A Fusion of Real and Virtual Information for Aiding Aircraft Pilotage in Low Visibility

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***Abstract*—Low visibility is the single most critical factor affecting both the safety and capacity of worldwide aviation operations. Enhanced Vision System (EVS) and Synthetic Vision System (SVS) are new assistant systems designed with the goal of eliminating poor visibility conditions as a causal factor to civil aircraft accidents and delays. Due to their great potential, both EVS and SVS have been drawing dramatic attention from academia to industry all over the world and they are moving from laboratory to practical application. In China, however, the progress is comparatively slow because of the costly and limited experimental resources. This paper reports on the preliminary work for developing EVS and SVS including the pioneer flight test in China for civil aviation use and its data analysis. A novel concept of merging real and virtual vision together is put forward in this paper.**

***Index Terms*—Low visibility, EVS, SVS, Fusion**

I. Introduction

Low visibility and reduced situational awareness have been cited as predominant causal factors affecting both the safety and capacity of worldwide aviation operations. In commercial aviation from 2000 to 2009, the second largest number of fatalities of all fatal accidents worldwide is categorized as Controlled Flight Into Terrain (CFIT) [1], where a mechanically sound and normally functioning airplane is inadvertently flown into the ground, water, or an obstacle, principally due to the lack of outside visual reference and situational awareness [2]. Besides, inclement weather is the single biggest factor causing air traffic delays since weather conditions fall below visual flight rule operations [3]. It is estimated that the number of aviation transportation airport will be more than 230 and the flight movements will be up to 14 million in China by 2015 [4]. Thus, how to improve the aviation efficiency and safety under limited airspace resource in degraded visibility conditions is of great importance for both airplane companies and airports. This is therefore the motivation for developing new assistant systems with the goal of eliminating low visibility conditions as a causal factor for civil aircraft accidents and delays.

The enhanced vision system (EVS) and synthetic vision system (SVS) are two visual aids designed to provide pilots with improved situational awareness at night and in poor visibility conditions through information fusion. An EVS, in Figure 1(a), is an electronic means to provide a display of the external scene by use of an imaging sensor, such as a Forward-Looking InfraRed or millimeter wave radar. While, SVS, in Figure 1(b), is a computerized image of the external scene topography, generated from aircraft attitude, high-precision navigation, and data of the terrain, obstacles, cultural features, and other required flight information [5]. Through the intelligent combination of different sensor data of the same scene, features of significance are enhanced and undesirable artifacts are minimized or removed.

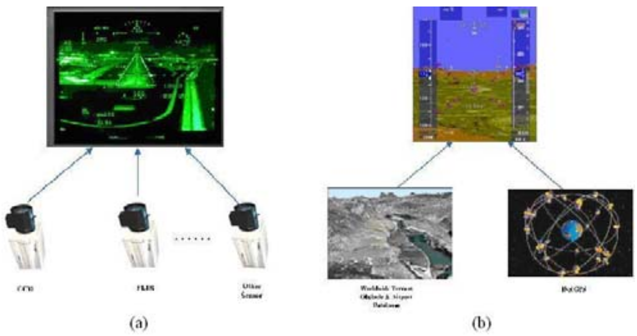

Figure 1. (a) Enhanced Vision System, (b) Synthetic Vision System

Due to their great potential, both EVS and SVS have been drawing dramatic attention from academia and industry all over the world. In academia, NASA has dedicated decades of time to develop such systems for their aviation safety programme. SPIE international Conference on Enhanced and Synthetic Vision is hold year after year in American since 1996. Moreover, in annual IEEE/AIAA Digital Avionics Systems Conference, it also has many reports about EVS and SVS. In industry, many avionic companies such as Honeywell, Rockwell,

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Thales, Aireyes,Inc, etc. have released their initiatives or prototypes of EVS and SVS in the past decade.

EVS and SVS have also gained significant attention in both civil and military fields of China recently. The progress, however, is comparatively slow as experimental resources like infrared sensor, inertial system, especially the aircraft are costly and limited. Consequently, few achievements has been reached.

This paper reports on the pioneer flight test for EVS and SVS in civil fields of China. The objective in this trial was to collect data for subsequent analysis and achieve intuitive fusion results for evaluating the merits and defects of EVS and SVS. The final goal of the project is to create an enhanced and synthetic vision system (ESVS) by merging real enhanced vision (EV) and virtual synthetic vision (SV) together. According to this, a novel concept of fusing real and virtual images is put forward. The paper place an emphasis on the details of primary flight test. Results of blending a visible band image with thermal imagery and fusing GPS\INS data with terrain database are also specified.

II. System and Algorithm Overview

Since the thermal sensor can provide more information about the environment than visible band sensor during poor visibility conditions such as rain, snow, fog or haze, the EVS demonstrator uses a combination of an infrared sensor and a visible band camera for image acquisition. The two image sensors are fixed tightly to minimize image registration difficulties. A navigation system including two GPS antennae and a gyro is also involved for synthetic vision generation. Figure 2 lays out the instrument employed in the tests.

Figure 2. From left to right: image sensors, gyro, and GPS antennae

Registration is required to remove the FOV differences in the cameras and all image fusion algorithms require registered images so that any pixel comparisons made are valid. The visible band image is used as the baseline and the IR data is registered to the VIS image by applying an affine transform to the IR imagery. A general representation of an affine transform[6] is $[y_1, y_2, 1] = [x_1, x_2, 1]T$ where

$$T = \begin{pmatrix} a_{11} & a_{12} & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & 1 \end{pmatrix} ,$$

x_1 and x_2 reference the input coordinate system, $y_1$and y_2 reference the output coordinate system, and a_{ij} are transform coefficients. Combine the two formulas above, the mapping functions are given as

$$y_1 = a_{11}x_1 + a_{21}x_2 + a_{31} \text{ and}$$

$$y_2 = a_{12}x_1 + a_{22}x_2 + a_{32} \quad .$$

Currently, the registration work is off-line. The same transform coefficients are used on all IR video frames since the camera alignment should not change during the flight test.

The registered images are fused by performing a pyramidal [7, 8] approach. As for low visibility scenario, VIS images provide fine silhouette while IR images highlight main features of interest, and the combination of these features then provides the added value fused output. It was for such reason a pyramidal scheme was chosen.

III. Trials for Data Acquisition and Analysis

The flight test was operated at Xinjin airport on board an experimental single-engine trainer, Cessna 172, in late 2011. The main objective of the flight test is to acquire intuitive visible and thermal aero images and navigation data in poor visibility conditions for the fellow-up analysis. The cameras were mounted at the support bracket of the left wing using professional aerial material, as shown in figure 3. And the navigation system was fixed at the upper part of the aircraft. The flight scenario consisted of several approaches and landings in foggy day condition and at night.

Figure 3. EVS sensors mounted on the aircraft

Figure 4 and Figure 5 illustrate an example set of images from flight trial at different period of time. Each image is separated into three sub-images, including CCD image at the bottom right, infrared image at the upper right and the fusion result of the aforementioned source of images on the left.

As shown in figure 4, the runway is almost invisible in the far field of CCD image. While in IR image, the edges of the runway are discriminable. The final enhanced, registered and fused output has significantly better contrast and brightness than either of the original inputs. In addition to the visibility of runway, the clear view in the near field of the fused image may also provide pilots with confidence.

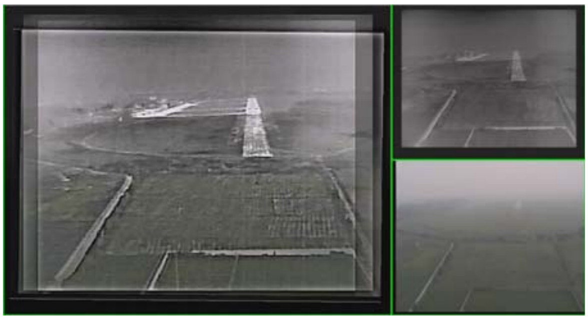

Figure 4. Original CCD image(bottom right), original IR image(upper right) &fused image(left)

Figure 5 shows the night condition of a landing process. As shown in the image, although the CCD camera captures the runway lights clearly, the infrared image provided a better reference of runway surroundings. And the fused image which takes advantages of the dual input, gives pilots help and support.

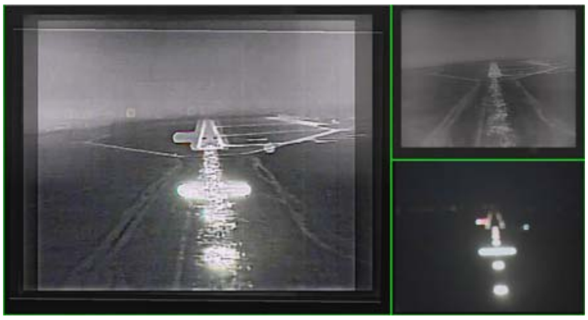

Figure 5. Original CCD image(bottom right), original IR image(upper right) &fused image(left)

A computerized virtual vision of an approach during flight test was also achieved. This synthetic vision was generated by fusing real longitude, latitude, altitude, heading, pitch and roll data retained from on-board navigation system together with pro-stored virtual terrain database and flight symbology. Figure 6 shows the final synthetic vision, the 30-meter precision Digital Elevation Model (DEM) of Xinjin and the model of Xinjin airport with texture of real images, from left to right respectively. Combination of DEM and airport model makes up the virtual terrain around the airport which is reflected in the synthetic vision. This method of merging real and virtual elements together is another way to make invisibles visible. Obviously, it can display more detailed and higher resolution image about the outside view than it is possible to obtain from the infrared sensor.

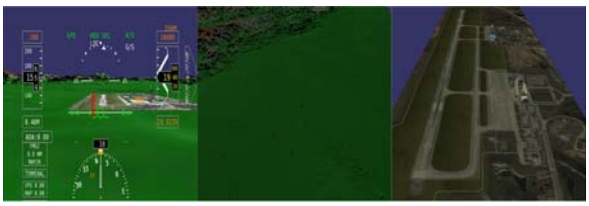

Figure 6. Form left to right: Synthetic Vision, Vision of Digital Elevation Model, and Model of Xinjin Airport

Both EV and SV are capable of providing an effective cue for pilots to view the outside world in degraded weather conditions. They have there strengths and weaknesses, though. A pilot gets a high degree of confidence in the enhanced vision since very little stands are between the EVS image and the real world. On the other hand, atmospheric influence, time of day, and sensor characteristics can be crucial factors in the quality of the EVS imagery. Synthetic vision, by virtue of being weather-independent, can be a good complement for the enhanced imagery. However, any errors in the terrain database or the measurement of the aircraft's position or orientation will cause the synthetic scene to be erroneous. Any of these potential problems could mislead the pilot to believe that the path of the aircraft is free of obstacles, when in fact it is not [9].

According to the facts above, there is an evident need for a means to combine SV, EV and even real vision together. This is the ultimate aim of the project and will be highlighted in the following work.

II. Conclusion

Experimental evidence has shown that merging dual waveband image streams in EVS may lead to a better quality of scenes and the fused image contained more information than one of the individual channels. Meanwhile, the benefit of the SVS for situational awareness was clear and it is a nice complement for EVS. In consideration of both merits and drawbacks represented in EVS and SVS, the combination of EV and SV is the inevitable course to be carried out.

In the work subsequently, the video streams of EVS will be registered, enhanced, and fused on a DSP platform in real-time with the refinement of the algorithms. Merging real enhanced vision with virtual synthetic scene is another necessary task required to be achieved at the same time. Further trials of the systems will then be conducted.

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