

Experimental Study with Enhanced Vision System Prototype Unit

VPS Naidu, Narayana Rao P., Sudesh K Kashyap, Shanthakumar N. and Girija G.

Multi Sensor Data Fusion Group
Flight Mechanics and Control Division
CSIR-National Aerospace Laboratories
Bangalore, India 560017
Email: vpsnaidu@gmail.com

Abstract—The National Civil Aircraft (NCA) being developed at National Aerospace Laboratories (NAL) is expected to have the capability of operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions. The key enabling technology for this is an Integrated Enhanced and Synthetic Vision System (IESVS), which is a combination of Enhanced Vision System (EVS), Synthetic Vision System (SVS), and Head-Up Display. A prototype of EVS consisting of Forward Looking Infra Red (FLIR) camera and CCD color camera is developed and tested at NAL. A Simulink block is developed to acquire the image data in real time (online) from a four channel frame grabber. An image fusion algorithm based on wavelets is developed to fuse the images from CCD and FLIR cameras. The affine transform used for image registration is computed by selecting the control points from both CCD and FLIR images. Test results from the experiments conducted on the runway during day and night (runway lights ON/OFF) conditions are presented.

I. INTRODUCTION

Increasing demand for air transportation puts the airline operators under tremendous pressure to maintain the timings of arrival and departure with no significant delay. The delay in flight operations depends upon various factors. One of the main factors that affect the flight operations is weather along the flight route. Reduced visibility due to adverse weather conditions makes it difficult to conduct flight operations in the same manner and rate as in visual meteorological conditions. Although navigation aids like Automatic Direction Finder (ADF), Distance Measuring Equipment (DME), VHF omnirange (VOR), Instrument Landing System (ILS), Microwave Landing System (MLS), Global Positioning System (GPS), etc. can provide solutions to many of the problems caused by low visibility, the potential now exists for providing enhanced visual references to the flight crew. Currently, several organizations around the world are working on Enhanced Flight Vision Systems (EFVS) and Synthetic Vision Systems (SVS) to provide solutions for this problem. According to FAA, EFVS is defined as a combination of Enhanced Vision System (EVS) and Head-Up Display (HUD). An Enhanced Vision System (EVS) is an electronic means to provide the flight crew with a sensor-derived or enhanced image of the external scene through the use of imaging sensors such as forward looking infrared, millimeter wave radiometry, millimeter wave radar, and/or low light level image intensifying. A Synthetic Vision

System (SVS) is an electronic means to display a computer-generated image of the applicable external topography from the perspective of the flight deck that is derived from aircraft attitude, altitude, position, and a coordinate-referenced database.

Of late the NASA Langley Research Center (LaRC) Aviation Safety and Security Program Office and Systems Engineering Directorate have been initiating projects to improve air travel safety [1]. One of the initiating project is the Synthetic Vision Systems (SVS) where innovative techniques to eliminate aircraft accidents caused due to poor visibility especially during landing and takeoff are being investigated. An Enhanced Vision System (EVS) combined with SVS is used to provide real-time scene from a vision sensor suite with Infra Red and visible cameras to a pilot. The vision sensors can provide more information about the environment than pilot observation during poor visibility conditions viz., fog, rain, snow or haze [1,2]. The main function of the EVS is to fuse the imaging sensor data to increase the information content and quality of the captured imagery, and to present the fused image instead of individual images to the pilot on head up display to increase the pilot situation awareness.

The National Civil Aircraft (NCA) proposed to be developed at National Aerospace Laboratories (NAL) is expected to have the capability of operation from airports with minimal infrastructure and instrumentation facility under all-weather conditions [3]. One of the technologies that hold promise for achieving this is the Integrated Enhanced and Synthetic Vision System (IESVS). IESVS can create near all-weather access to any touchdown zone at any landing facility while avoiding costs for land acquisition, approach lighting, ground-based precision guidance systems (ILS), radar and control tower infrastructure. The ability to see in all directions, even in reduced visibility conditions, offers considerable benefits for operational effectiveness and safety.

Multi Sensor Data Fusion (MSDF) group of Flight Mechanics and Control Division (FMCD)/NAL has embarked on the IESVS development for NCA. IESVS involves integration EVS and SVS. While SVS is a computer generated image of the surroundings using stored terrain data base, EVS involves integration of weather penetrating sensors to give the pilot a real time clear picture of the surroundings when visibility is

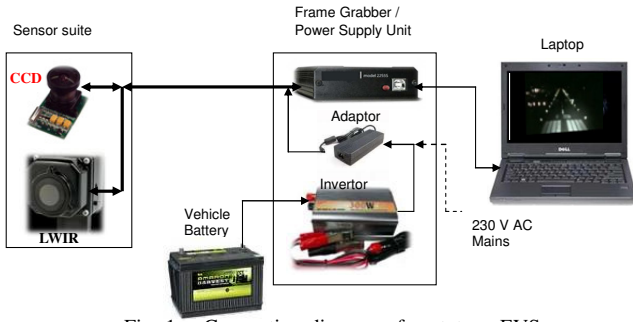


Fig. 1. Connection diagram of prototype EVS

poor. EVS developed as a part of IESVS is presented in this paper.

II. EVS PROTOTYPE

The information flow diagram of the EVS prototype is shown in Fig-1. The sensor suite consists of image sensing devices viz., Charge Coupled Device (CCD) camera and Long Wave InfraRed (LWIR) camera [4] are powered by 12V DC from vehicles battery. CCD that detects $0.4-0.78\mu\text{m}$ band and it can capture runway markings, skyline, and citylights in good visibility conditions. LWIR senses radiation in $7.5-14\mu\text{m}$ band and it can capture background scenery, terrain features and obstacles at night and in other low visibility conditions. Vehicles battery of 12V DC is fed to inverter where the inverter converts 12V DC to 230V AC and in-turn fed to 12V DC adaptor as shown in Fig-1. This arrangement is to avoid variation in the power supply if directly fed from the vehicle battery. For laboratory experiments, both battery and inverter can be bypassed by connecting 230V AC mains directly to the 12V DC adaptor. The image/video data gathered by the image sensing devices is fed to frame grabber. The frame grabber unit has four analog input channels that can acquire the data and output the digital frame data at a rate of 15Hz by each channel [5]. Since the prototype has two sensing devices only two channels will be active and the frame grabber could able to provide the image frames at a rate of 30Hz by each of the two channels. The output of the frame grabber is fed to laptop for video acquiring and other image processing through the USB port. The frame grabber is powered by USB port of the laptop/PC.

The individual components/devices used in this experiment are shown in Fig-2. The integration of these devices is done at the laboratory and tested.

A. Processing

The Matlab Simulink model of EVS system is shown in Fig-3. Image registration has been done since the videos are not bore sighted. The registered images are fused using wavelets.

B. Image Acquisition

Sensoray frame grabber (S2255) is used to acquire video data from CCD also known as EO (electro optic) and LWIR imaging sensors in the development of Enhanced Vision prototype. Source code in C++ is available in Sensoray website for interfacing the frame grabber to PC. The equivalent Matlab or

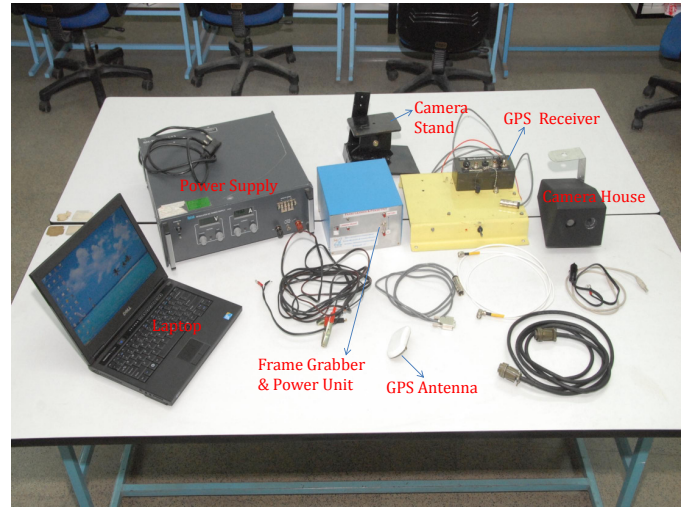


Fig. 2. EVS Components

Simulink code is not available. An attempt is made to develop the interface C++ code in Simulink using legacy code [6]. The developed Simulink block is shown in Fig-4.

C. Image Registration

The acquired data is converted to double precision since the image registration and image fusion algorithms work on data in double format. Unregistered images from CCD and LWIR cameras taken at MSDF Lab are shown in Fig 5 (top). Image registration [7-9] is done by selecting the control points from EO and LWIR images of size 640×480 . The selected control points are:

EO_points = [584 146; 306 204; 113 419; 178 161; 535 367; 431 368; 171 411; 14 309];
 LWIR_points = [622 135; 357 196; 172 438; 238 148; 577 384; 485 386; 232 432; 84 313];

The following matlab function is used to find the affine transform between the two images.

```
tmatrix = cp2tform(EO_points,LWIR_points,'affine');
The tmatrix is a structure as:
```

```
ndims_in : 2
ndims_out : 2
forward_fcn : @fwd_affine
inverse_fcn : @inv_affine
tdata : [1 x 1struct]
```

The affine transform is:

$$tmatrix = t.tdata.T = \begin{bmatrix} 1.0356 & -0.0092 & 0 \\ 0.0270 & 0.8817 & 0 \\ -52.4870 & 32.9069 & 1 \end{bmatrix}$$

The simulink block for image registration is shown in Fig 6 and registered image obtained from this block is shown in Fig 5 (bottom). Since the cameras are fixed, the affine transform obtained earlier can be used for subsequent experiments.

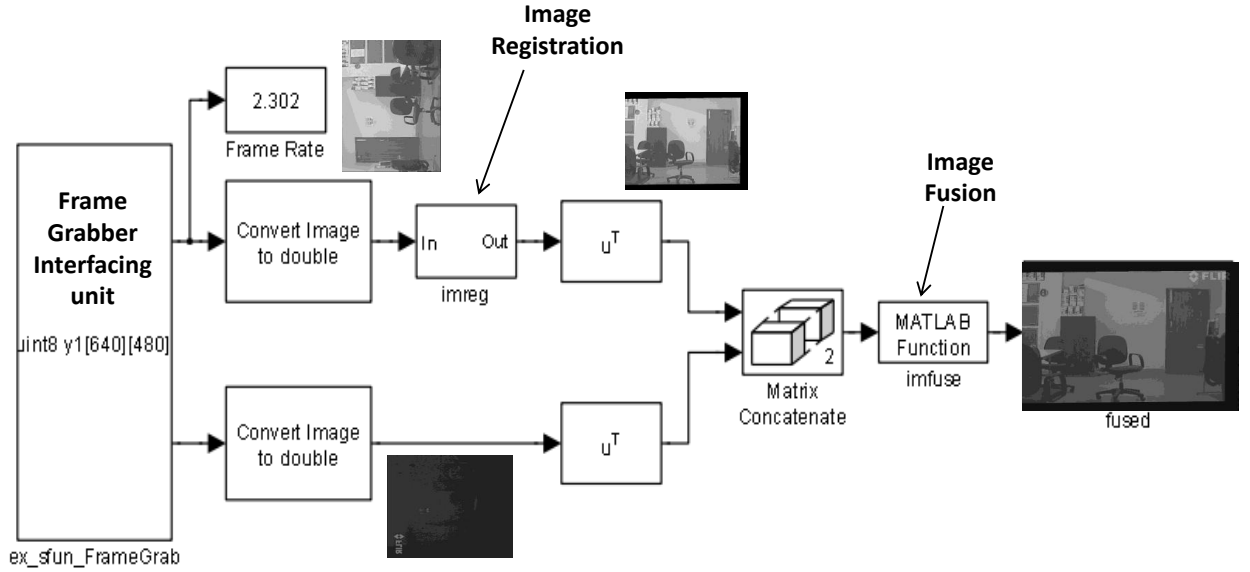


Fig. 3. Simulink model of EVS prototype

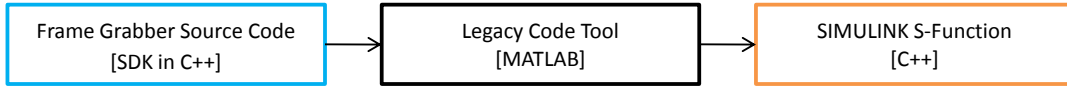


Fig. 4. Legacy code for frame grabber interfacing unit



Fig. 5. Unregistered(top) and Registered(bottom) Images

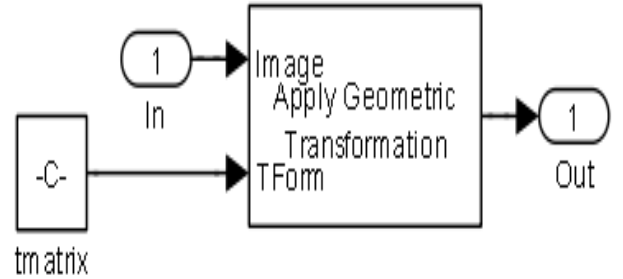


Fig. 6. Simulink block for image registration

The detailed coefficients at l^{th} level are denoted as Ψ_l^V, Ψ_l^H and Ψ_l^D respectively. The schematic diagram for the wavelet based image fusion scheme is shown in Fig 7. The images to be fused I_1 and I_2 are decomposed into $L(l = 1, 2, \dots, L)$ levels using wavelets. At each decomposition level ($l = 1, 2, \dots, L$), the fusion rule will select the larger absolute value of the two detailed coefficients, since the detailed coefficients correspond to sharper brightness changes in the images such as edges and object boundaries etc. These coefficients are fluctuating around zero. At the coarsest level ($l = L$), the fusion rule take average of the approximation coefficients since the approximation coefficients at coarser level are the smoothed and subsampled version of the original image. The fused image I_f can be obtained using :

D. Image Fusion

The registered images are fused using wavelets with one level of decomposition [10, 11]. The complete level decompositions may be represented as:

$$I \rightarrow \{\Phi_L, \{\Psi_l^V, \Psi_l^H, \Psi_l^D\}_{l=1}^L\} \quad (1)$$

Where Φ_L is the approximation coefficients at coarser level.

$$I_f \rightarrow \{^f\Phi_L, \{^f\Psi_l^V, ^f\Psi_l^H, ^f\Psi_l^D\}_{l=1}^L\} \quad (2)$$

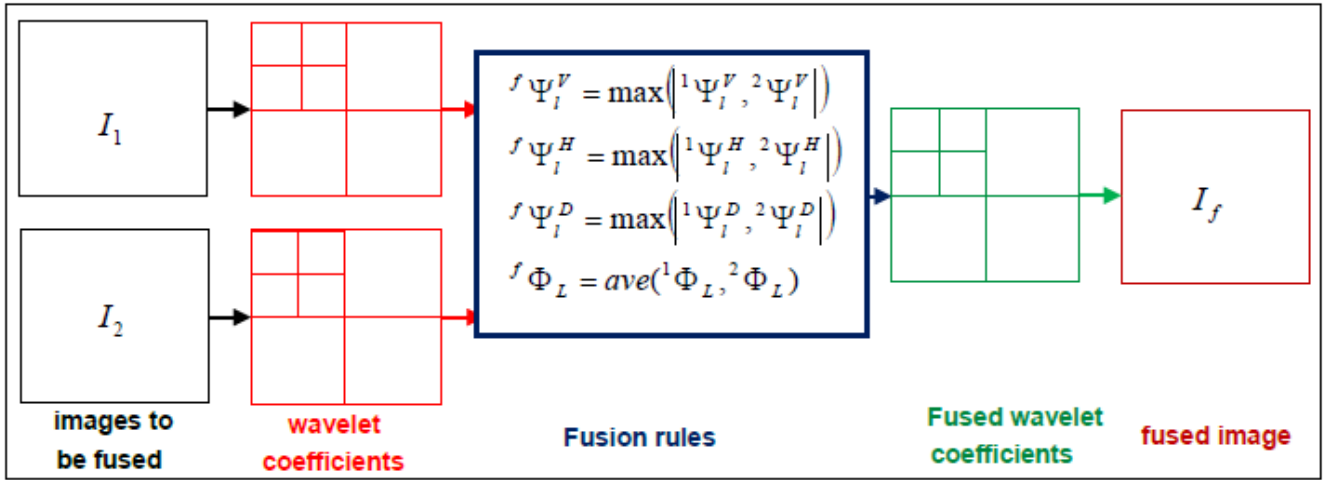


Fig. 7. Schematic diagram of the wavelet based image fusion scheme



Fig. 8. EVS prototype unit with stand mounted on test vehicle



Fig. 9. Rear view of the test vehicle

III. EXPERIMENTAL RESULTS

After laboratory tests the EVS prototype unit along with GPS receiver is mounted on the ground test vehicle to carry out tests on airport runway. The closed view of sensor suite along with GPS antenna mounted on the ground test vehicle is shown in Fig 8. Frame grabber & power supply unit and laptop are placed inside the vehicle as shown in Fig 9 for recording the data on line.

Experiments were conducted on runway on 11th Jan 2010 during day time and 13th Jan 2010 after sunset. During both the days test vehicle was driven on the runway from one end to the other end and return. During the run, video was captured from both the cameras, fused online and recorded on the laptop. Fig 10 shows the image recorded by CCD camera and LWIR (FLIR Forward looking Infrared) camera on the runway after sunset with runway lights ON. From the figure it can be seen that only runway lights are visible in CCD

camera and not the other features of the runway, whereas in LWIR camera it is the other way i.e. only runway markings are visible. Once both the images are fused with proper image registration (ref from section IIc), the fused image contains all the necessary information of the runway and hence pilot can have better situational awareness of the runway.

Objective of this experiment is to study the characteristics of the image sensors across different weather conditions during day and night. The data generated will also be useful to evaluate the image fusion algorithms developed in-house for automatic target recognition (ATR) research. Apart from images of aircraft and helicopters landing, taxiing and takeoff, images containing runway markers were also acquired for the purpose of runway feature extraction. It is also proposed to utilize this data to arrive at fusion quality metrics based on the visibility criterion.



Fig. 10. Runway view

IV. CONCLUSION

Enhanced vision system (EVS) prototype is developed and tested as part of integrated enhanced synthetic vision system (IESVS). Legacy code for frame grabber interfacing unit has been developed to grab the video in Simulink environment to test the EVS prototype in real time. Affine transform is computed by choosing the control points from CCD and LWIR images for image registration and it can be used for subsequent experiments since the imaging sensors are fixed in sensor suite. Wavelet based image fusion algorithm has been used to fuse the CCD and LWIR images. EVS prototype is tested at airport during day and night (with runway lights ON and OFF) conditions. The fused image contains all the information/features of runway and hence pilot can have better situational awareness of the runway. The knowledge gained from this prototype experiment would be very useful for integrating the synthetic vision and also for automatic target recognition of runway obstacles.

REFERENCES

- [1] Glenn D. Hines, Zia-ur Rahman, Daniel J. Jobson, Glenn A. Woodell, and Steven D. Harrah, Real-time enhanced vision system, *Enhanced and Synthetic Vision 2005*. Edited by Verly, Jacques G. Proceedings of the SPIE, Volume 5802, pp. 127-134 (2005).
- [2] Peter Hecker; Hans-Ullrich Doehler; Reiner Suikat, Enhanced vision meets pilot assistance, *Enhanced and Synthetic Vision 1999*, Edited by Verly, Jacques G. Proceedings of the SPIE., Vol. 3691, pp.125-136 (1999)
- [3] Giriya Gopalratnam, Data Fusion for Integrated Enhanced Vision System for Transport Aircraft, Project Proposal, FMCD, NAL, December 2007
- [4] <http://www.flir.com>
- [5] <http://www.sensoray.com/products/2255.htm>
- [6] http://www.mathworks.de/access/helpdesk/help/toolbox/simulink/slref/legacy_code.html
- [7] <http://www.mathworks.com/access/helpdesk/help/toolbox/images/f20-14983.html>
- [8] <http://www.math.tau.ac.il/~turkel/notes/registration.pdf>
- [9] Barbara Zitova and Jan Flusser, Image registration methods: a survey, *Image and Vision Computing*, Vol.21, pp.977-1000, 2003
- [10] Gonzalo Pajares and Jesus Manuel de la Cruz, A Wavelet-based Image Fusion Tutorial, *Pattern Recognition*, Vol. 37, pp. 1855-1872, 2004.

- [11] VPS Naidu and J.R. Raol, Pixel-Level Image Fusion using Wavelets and Principal Component Analysis A Comparative Analysis *Defence Science Journal*, Vol.58, No.3, pp.338-352, May 2008.