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Positioning based on runway threshold imaging

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ABSTRACT

This paper aims at providing an introduction to the use of digital area scan cameras as opposed to the more traditional line scan cameras for the purpose of using imaging of the runway threshold as position updates.

INTRODUCTION

The key element of any flight inspection system is the position reference provided by the system. Many flight inspection organizations worldwide - commercial, military or governmental - prefers to rely on more than one position reference source. Quite often a blend between several sources is used.

While GNSS-based systems today are the most used position reference systems, many users prefer their secondary system to be completely independent of GNSS. One type of such system is based on using a camera coupled with an Inertial Reference Unit (IRU) and a Laser Range Finder (LRF). Such systems are often referred to as “TV positioning systems” (TVPS), or “camera based positioning system”. They provide an alternative reference completely independent of the GNSS domain.

While flight inspection TVPS up to now have been utilizing line-scan technology cameras to detect the runway threshold, the enormous advances in digital camera and image technology over the last years have made such line-scan technology outdated. The modern hi-speed, hi-quality digital matrix cameras combined with the excessive computer power available today, enables a stream of full size images to be captured and analyzed.

BACKGROUND: DESCRIPTION OF A TYPICAL SYSTEM

A camera based position reference system typically consists of the following main components:

1. Camera
2. Inertial Reference Unit (IRU)
3. Laser Range Finder (LRF)
4. Processing Unit

The principle is quite simple: The images captured from the airborne camera as the aircraft passes the threshold or a reference point, is compared with information in a database. The image is corrected and compared with the reference information using the latest image processing and recognition techniques. The IRU and the LRF is used for aircraft attitude and altitude corrections. Once the corrections are made, the known position can be fed into the position filter model.

During the approach towards the reference point, the IRU data is stored and time-stamped. Accurate timing information is of course essential. By feeding the highly accurate positions from the image processing into the flight track estimation, the stored flight track is re-processed providing a new and accurate flight path. This process is done in a matter of seconds. New and accurate flight inspection data is then calculated and presented. The accuracy of the camera solution is demonstrated to be sufficient for ICAO ILS CAT III flight inspections.

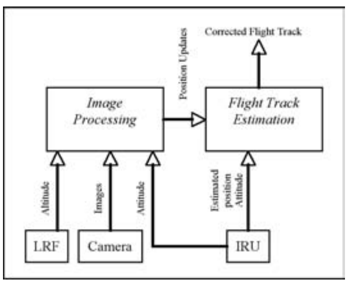


Figure 1 - Typical camera / LRF / IRU coupled system

The triggering of the threshold imaging when the aircraft is approaching the threshold may be fully automatic or manual.

CAMERA TECHNOLOGIES

Line scan sensors

In previous installations of camera based positioning systems, more or less invariably a line-scan camera has been used for the task of threshold position detection. Line-scan cameras are typically built for use in production lines, where objects are passing by the camera, or the camera is passing by the object. A line-scan camera will, as its name suggests, take an image of only one line of pixels at a time. A standard, not too modern fax-machine is a perfect example of a well-known device utilizing line-scan camera technology.

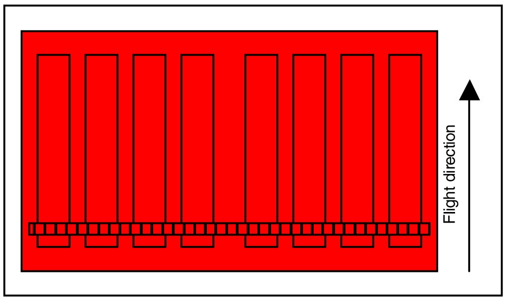


Figure 2 - Line scan camera covers one pixel line at a given time

Area scan (matrix) sensors

Also called array sensor, an area scan sensor consists of a square of photo sensors, rather than just one line. Through the recent years, digital cameras have appeared nearly everywhere, making the price of such sensor arrays fall dramatically. At the same time, availability has increased significantly, and specialized image sensors may be found for almost any imaginable (or image-able) application.

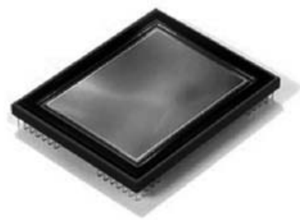


Figure 3 - Area scan image sensor

Standardization has also made the interfacing to such equipment easier. Standard hardware interfaces to the sensors allows a variety of manufacturers to offer their solutions. Further, new standards in extremely high speed data transfers, such as CameraLink, allow real-time transfer of images from cameras to computers for processing, even with hundreds of images captured every second.

Sensor technology

Digital image sensors (both area scan and line scan) are typically based on one of two types of technology: CCD or CMOS

CCD or CMOS?

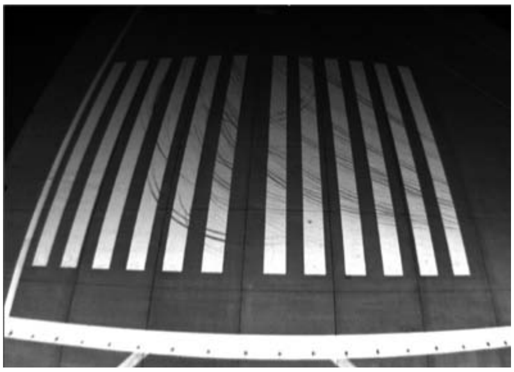
The CCD technology (Charged Coupled Device) has been the leading technology in digital imaging for many years. During the recent years, however, CMOS imagers have resurged as a strong competitor. As with most such “technology battles”, both sides have their benefits and disadvantages.

CCD sensors have inherent less noise due to its design, and provide in this regard better quality image and dynamic range. CCD sensors also have better base design towards achieving better shuttering mechanisms. CMOS sensors on the other hand provides higher speeds (images pr second) and also has advantages related to image parameters such as

smearing and blooming. One additional advantage of CMOS is the overall smaller size ("one-chip solution") and corresponding lower power consumption.
For the application of a threshold camera, suitable candidates may be found from both the CCD and CMOS camps.

Resolution and Optics

When evaluating the actual camera to use, it is also necessary to look into the optics required for the mission at hand. For a runway threshold camera, one of the key factors is to have a wide field-of-view (FOV) to ensure image capture of the region of interest.
The aircraft will typically pass the runway threshold at 50-100 ft, and a FOV of > 60 degrees (ultra wide-angle) is required. As such ultra wide-angle lenses have a very large depth of view, the iris may be fixed at full opening and the focus set to infinity. The shutter time of the image sensors may be adjusted over a very wide range, further enabling high quality images to be captured with such settings.



A wider field of view lens will give higher chance of capturing the region of interest even with severe aircraft roll, pitch and heading offsets.
The actual region of interest is normally the center of the threshold. As the image is captured during the final stage of the approach, the aircraft attitude will normally be close to level, at least in the roll component. This indicates that the region of interest is very likely to be captured successfully even with far less than 90 degree field of view.
The main advantages of smaller field of view is less image distortion, better resolution (pixels pr. meter) and thus better accuracy.

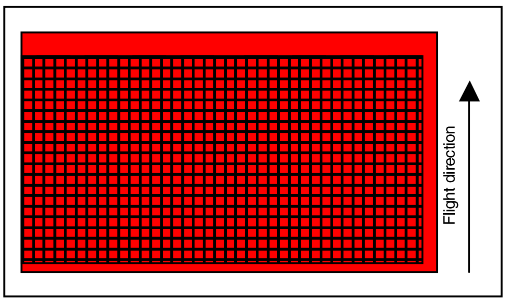


Figure 5 - Area scan covering entire area of interest in one instance

Area scan vs. line scan

When an image of the threshold shall be captured using a line scan camera, the "irregular" movement of the aircraft may make a very disturbed image. The actual image exposure typically lasts for several seconds, and turbulence or sudden movements of the aircraft may create image effects that are hard to fully rectify in post processing.
Additionally, the image is not equidistant as each line is sampled at certain time intervals. Therefore, any variation in aircraft speed or pitch may make the distance between lines non-constant.
Although most of these effects may be partially corrected during post processing, it introduces additional uncertainty and complexity to the system.
Using an area scan camera instantly removes many of these difficulties. And it even produces better results and further possibilities.
First of all, with an area scan camera the system acquires a full image, not just a line at a time. Therefore, the full image is captured "instantly". The exposure time may be automatically controlled, and may be as low as 1/50 000 of a second under given circumstances.
Further, several images are taken in sequence. This ensures that suitable image candidates may be selected for further processing to calculate the aircraft position. As an additional possibility, several of these images may be used simultaneously to calculate the aircraft position using multiple viewing angles. Such triangulation will yield even higher accuracies and creates a more robust solution.

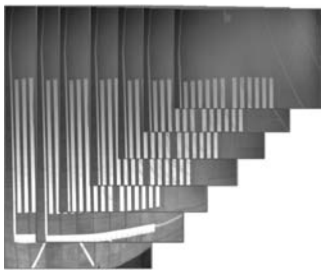
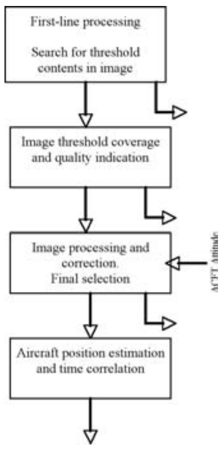


Figure 6 - Area scan camera overlap

Figure 6 shows an illustration of overlap with an area scan camera. With typical image rates, more than 20 images may contain all, or close to all, of the threshold. These images will all be from slightly different positions.

IMAGE PROCESSING

One of the reasons line scan cameras have been the choice for many years is the relatively small amount of data it is outputting. This enables online processing and data storage to take place with very modest computer power available.
However, today we see that the computer power available in a modern system is fully feasible of processing streams of full size images captured by an area scan camera. A typical such system may acquire 15-20 images pr second, creating 50 megabytes of data.
These images will first pass through a first-line processing stage to rapidly determine if they may be of interest or not. More detailed processing will search for the threshold and determine a quality factor, indicating how much of the area of interest (i.e. the threshold) is in view.
Finally the best images are processed and corrected for aircraft attitude. Calibration factors for camera, lens and installation are applied. Then the actual position of the aircraft is calculated.



With the enormous advance of digital images in both industry and home over the last years, COTS image processing tools and components are becoming widespread available. For industrial computer packages, libraries of highly advanced image processing functions may be purchased and integrated into your own software.
This makes it possible to develop very complicated image correction strategies without having to implement the low-level algorithms.
A typical set of image processing performed is:

1. Noise reduction
2. Global intensity corrections – to correct for less-than-perfect exposure
3. Contrast enhancement
4. Removal of any motion blur
5. Correction of lens distortion – see figures 7 and 8
6. Edge detection – to locate the threshold in the image

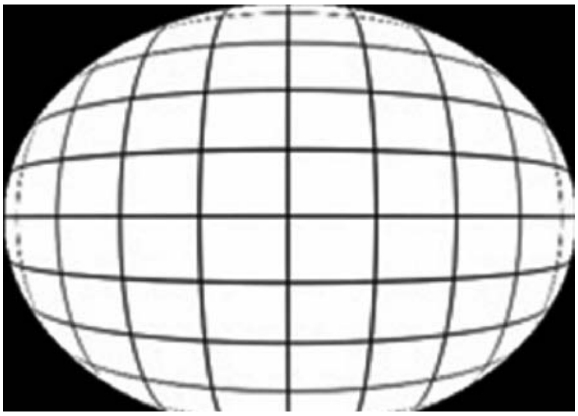


Figure 7 - Barrel distortion

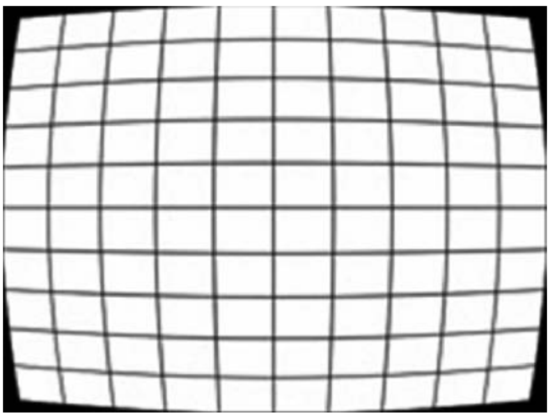


Figure 8 - Fisheye distortion

All of the algorithms needed in such a strategy are available in industrial image processing packages, providing excellent results and stability.

The threshold itself has very distinct features that are easily recognizable by image processing software. With the high quality images acquired by an area scan camera solution, calculating the aircraft position based on the known position of the threshold yields very accurate results.

INSTALLATION ISSUES

One of the major cost issues for a full camera system is the actual installation and necessary modifications to the aircraft.
Obviously, the actual cameras and the Laser Range Finder must be placed in an area with unobscured downward view. The area must be covered with a glass with suitable optical performance. As the actual computing section is placed away from the camera section, the amount of space required is quite small.

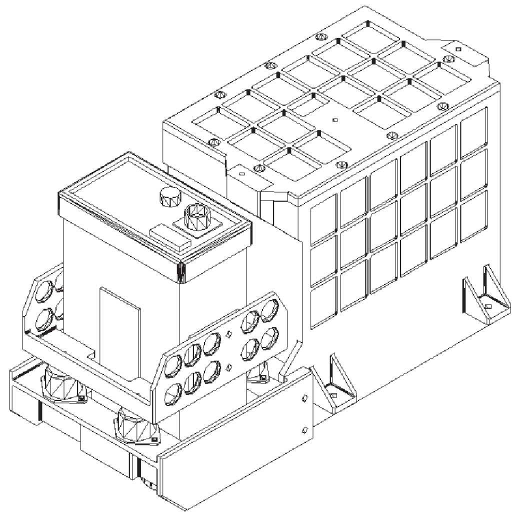


Figure 9 - Example of mechanical arrangement

CONCLUSION

The continuing technological advances have made high-quality area scan image sensors commonly available. Their widespread use makes the availability and diversity in this field ever increasing, providing many excellent options for finding suitable solutions for runway threshold cameras based on this technology.
Further, the necessary computer power is readily available to perform the CPU-intensive image processing required in near real-time.
Standardized hardware solutions as well as camera communication protocols make the implementation and design of such solutions much more feasible, both technically and economically.
Image processing algorithms for these types of applications are available as packages. This allows the developers of such systems to rapidly provide new and enhanced strategies to achieve the desired accuracy and quality of the final results.
We are constantly seeking for more cost effective solutions for flight inspection. The development of the new UNICAM camera system demonstrates this commitment.