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Scene analysis for autonomous system control

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Abstract

The potential of autonomous airborne platforms have long been considered for applications in surveillance, exploration and search and rescue. For example, an autonomous blimp or airship, able to navigate through complex unstructured environments, could be used to survey the aftermath of dangerous earthquake zones, or be employed to provide unique replay angles in sporting events. Therefore autonomous airships fill an important gap in the spectrum of aerial observations, supplying images with better resolution and much more acquisition flexibility than those acquired through satellite or airplanes. This paper proposes to configure a semi-autonomous Unmanned Aerial Vehicle (UAV) for research into navigation and tracking through visual servoing using an airborne robotic platform. The architecture incorporates an object detection/tracking algorithm, which aims to provide robust performance under practical indoor environments. Station keeping techniques are also integrated to allow the airborne platform to hover in a static position above a desired target. Through combining the Circular Hough Transform with a number of image processing techniques, a resilient landmark segmentation algorithm is produced. 'Path Prediction', 'Velocity Prediction' and a 'Dynamic Radius' algorithm are developed to improve the speed and reliability of visual tracking. In addition, a 'Heuristic Grid' approach is examined as a means of performing station holding with the autonomous platform. The system is capable of segmenting and tracking the desired landmark from an image scene. A series of control commands are then sent to the autonomous vehicle to successfully keep the target within the image window.

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SCENE ANALYSIS FOR AUTONOMOUS SYSTEM CONTROL

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ABSTRACT

The potential of autonomous airborne platforms have long been considered for applications in surveillance, exploration and search and rescue. For example, an autonomous blimp or airship, able to navigate through complex unstructured environments, could be used to survey the aftermath of dangerous earthquake zones, or be employed to provide unique replay angles in sporting events. Therefore autonomous airships fill an important gap in the spectrum of aerial observations, supplying images with better resolution and much more acquisition flexibility than those acquired through satellite or airplanes.

This paper proposes to configure a semi-autonomous Unmanned Aerial Vehicle (UAV) for research into navigation and tracking through visual servoing using an airborne robotic platform. The architecture incorporates an object detection/tracking algorithm, which aims to provide robust performance under practical indoor environments. Station keeping techniques are also integrated to allow the airborne platform to hover in a static position above a desired target.

Through combining the Circular Hough Transform with a number of image processing techniques, a resilient landmark segmentation algorithm is produced. 'Path Prediction', 'Velocity Prediction' and a 'Dynamic Radius' algorithm are developed to improve the speed and reliability of visual tracking. In addition, a 'Heuristic Grid' approach is examined as a means of performing station holding with the autonomous platform.

The system is capable of segmenting and tracking the desired landmark from an image scene. A series of control commands are then sent to the autonomous vehicle to successfully keep the target within the image window.

1. INTRODUCTION

The aim of this paper is to configure a semi-autonomous Unmanned Aerial Vehicle (UAV) for ongoing research in navigation and tracking through visual servoing using an airborne robotic platform. The architecture incorporates an object detection/tracking algorithm, which provides robust performance under practical indoor environments. Station keeping techniques have also been integrated to allow the airborne platform to hover in a static position above a desired target.

This paper involves three key areas of engineering; image processing, artificial intelligence and real-time

control. The major goals can be subdivided into the following objectives:

1. To develop image-processing techniques that enhance image characteristics to aid in the development of object extraction algorithms.
2. To implement a suitable object tracking scheme which is both resilient to noise and lighting conditions.
3. To incorporate a station keeping algorithm, capable of maintaining the position of the autonomous platform over a stationary landmark.

2. CIRCULAR HOUGH TRANSFORM

2.1. Circular Hough Transform

The Circular Hough Transform (CHT) is an image processing technique aimed at locating circles of a given radius within an edged image frame. The circle detection is achieved through a method which is equivalent to performing a convolution between the image and a circle operator [1].

A circle can be defined by the parametric equation,

$$(x - a)^2 + (y - b)^2 = r^2 \quad (1)$$

where (a, b) is the centre point of the circle, and r is the radius of the circle. For any single pixel (x, y) the equation is variable in three dimensions, with a, b and r being the unknowns. For a fixed value of r , this problem is reduced to two dimensions.

Given an edge enhanced image, each non-zero pixel located at the coordinate (x, y) , is assumed to represent a point on a circle. Each possible (a, b) pair for the given radius at the given point then represents a vote in an (a, b) accumulator space. A vote is defined as a count of the number of times an (a, b) pair occurs. Now considering all the edge pixels in a set belong to the same circle in the spatial image, the corresponding parameter space votes produce a local maximum at a single common intersection point. If the edge pixel set contains pixels that do not belong to the circle, the corresponding votes intersect at other points [2].

3. LANDMARK SEGMENTATION AND TRACKING

3.1. The Combined Algorithm

In the following section, the image processing techniques are combined with the Circular Hough Transform to create a robust and real time landmark

segmentation and tracking algorithm. This combined algorithm attempts to segment and track red circular objects from the image scene. Once the targeted has been extracted, the pose of the autonomous platform relative to the landmark can be established. Control signals can then be sent to the UAV motors to adjust the position of the platform relative to the segmented target.

Considering the input video stream provides colour images of 8-bit resolution, colour segmentation must first be applied to extract areas similar in colour to the desired target. Binary erosion, followed by dilation is then employed to remove unwanted noise from the segmented frame, before a Sobel edge detector is utilised.

These initial pre-processing techniques have prepared the image for the CHT to be applied, from which the centroid and the bounding area of the desired object are obtained. The bounding area is then drawn onto the original image, highlighting the desired landmark. The flow diagram in Figure 1 illustrates this procedure.

Figure 1. Flow diagram of the Landmark Segmentation Algorithm

3.2. Improving the Combined Algorithm

In order to improve the performance of the tracking for real time applications, the region of the image, which the search is performed, can be narrowed through prediction. By narrowing the search field, less computation is required, thus improving the speed of the tracking. Two methods of target location prediction, proximity based prediction and velocity based prediction [3], were examined.

In addition, experiments were conducted to determine the effects of analysing a reduced set of pixels in a search region. It was found that if the target object was large, with reference to the size of the image frame, the CHT could still provide accurate results.

Due to the fact that the CHT only searches for landmarks of a given radius, a search radius prediction algorithm was implemented to successfully estimate the objects next radius utilising the current image frame. Therefore, the value of the search radius of the desired target appropriately adapts to the changing size of the object whilst it is being tracked, allowing continual tracking of a spherical object in a real time environment.

3.3. Proximity Based Prediction

In this method, when an object is identified using the CHT the new candidate search region is established by expanding the target window in all directions outwards from the located object. As a result, a perimeter around the previously located object is generated. The search for the object in the next image frame is then only conducted within the generated perimeter, consequently reducing the amount of processing required. This method assumes the difference of the target between image frames does not cause the target to move outside the boundary of the search region. The theory of proximity based prediction is illustrated in Figure 2.

Where,

$$x_0' = x_0 - \frac{(x_1 - x_0)}{2} \quad (6-1) \quad y_0' = y_0 - \frac{(y_1 - y_0)}{2} \quad (6-2)$$

$$x_1' = x_1 + \frac{(x_1 - x_0)}{2} \quad (6-3) \quad y_1' = y_1 + \frac{(y_1 - y_0)}{2} \quad (6-4)$$

Figure 2. Proximity Based Prediction – Candidate target region

3.4. Velocity Based Prediction

According to Okada et al [3], if images are captured at short enough time intervals, the velocity of the moving object can be considered to be nearly constant between two successive frames. With this assumption, the candidate search region can be estimated by shifting the previous target window by the previous target velocity and enlarging it, as seen in Figure 3 [3]. This process is known as Velocity Based Prediction.

This form of prediction was found to provide significant benefits in situations where the delta of the targeted object would normally cause the target to exceed the boundary of the search region. Through combining

“Proximity Based Prediction” with “Velocity Based Prediction”, a more accurate prediction algorithm is developed. The search region of the combined algorithms encompasses both the target regions calculated from each individual prediction method. By increasing the search region to encompass both calculated target areas, the efficiency of the algorithm is moderately sacrificed for improved accuracy.

Figure 3. Velocity Based Prediction – candidate target region [3]

3.5. Reducing the Analysed Pixel Set

The original CHT is an exhaustive algorithm which requires every pixel in a search region to be analysed in order to determine the location of the centroid of a possible circle. Each pixel is analysed and then votes on possible centroids are accumulated in an accumulator space. However it was found that if only every second pixel in a search region was analysed, sufficiently accurate results could still be obtained. This consequently doubled the tracking speed. For large objects, it was found that accurate results could still be achieved for just a quarter of the number of pixels, thereby increasing the speed of tracking by a factor of four.

3.6. Dynamic Radius

The CHT requires the radius of the desired target to be defined before the algorithm can successfully locate the object within an image frame. However, if the viewing distance from the target was to change, the radius of the object in the image frame would vary. For this reason, a dynamic radius algorithm is required in order for a circular object to be continually traced.

Figure 4. Identifying the upper, lower, left, and right most pixels within a search region.

Under the current dynamic radius algorithm, all pixels within the boundary of the last search region are analysed. The upper, lower, left and right most non-zero pixels are then assumed to belong to the targeted object. The horizontal and vertical distance, in pixels, between

the upper and lower, and left and right most non-zero pixels are then determined. The maximum between these two distances is taken to be a possible value for the diameter of the object. This is illustrated in Figure 4.

The following equation is then employed to determine the new search radius,

$$\begin{aligned} & \text{If } \text{predicted_radius} \leq \text{previous_radius} \\ & \quad \text{New_radius} = \text{predicted_radius} \\ & \text{Else if } \text{predicted_radius} > \text{previous_radius} \\ & \quad \text{New_radius} = \text{previous_radius} + \\ & \quad \quad (\text{possible_radius} - \text{previous_radius}) / 2 \end{aligned}$$

4. UAV SYSTEM DESIGN

4.1. System Design

The UAV comprises of two main categories; the ground control, and the airborne robotic platform. On the ground, a remote computer communicates with the autonomous platform via a radio transmitter/receiver. A TV capture card is utilised to feed a video signal sent from the autonomous platform to the remote computer, where the image processing is performed.

The autonomous platform incorporates an onboard video camera, wireless video transmitter and radio control receiver. Images taken from the video camera are transmitted to the wireless receiver of remote computer. Control signals sent back from the computer are received with the radio control receiver.

5. STATION HOLDING

5.1. Heuristic Grid Decisions

Due to the number elements which can affect the control motion of the blimp, a heuristic grid based approach was exercised to perform the control decisions. The image frames supplied to the desktop computer from the wireless camera are divided into sections. Depending on which grid cell the segmented landmark in the image frame was located in, different control directives, optimally calculated through prior experimentation, are applied. These control directives, based on heuristic decisions, aim to bring the target object into the central grid of the image frame. This was achieved by rotating the vehicle left or right, or thrusting the blimp backwards or forwards. By maintaining the target within this cell, the task of station keeping was achieved.

The image frame was originally divided into a grid design, as illustrated in Figure 5, where cell 5 indicated the desired location of the targeted landmark object. If the landmark object was located in cells 1, 3, 4, 6, 7, or 9, rotations are applied to shift the objects position to either cell 2 or 10. Hence, if the targeted object was to lie within either cell 2, 8, 10 or cell 11, simple thrusts in the forward or reverse direction can be employed to bring the target into cell 5. In addition, if the target lies within

the central cell, upward thrusts would be applied to maintain the height of the dirigible.

Figure 5. Grid Design

Figure 6. Paths taken by autonomous platform.

6. RESULTS

From Frames 1 to 2, the blimp attempts to move in the forward direction to bring the target into the central grid of the image frame. This movement however causes the blimp to rotate. Frames 3 to 7 illustrate how the platform rotates on its axis to eventually bring the object into either of the upper middle cells. This aim is eventually achieved by Frame 8, and once again the blimp is required to thrust in the forward direction to bring the landmark into the central square as seen in Frame 9.

7. CONCLUSIONS

The aim of this paper was to configure a semi-autonomous Unmanned Aerial Vehicle (UAV) for on going research in navigation and tracking through visual servoing with an airborne robotic platform.

The first objective was to develop image-processing techniques to enhance image characteristics in order to aid in the development of object extraction algorithms. The second major objective was to implement a suitable object tracking scheme which was both resilient to noise and lighting conditions. Finally, a station keeping algorithm was required to allow the autonomous platform to maintain its position over a stationary spherical landmark. All three major goals have been successfully achieved.

The Circular Hough Transform is an image processing technique aimed at locating circles of a given radius within an edged image frame. This algorithm demonstrated resilience in cluttered environments and even when the target was occluded. Through integrating the Circular Hough Transform with a series of pre-processing techniques, a customised landmark segmentation algorithm was developed. Improvements were then made to the combined algorithm through the incorporation of proximity based target prediction, velocity based prediction, a dynamic radius algorithm and through reducing the analysed set of pixels.

Through the use of a heuristic grid approach, station keeping was successfully achieved. Depending on which grid cell the segmented landmark in the image frame was located in, different control directives, calculated through prior experimentation, were applied to return the target to the central square. The final result was a semi-autonomous Unmanned Aerial Vehicle (UAV) designed as a basis for on going research in navigation and tracking through visual servoing with an airborne robotic platform.

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