FORWARD LOOKING INFRARED SIMULATION FIDELITY IN AIRCREW TRAINING DEVICES

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ABSTRACT

Simulating FLIR imagery requires integration of visual simulation technology with IR modeling and prediction. Analyses of simulated FLIR and consideration of training needs indicates that high fidelity simulation of all FLIR components is not required for many aircrew training applications. The different components of FLIR simulation i.e., predicting IR exitance from surface features, modeling atmospheric attenuation, and simulating sensor effects, are independent and an appropriate level of simulation complexity for each component must be selected for a particular application. Effective combinations of component fidelity for various training applications are described. Simulating sensor and atmospheric effects on FLIR imagery will have a high training payoff for many applications at relatively low cost. Developing a FLIR simulation system which will support thermally accurate IR predictions for any user specified mission scenario will require extensive development and data base support; the training applications which require such systems are limited.

INTRODUCTION

Forward Looking Infrared (FLIR) systems function by detecting the minute differences in infrared (IR) energy radiated from surfaces and imaging these differences as variations in brightness on a video display. Although a FLIR image gives the first impression of being very similar to a visual image, there are significant differences. The most important of these differences is that FLIR imagery varies over time. Due to changes in environmental conditions, FLIR imagery for a given scene will vary in visibility range, level of contrast, and the relative brightness of objects. A fully developed FLIR simulation would therefore incorporate the imaging capabilities of visual simulations with the ability to alter the thermal characteristics of the scene based on environmental conditions specified in training scenarios. Peters [4] estimated that 27 color tables would be necessary to simulate the different scenes resulting from variations in cloud cover, rain, wind speed, and IR viewing range for any given place, day, and time. Add color tables for effects due to air temperature, time of day, and month of the year and the number of combinations will easily exceed 10,000.

A very high fidelity FLIR simulation will include high quality visual imagery plus the capability to recreate the IR characteristics for any desired set of environmental conditions. However, the costs for IR effects modeling and database construction for this type of system will be very high. A more practical approach is to selectively incorporate different levels of fidelity based on training considerations: what is the intended use for the system, who will use it, how often, and what skills are to be learned? By applying the answers to these questions to the different components of a FLIR simulator for aircrew training, the designer can control system cost and complexity by limiting the range of variability to be simulated. This level of control is possible because there are three independent components within FLIR simulation: estimation of IR exitance from surfaces, atmospheric attenuation of IR energy between the surface and the sensor, and effects due to the sensor itself (Geltmacher [3]). Each of these components requires a separate modeling effort with its own advantages, costs, and limitations. Comparing the costs and benefits of simulating each of these components with the requirements for a particular training task allows designers to choose an appropriate level of simulation fidelity.

SIMULATING FLIR

IR simulation and modeling is a well-developed and mature technology most often used in systems development, targeting, and image analysis. High fidelity simulation for a small target area is the paramount concern. Most often, modeling is limited to a single target on a uniform background. Predictions for multiple objects within a scene or speed of computation have rarely been concerns for these types of simulations.

Simulating navigation and targeting FLIRs for aircrew training devices presents different problems from simulation for engineering analysis. Flight training simulators need to display a relatively large area within the sensor's field of view, in real time, and be compatible with available input data and computer image generators. Flight training systems must allow simulation of a variety of tactical situations with sufficient accuracy to train combat skills. Armstrong Laboratory has developed a FLIR simulation system based on integrating IR modeling and simulation with real-time visual simulation (Crane and Evans [1]).

Approach

The approach selected was to combine off line IR preprocessing, a real-time visual computer image generator (CIG), and sensor simulation postprocessing. The off line preprocessor function is to accept scenario and weather input and to estimate IR exitance for features in an existing visual data base. In real time, the CIG then converts exitance values into gray scale values, generates visual imagery for the specified field of view, adds texture, and determines visibility range based on atmospheric conditions. The postprocessor then simulates sensor functions, effects, and controls.

IR Energy Estimation

The preprocessor converts a visual data base into an IR data base. The visual data base consists of face definitions and red-green-blue color codes assigned by the data base modeler. For input to the IR preprocessor, each face must also carry the Defense Mapping Agency (DMA) Feature Identification Descriptors (FID) and Surface Material Codes (SMC) from the original Digital Feature Analysis Data (DFAD) database. These codes identify the feature type and surface materials of the objects to be depicted in the simulation. FID and SMC codes were developed to support radar rather than IR simulation. While algorithms are available to predict radar reflectivity directly from these codes, additional data is necessary to predict IR exitance. Estimates of the IR significant properties of 640 FID/SMC combinations were compiled by the algorithm's designers and stored within the preprocessor. These properties include emissivity, reflectivity, material thickness and composition, thermal conductivity and other factors which affect IR signature (Wolfe and Zissis [5]). The values assigned for these properties are the parameters used in the IR prediction equations. Specific scenario inputs are provided by the user. These are:

- -Latitude and longitude, time of day, and day of year
- -Air temperature (can be estimated if desired)
- -Humidity, wind speed, and haze
- -Rainfall rate and rain temperature
- -IR band desired: 3-5 or 8-14 microns.

IR exitance in watts/square meter is then estimated using a set of prediction equations based on first principles.

Real time functions

The visual CIG accepts input from the IR preprocessor and outputs textured, monochrome imagery with appropriate field of view and visibility range. This step incorporates both visual imaging and simulating atmospheric effects. Sensor effects and controls are simulated in real time by postprocessing functions. Each of these steps contributes to overall simulation fidelity and variability.

Texture and Scene Realism. Use of CIG texture patterns greatly increases scene realism but often interferes with presentation of estimated IR exitances. In simulated FLIR imagery at Armstrong Laboratory, the effects of texturing often overwhelmed the results of IR exitance prediction. For example, exitance values for a farm were predicted under different conditions so that the metal barn was either warmer or cooler than the wood house (see Figures 1 and 2). However, when these scenes were imaged, the nearby trees and fields which consist of simple polygons with overlying texture patterns did not change brightness. When the texture feature was disabled, the predicted IR differences were apparent but scene realism suffered dramatically. Integrating texture with FLIR simulation required the development of special texture patterns which did display differences in IR exitance without sacrificing scene realism.

Other special texture patterns can also increase the fidelity of simulated FLIR imagery. For example, desert plants such as creosote or tumbleweed show more contrast and texture in IR than in visible light. This effect can be simulated by using different texture patterns for visual and FLIR imagery. The resulting imagery displays both IR modeling effects and scene realism but with increased database development cost.

Figure 1. Simulated IR image of a wood house and metal barn with textured fields and trees.

Figure 2. Scene from Figure 1 imaged for different environmental conditions. Note that the predicted IR exitance for the house and barn have changed but that the brightness of the textured trees and fields have not.

Atmospheric Effects. The atmospheric effects which were modeled in the IR preprocessor only simulate effects of humidity or haze on the amount of sunlight which falls on surfaces. The preprocessor cannot simulate real-time effects resulting from the atmosphere between the sensor and target. A range-visibility function in the CIG attenuates visual image contrast with increasing range. For FLIR simulation, a computer model of atmospheric transmissivity such as LOWTRAN is used to establish an IR range-visibility function based on levels of humidity and haze specified in the chosen scenario. These scenario specific functions are substituted for the visible light attenuation functions to determine FLIR visibility range (see Figures 3 and 4).

Figure 3. Simulated IR scene with low humidity and long visibility range.

Figure 4. Simulated IR scene from Figure 3 but with reduced visibility due to increased humidity.

Sensor Characteristics. Simulated sensor effects and controls are added to the monochrome imagery by real-time post processor functions. Simulated pilot controls include: polarity (white hot/black hot) selection, gain, level, and magnification on a targeting channel. Sensor effects include AC restoration, system faults, blur, and noise. A sensor effect which is difficult to simulate using the three stage approach is a FLIR system's automatic gain control (AGC). If a given system has eight levels of brightness, the AGC will assign level zero to the coolest object within the sensor's instantaneous field of view and level seven to the warmest. The effect of AGC is to provide an image with a full range of contrast from white to black for any scene content. In three stage FLIR simulation, object brightness is proportional to predicted exitance for all features in the data base. Potentially, exitance values might be required for ice and a blast furnace. These exitance values are then mapped onto a limited range of brightness levels. If a simulated scene contains objects with a wide range of predicted exitance values such as water, soil, and concrete, the overall contrast within the scene will be acceptable. When simulating low level flight using a navigation FLIR, however, it was found that many scenes contain relatively homogenous features such as soil, rock, and sand. Differences in predicted IR were quite small and the contrast in simulated scenes was very low. Imagery tended to contain a narrow range of grey values without any black or white.

Simulating AGC increases image realism greatly. Different approaches to simulating AGC, however, illustrate the tradeoffs between system complexity and the range of conditions which can be simulated. For example, a given system may be used primarily for training low level navigation over largely unpopulated areas. In this case, few objects would be expected to be much warmer or cooler than the surrounding terrain. AGC can be simulated for this system by selecting a function to map IR exitance onto brightness which will emphasize the middle range of values. This will maximize contrast for areas such as deserts or forests but there will be little distinction among warm or cool objects. While the solution is inexpensive and appropriate for the intended application, the system could not be used for training target recognition within a city where there are many warm objects to be imaged. Alternatively, predicting IR exitance at frame rates for objects within the sensor's field of view rather than preprocessing the entire database or frame rate image processing will also simulate AGC. Either of these approaches requires additional computing power but will increase the range of scenes which can be simulated.

Advantages and Limitations

Any FLIR simulation system must depict a visual database in terms of IR exitance for at least one set of environmental conditions. The IR preprocessor at Armstrong Laboratory is an attempt to increase FLIR simulation fidelity by allowing instructors to select any environmental conditions for a particular scenario. There are, however, limitations in this approach. The IR estimation algorithms apply only to DFAD features. IR signatures of smaller objects such as vehicles or any features with internal heat sources must be derived from other sources. Also, features unique to the IR spectrum including heat trails and exhaust plumes must be modeled separately. The IR exitance prediction model is very sensitive to the material parameters assigned to each feature. Changing the assumptions made regarding the characteristics of surfaces such as material thickness or thermal conductivity can significantly change the predicted IR exitance. In Armstrong Laboratory's FLIR simulation system, the thermal characteristics of each feature are based only on the DMA FID and SMC codes and the modeler's knowledge of their typical characteristics. If the characteristics of a given feature are different from the DMA feature or if the modeler's assumptions for a particular object are not correct, the IR exitance estimate can be significantly in error. It must also be recognized that even the most sophisticated IR modeling system cannot generate an exact prediction of what a FLIR scene will look like at a given time and date. FLIR imagery is highly susceptible to transient local weather effects including clouds and wind gusts. Predicted IR exitance values must therefore be treated as having large error tolerances.

The IR preprocessor supports two functions in generating FLIR databases: 1) thermal fidelity, and 2) the ability to simulate a given gaming area for a variety of environmental conditions. It is also possible to develop a high fidelity FLIR database for a single set of conditions using alternate sources of IR information. Using this approach, most of the IR significant variables such as day of the year, time of day, and air temperature would be constant for all simulations. Other variables, however, including IR visibility range, overall contrast, target to background contrast for non-DFAD features, and FLIR systems effects could be changed at will using other functions within the simulator. Selecting the number and type of IR conditions to be supported for a given simulator must be based on training needs.

FLIR SIMULATION, IR FIDELITY, AND TRAINING NEEDS

The advantage of the three stage approach to FLIR simulation is that it provides designers with many options. Selecting among these options determines the level of fidelity and the range of variables which will be simulated by a given system. Careful consideration of training objectives should drive the selection process. For example, objectives for preliminary training on the characteristics of FLIR imagery include:

- -Differences between IR and visual imagery
- -Scene characteristics unique to FLIR
- -The effects of environmental variables on FLIR
- -Hazards such as the near invisibility of wires in FLIR
- -Target appearance for a variety of targets and conditions

This type of training is not specific to a single FLIR system and does not require interactive flight through a gaming area. Instead, the emphasis is on high thermal fidelity, multiple examples of scenes under different weather conditions, and examples of many different types of scenes and targets. For this application, simulation would not provide the necessary level of image detail or thermal fidelity. Instead, video presentation of recorded real world imagery would be a more appropriate medium to fulfil these particular training objectives.

Initial Weapons Systems Training

The focus of initial training on a FLIR equipped weapons system is on safe operation and learning to use the various systems. Training is limited to a period of several weeks using highly scripted scenarios. The objectives of initial training are typically:

-Learn operating procedures
--Functions and applications of system features
--Displays and controls
--Handoffs, coordination, and timing of events

-Integrate FLIR operation, navigation, and weapons employment
--Consolidate visual tasks (e.g., target acquisition) with systems tasks (e.g., navigation and weapons release)
--Sequences of operations
--Workload management

Examining these training objectives helps to define the fidelity requirements for the three components of FLIR simulation.

IR Energy Estimation. There is no need in initial weapons system training to illustrate the effects of varying environmental conditions on FLIR imagery. Given the objectives and the limited duration of training, it is highly unlikely that an instructor would use this training to demonstrate the effects of time of day or air temperature on image quality. An IR database with rank order correlation to real world imagery for a single set of environmental conditions will fully support initial training. Low fidelity FLIR simulation such as monochrome visual imagery may also be acceptable providing that subject matter experts have screened the imagery to remove conspicuous errors.

Atmospheric Attenuation. IR visibility is largely a function of humidity and haze and can be varied using the CIG's on-line range-visibility function. The effect of poor IR visibility is similar to driving in fog. Decreasing IR visibility during the later stages of training would reduce the time a student has available to perform a given task since objects would not be visible in the FLIR until they were at relatively close range. This function could also be used to tailor a training sortie to match local weather conditions. If the training curriculum calls for the student to practice an operation in the simulator and then in the aircraft, IR visibility in the simulator could be set to match predicted real-world conditions. Overall, changing the atmospheric attenuation function provides limited variability in FLIR imagery at a significantly lower cost than manipulating the IR database. Although this feature may not be a firm requirement, inclusion of atmospheric attenuation effects could have high utility depending on the training syllabus.

Sensor Effects. Very high fidelity is required in simulating the effects, displays, and controls of the specific FLIR system being simulated. The effects of operator controls such as gain, level, and polarity reversal must be accurately modeled since learning to use these functions is a major objective of initial training. Modeling system faults is also required if students are to learn specific procedures for diagnosing and responding to systems failures.

Continuation Training

The primary application for thermally accurate simulated FLIR imagery is full mission training using an Operational Flight Trainer (OFT). In this application, students focus on consolidating their skills and tactical employment of their weapons system under many different conditions. While the duration of a particular training event is limited, students can expect to return to the OFT many times over several years. The objectives of continuation training are typically:

-Upgrade skills to employ new systems or weapons
-Operate under simulated threats
-Tactics development and evaluation
-Full mission training

IR Energy Estimation: IR exitance of features. The capability to model variability in IR exitance will be of greater value for continuation training than for initial training. Using this capability, training scenarios for journeyman and expert crews can be tailored to demonstrate the range of conditions which might be expected within an operational environment. Opportunities for such training include: 1) before a deployment, 2) for new crews entering an area, or 3) for repeated simulator sorties within an operational area as the seasons change. This capability will require the ability to model the major environmental variables including time of day, month of the year, air temperature, and cloud cover. High fidelity modeling of absolute temperature differences among objects is not required. The effects of simulated AGC plus operator controlled gain and level controls will support full system operation if the relative exitance of features in the database have rank order correlation with the real world.

IR Energy Estimation: Database Enhancements. A number of enhancements will be necessary to support a thermally accurate database for continuation training. IR signatures of DFAD features which have internal heat sources such as a power plant with cooling towers or a heated building cannot be modeled accurately using a preprocessor similar to the one at Armstrong Laboratory. Non-DFAD objects including vehicles must be modeled separately. Models of moving vehicles may also include heat trails and exhaust plumes which are visible only in FLIR. In addition, local weather effects such as snow cover or bodies of water which may freeze in winter must be added to the IR prediction model. These database enhancements will be of greatest training value for students in continuation training who have mastered systems operations skills. These students will be focusing on integrating FLIR systems operation into combat missions. Training for tasks such as navigation within populated areas, target recognition and discrimination will benefit the most from these types of database enhancements. Unlike the IR signatures of DFAD objects which change in response to environmental variables, the IR signatures of features with internal heat sources are relatively constant. Once modeled, they can be inserted into different scenarios without modification.

Atmospheric Attenuation. Modeling of variable range-visibility due to humidity and haze is required for continuation training. In addition, local atmospheric conditions such as smoke, fog, or rain showers can be incorporated into the database as translucent texture patterns.

Sensor Effects. As for initial training, very high fidelity is required for modeling sensor effects, controls, and displays.

SUMMARY AND CONCLUSIONS

There are three components which must be evaluated when determining the fidelity requirements for a given FLIR training system. The first component involves the preparation of an IR database. Designers may elect to use fixed grey shades which represent a single set of environmental conditions. Alternatively, designers may choose to use a data base preprocessor which will predict IR exitance for any set of environmental conditions. The increases in flexibility provided by a preprocessor will be of significant importance for continuation training providing students will have the opportunity to train in the same gaming area under different conditions. The second component is the computer image generator which provides both imagery and a number of real-time FLIR effects. Simulating atmospheric attenuation of IR visibility resulting from haze and humidity demonstrates the variability of FLIR imagery at low cost. The third component is the simulation of FLIR system specific effects, displays, and controls. High fidelity is required for this component in all aircrew training devices.

Simulating FLIR imagery for aircrew training has been seen as the integration of visual simulation technology with IR modeling. The major emphasis within the science of IR modeling has been thermal accuracy. Due to the number of factors that influence IR exitance and the large number of assumptions that must be made regarding the IR characteristics of DFAD features, it has proven to be extremely difficult to incorporate high accuracy thermal modeling into aircrew training simulators. The other aspects of FLIR simulation, i.e., atmospheric and sensor effects, are much more tractable and will have a greater payoff for most training applications. By analyzing the training objectives of each proposed FLIR simulation system, it is possible to select the levels of fidelity required and to translate training requirements into engineering specifications.

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