considered as a future resolution to the light sensitivity issues.

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