AUTOMATIC GUIDANCE AND CONTROL FOR RECOVERY OF REMOTELY PILOTED VEHICLES

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ABSTRACT

Modern remotely piloted vehicles are used extensively for aerial surveillance operations. Many recovery methods have been employed with varying degrees of success. However, manual flying requires significant operator skill. This research is aimed at producing a closed loop automatic landing system for remotely piloted vehicles. The system under investigation utilises a ground based video camera to track the RPV and produce guidance commands to fly the aeroplane down the axis of the video image to a height suitable to initiate the flare for landing. The system is based on signal processing micro computers, and video data is processed at field rate to locate and track the aircraft and subsequently generate error signals from the centre line which are fed to a telemetry interface to guide and control the aircraft on the approach. The paper details the system hardware of a prototype system and outlines the image processing algorithm for target recognition and tracking.

INTRODUCTION

This paper is a report on progress of a collaborative research programme undertaken in the Electrical Engineering department of the University of Bath, in conjunction with Flight Refuelling Ltd. This company has extensive experience in the design, manufacture and operation of remotely piloted vehicles (RPV) and unmanned aircraft (UMA). RPV are increasingly gaining acceptance for use in aerial surveillance and reconnaissance work. In general they are launched from a mobile base station and can operate on radii from the base station of the order of 50 Km. Facilities exist to communicate with the airborne vehicle through a telemetry link. Commands can be sent to the vehicle enabling manual control of the aircraft and selection of auto-pilot modes. The base station also monitors aircraft states through the telemetry link. The recovery of these airborne vehicles back to the base station however still presents some problems to the successful operation of these systems.

Various recovery techniques have been employed to date. These include:

a) Manually controlled approach and landing

b) Manual guidance into a net

c) Parachute recovery

None of these techniques has proved completely satisfactory. Methods a) and b) require considerable skill on behalf of the ground based pilot controlling the vehicle through the telemetry link. Method c) is subject to wind drift after deployment of the parachute. All of these methods give a high probability of structural damage to the vehicle on contact with the ground. To enhance the operational reliability of the system, it is desirable to automate the recovery phase. Automatic approach and landing systems are in daily use by commercial aircraft and the techniques of glide-slope, localiser and automatic flare control to touch down are well proven. These systems make use of large fixed ground installations to generate an ILS or MLS beam down which the aircraft flies. Beam errors are detected on board the aircraft and fed to the auto pilot to control the approach. The flare manoeuver generally uses a radio-altimeter as the primary sensor. On an RPV beam sensors are not available nor indeed is the radio-altimeter. To improve the RPV recovery phase while still preserving the mobility of the ground station, a portable ground based beam error detection system has been investigated. The axis through the centre of the lens of the video camera designates the 'beam' down which the RPV is to fly in a coupled approach. Displacement of the RPV image from the centre of the screen gives a measurement of beam angular errors. The signals generated from the detection system are to be processed by the ground station and telemetered back to the aircraft as height rate and heading commands. The glide-slope and localiser control loops are closed through the ground station obviating the need to modify the airborne autopilot. In addition the need to instal ILS/MLS receiving equipment on board each RPV which would give a subsequent reduction in payload capability is also removed. The beam error sensing system should ideally be small, portable and passive and so a video camera was chosen as the primary sensor for the purpose of this investigation. Although a standard Pal camera operating in the visual spectrum was used for the investigation, an Infra-Red imaging device could be substituted directly without modification of the beam error detection hardware or soft ware. The objective of this research then has been to construct the primary sensor of a video guided automatic landing system for unmanned aircraft with a minimum of change to the existing configuration and a substantial reduction in the level of operator skill required.

SYSTEM OPERATION

In operation the RPV would be flown into the field of view of the camera at a range of up to two kilometers. This can readily be achieved by the automatic way-point navigation system already existing. The operator monitoring the video camera would detect the target image of the RPV when it enters the field of view and then engage the system to lock on to the 'target'.

The target image would be automatically tracked and beam error signals generated from a measurement of offset of the image from the centre of the screen in terms of glide-slope and localiser beam angular errors. These signals would be used to control the RPV through glide-slope and localiser capture until the target image is in the centre of the screen indicating that the beam errors have been nullified and the aircraft is established on the beam. After the capture phase the RPV would be maintained on the beam by the glide slope and localiser control laws using the video generated beam error signals. A facility is provided to superimpose a cross pointer on the centre of the target as defined by the image processing system. This enables the operator to monitor on line the accuracy of the results of the image processing. A facility also exists for the operator to renominate the target in the event of loss of target tracking by the system. This is achieved using a joystick control to align a relocatable window over the target image.

SYSTEM REQUIREMENTS

To provide a good resolution in terms of beam angular error, each field is sampled at a pixel frequency of approximately 7 MHz providing 320 pixels/line and 256 lines/field This gives a total of 81 600 pixels per field. The actual beam error resolution depends on the choice of camera lens. Test were performed using a 6 degrees angle of view giving a resolution of approximately 0.02 degrees per pixel in both horizontal and vertical directions. To provide good approach control it is desirable to maintain the band width of the beam error detection system well above the frequencies of the glide-slope and localiser control laws. It is envisage that these will have a natural frequency of approximately 0.2 Hz. To accommodate this it was decided to design for a beam error tracking bandwidth of 2.0 Hz and this in turn gave an objective of processing image data at field rate thus providing an update of beam error information every 20ms. To achieve this objective with the full field of data at the defined resolution only some ten programming instructions on average could be allocated to each pixel even with a 40 MHz processor. This would not permit a suitable image processing algorithm to be employed. As the target image of the RPV initially occupies only some twenty pixels at a range of 2 Km, it is clear that the bulk of the field image data is redundant. To reduce the amount of image data to be processed, thus enabling more complex image processing calculation to be performed, and also to reduce hardware data storage requirements, a relocatable window within the field was created. This had a total of 6,400 pixels i.e. only some 8% of the total field giving a 12 fold increase in the number of processor instructions per pixel.

SYSTEM MODULES

The image processing hardware consists of four main modules. Their functions are:

1. Target windowing.
2. Video decomposition, digitisation and recombination.
3. Video storage and multiplexing.
4. Image processing.

RELOCATABLE WINDOW

The relocatable window was generated using a separate microprocessor to control the position of the window within the field. A facility to alter the aspect ratio of the window to accommodate the changing shape and size of the target image as it approaches down the beam towards the camera was provided. Initially a square window of 80 x 80 pixels was employed for the target acquisition phase. To achieve the window generation the entire field or 81 600 pixels was bit mapped in RAM by the window microprocessor. A binary map consisting of 1's within the designated window area and 0's elsewhere in the field, was created.

This data was then serially clocked out from RAM at a pixel frequency of 7 MHz in synchronism with each start of line signal on a given field. The bit stream of 1's within the window indicated a valid pixel and this was used to control the sampling and loading of video pixel data into the field store. Because of the comparatively slow speed of the window control processor two RAMS were provided both bit mapping the entire field. One RAM had the preceding field's window area erased and was then updated by the processor with new window data to be used on the subsequent field, while the other RAM was providing sampling storage functions for the current field. At the end of each field the RAMS toggled and in this way the window shape information was updated every 20ms. Ref. 1.

VIDEO DATA DIGITISATION

The video data for image processing was initially split into its three component colours Red, Green and Blue using a Philips TDA3516A decoder. Each of these components was digitised using three RCA-CA3306 flash converters which digitised to 7 bit accuracy with a measured settling time of 60 ns. The most significant five bits of each colour were combined into a 16 bit word giving one spare bit to be used as a tag for the digitised pixel. This was used to indicate if a pixel was a valid target pixel or not during image processing. Details of the design of the module are given in 4.

RECOMBINATION OF VIDEO DATA

A means to display the digitised video data within the field was provided in order that the results of the image processing could be monitored by an operator. This was achieved by a video overlay component, the Motorola

MC1378. This device is capable of switching between two video sources at pixel frequency. One video source is emanating from the camera, while the other is clocked out from the fieldstore, and converted to the analogue component RGB signals using a DAC0800 device. In this manner, processed window video data from the fieldstore is recombined into the total field composite video signal at the correct location of the window. The switching of the overlay module was also controlled by the data clocked out from the windowing processor RAM.

VIDEO DATA STORAGE

To ensure the latest video data is available for image processing the video fieldstore is again duplicated and toggled at field rate. One fieldstore is in communication with the image processing microprocessor while the other is being read out after processing and converted for display. This second fieldstore is then updated with the latest incoming digitised window data. These operations require two accesses to the fieldstore within the pixel period of 140ns requiring the use high speed RAM. 15 ns access time IDT 7164 RAM was used in the system. To permit ease of testing a facility was incorporated in the design of the fieldstore which manually inhibited both the update of the video information and the toggling of the RAM. Data could still be clocked out from the RAM and this provided an effective freeze of window data on the screen. This greatly enhanced the ability to investigate the results of the image processing during testing of the system. It was also possible to observe that no corruption of data had occurred due to contention during multiplexing of the RAM between incoming camera data and processed data from the image processor module. This facility is required only for test purposes and is not used in normal operation. The design of the fieldstore including all data and address bus timing to avoid contention is given in 2.

IMAGE PROCESSOR

The Image Processing microprocessor chosen was a TMS 320 E25. The main advantage of this processor over the first generation series is the reduced instruction cycle time of 100ns. In addition the facility to directly access data memory in a single clock cycle compared with three clock cycles for the first generation processors gives a significant reduction in computing time overheads. This is a very important consideration when handling the large quantity of image date within a fixed time constraint. The E-series of processors have a 4k capacity EPROM built in reducing component count and hardware complexity. Experience of the Texas Instruments 320 family existed and software development tools were available which influenced the choice of digital signal processor. To accommodate Processor and RAM timing requirements, it was necessary to use advanced CMOS technology logic in the interface to the video frame store. Details of timing diagrams and the design and construction of this are to be found in 3.

SOFTWARE DETAILS

Target image recognition is performed by using a bitmask on each pixel of the digitised window data For development a predetermined signature of the RPV image was used to distinguish a target pixel from the background. The x-y co-ordinates of each pixel within the window are defined in terms of window co-ordinates. Each identified target pixel was taken to have the same effective weighting and so a non complex algorithm is used to find the centroid of the target in terms of window co-ordinates.

$$\overline{x} = \Sigma\, x/n \;;\quad \overline{y} = \Sigma\, y/n \qquad (1)$$

Where n is the total number of target pixels identified.

To ensure the window is super imposed on the target, the image processing algorithm generates new co-ordinates for the window location as a result of the target position calculated within the window. These co-ordinates are passed to the window generator processor for update on the next field. In this manner the window is driven such that the centroid of the target image of the RPV is retained as close to the centre of the window as possible. Movement of the window was inhibited if the centroid of the target deviated from the centre of the window by less than 12% of the window dimensions. This resulted in a smother tracking operation, and proved to be more acceptable to the operator. To provide a degree of noise immunity, a minimum target size was defined, this was set to ten pixels and if the target size was identified as being less than that, the window was not relocated. The image processing still designated the centre of the identified target with the superimposed cross. The absolute location of the centroid of the target is also calculated in screen co-ordinates relative to the centre of the screen to give glide-slope and beam angular error signals. Details of software development are to be found in 5.

CONCLUSIONS AND FUTURE DEVELOPMENT

A prototype system has been successfully constructed and laboratory tested using computer generated target images to simulate the RPV. These have been viewed by the video camera and have been successfully locked on to and tracked at field rate demonstrating a tracking bandwidth of 2Hz. A cross depicting the result of the image processing algorithm is displayed on the target image and the operator can easily monitor that the system is in lock. In initial field trials it is proposed to highlight the actual RPV to enable a good contrast to be established between the target image and the background.

Development improvements are anticipated and these include automatic acquisition and lock on to the target image. This can readily be achieved using a background subtraction algorithm to detect movement of the target relative to the static background. This would remove the current need for the operator to nominate the target. The window can systematically scan the screen until the target is located. In the event of loss of tracking the same scanning procedure would be used to relocate the target image. Target image shape recognition has not been included in the prototype system at this stage. It is however possible to incorporate shape recognition using the vector -orthogonal scanning technique outlined in 6 and 7. Shape recognition would reduce the overall bandwidth of the system requiring more than one field of processing time. The subsequent bandwidth should still be more than adequate for the approach control laws. In anticipation of this a facility has been incorporated in the system such that the image processor has control over the toggle of the video rams permitting additional processing running through a number of fields to be performed. The other video ram continues to update during this period providing most up to date data for subsequent processing. With adequate highlighting of the RPV the shape recognition algorithm is considered unnecessary for preliminary flight testing. It is envisaged that a provision to enable the operator to redefine the image mask on line will prove beneficial under operational conditions. This will enable the system to effectively relearn the target attributes on the approach.

The system has been proven in prototype form and is currently awaiting incorporation in the ground station for preliminary field trials.

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