

GEO-SPECIFIC WEATHER-DEPENDENT DIURNAL INFRARED IMAGE SIMULATION

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ABSTRACT

An increasing reliance on infrared (IR) sensors for accurate detection, classification, and tracking of Time-Critical Targets (TCTs) in background clutter has resulted in a growing need for physical model-based, yet real-time and affordable, weather-dependent diurnal IR image simulation of TCTs embedded in geospecific backgrounds for weapons systems training, mission planning, mission rehearsal as well as weapon system development and testing. The problem is that model-based IR image simulation requires time-consuming estimation of IR model parameters for a large number of objects, materials, and geographic areas. The problem becomes especially severe when simulating imagery of denied access areas where IR characteristics of background materials and objects for every pixel on the ground are unavailable or difficult to obtain.

Therefore, we have developed an approach to weather-dependent diurnal IR background image simulation based on IR model parameter estimation from Multi-Spectral Imagery (MSI) such as available from commercial satellite and tactical reconnaissance sources. This paper describes the processes and results of thermal mass and visible emissivity estimation from Landsat Thematic Mapper visible and thermal band MSI data. Simulated thermal images of geospecific backgrounds at various times of day are shown using the estimated parameters and real geospecific weather data as inputs to AIRSIM - the US Air Force IR Synthetic Image Model. The significance of this approach is that the thermal models used can be applied equally well to targets and backgrounds. Use of the same physics-based model for both assures that there will be no false target/background contrast due to use of different models for each. Another major feature is that this approach allows automated generation of IR databases over large areas of terrain while retaining major thermal properties absent from DMA data, such as thermal mass. This allows for more complete and accurate representation of diurnal and weather effects in simulated imagery while achieving high realism from geospecific weather and terrain data.

ABOUT THE AUTHORS

Budimir Zvolanek is a Senior Principal Technical Specialist at McDonnell Douglas Aerospace, pursuing a career in signal processing, data acquisition, electronic imaging, multi-spectral infrared and radar image processing and simulation, displays, artificial neural networks, and databases. Budimir has published extensively on the subjects and received the 1993 I/ITSEC Best Paper Award nomination for DoD Standard Simulator Data Base Project 2851 Correlation Testing. He led the development of F-14A radar simulator hardware and automatic ship target recognition algorithms and software. Mr. Zvolanek received his M.S.E.E. degree from Washington University in St. Louis, Missouri.

Dave Coblitz is a Senior Principal Technical Specialist with over 20 years of engineering experience in DoD research and development programs. His experience covers a broad range of topics including real-time and non-real-time simulation, aircrew training techniques, automatic target tracking and information systems, and holography. He has authored numerous papers in the fields of advanced training techniques, the use of on-board and ground-based computer-generated imagery, automatic target recognition, passive night attack, and visually coupled systems design. Dave is a registered patent agent and has patents issued on a reflection elimination method and an adaptive electronic filter.

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1. INTRODUCTION

The nature of combat has changed in recent years away from strategically preplanned battles and scenarios in a few large pre-selected areas of the world toward engagements in many small areas anywhere in the world. As a result, warfighters will increasingly rely on information acquired by tactical aerial reconnaissance (recce) resources to rapidly develop battle plans for the resolution of such localized conflicts. The warfighters therefore need an affordable capability to preview simulated IR imagery of not only isolated Time-Critical Targets (TCTs) but also of the TCTs embedded in geospecific backgrounds and under geospecific weather conditions.

Similarly, the air-to-ground weapons systems shooters will also rely on the tactical recce information - but to plan, preview, and rehearse missions. Up-to-date real-world imagery, terrain elevation, and meteorological data will be used to lay down ingress and egress routes to the TCTs for aircraft and high-value weapons and evaluate mission risk. The geospecific data will be used to simulate geographic environment-dependent infrared (IR) sensor imagery and insert the imagery in real-time into shooter's simulator displays to practice navigation and targeting. The simulated IR imagery will also be used to prepare reference scenes for autonomous weapon terminal guidance.

To accomplish the geospecific weather-dependent diurnal real-time IR image simulation, physical IR model-based techniques are needed. The problem is that complex model-based IR image simulation requires time-consuming and costly estimation of IR model parameters for a large number of objects and materials at high spatial resolution and over many geographic areas. The problem is especially severe when simulating imagery over areas with denied access where information about background material composition and material thermal IR characteristics is unavailable or extremely difficult to obtain. Furthermore, most physics-based IR models simulate accurate IR imagery but not at real-time image generator update rates of 30 or 60 Hz.

Therefore, we have developed an approach to geospecific weather-dependent diurnal IR background estimation from recce or commercial Multi-Spectral I image simulation based on IR model parameter

imagery (MSI). Described below is an IR image simulation process that is based on physical modeling of the IR imaging environment yet can satisfy training and mission rehearsal real time simulation requirements. The following sections contain details and results of the approach tested using Landsat Thematic Mapper imagery and geospecific weather data.

2. GEOSPECIFIC DIURNAL WEATHER-DEPENDENT THERMAL IMAGE PREDICTION

The objective of the effort described in this paper was to develop and demonstrate the capability to use geospecific terrain imagery and geospecific diurnal weather data for diurnal IR image simulation.

The core of the IR simulation processing (Figure 2-1) is an off-the-shelf existing thermal model program developed for the US Air Force^{1,2}. This program, called 'therm', is part of the 'AIRSIM' software used to predict thermal imagery in a camouflage, concealment, and deception environment. 'therm' is used to generate a Temperature File containing predicted radiometric temperatures of modeled objects from the input Object File and for geospecific weather conditions and times of day from the input Weather File. The object file contains the parameters that describe the properties of any object reacting to that environment. While the parameters for the weather file are readily available from Government sources, the object parameters needed to drive a physical model are more difficult to obtain and are the primary subject of this paper

The AIRSIM input Object File consists of 10 thermal model parameters such as specific heat, thermal conductivity, thermal and visible emissivities, and sky exposure area for each modeled object material. We created the object file by editing the parameter values using estimates of thermal mass and visible emissivity from the Long-Wave IR (LWIR) and three visible bands of Landsat Thematic Mapper (TM)

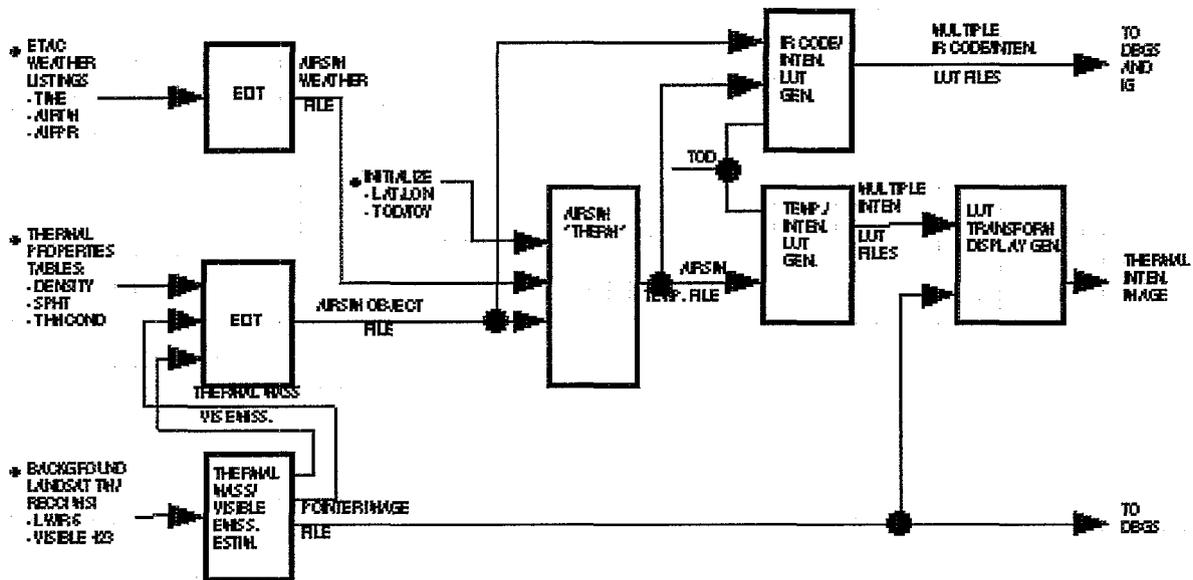


Figure 2-1 Geospecific Diurnal Weather-Dependent Thermal Image Prediction

imagery and using supplementary thermal characterization of materials from reference tables in the AIRSIM handbook².

The AIRSIM input Weather File contains meteorological data at regular time-of-day (TOD) intervals. The data consists of 12 parameters such as air temperature, air pressure, and dew point for each TOD. The file is produced by editing actual geospecific meteorological observation data or simulating weather conditions typical of the geographic area.

The AIRSIM output Temperature File contains a header and a series of real and radiometric point temperature predictions for one or more times of day specified during 'therm' run. The time of year

ate) and geographic latitude and longitude are specified during AIRSIM initialization.

For further IG or database generation use, a program is available to create a Look-Up Table (LUT) File for directly converting the IR codes, upon which the Object File is based, into display image intensities corresponding to the predicted temperatures.

To predict diurnal weather-dependent variations in thermal IR imagery, physics-based IR models utilize a number of independent parameters describing the objects and materials in the imagery. The AIRSIM model used here utilizes the following parameters stored in the Object File:

- Density: grams/cm³; equal to thermal Mass value (Langley/degC=cal/cm²degC) when the product of Specific Heat times Thickness = 5* 0.2000 = 1.0
- SpHt: cal/gram/degC; specific heat
- ThmCond: cal/cm/hour/degC; thermal conductivity
- Thick: cm; effective thickness
- EmV: fraction; visible emissivity = (1-reflectance); 1 = 100%
- EmTh: fraction; thermal emissivity; 1 = 100%
- XpA: fraction; surface exposure; 0.5 = 100% of outer surface

3. IR PARAMETER ESTIMATION FROM LANDSAT TM MULTI-SPECTRAL IMAGERY

- dPw: Langley/hour=cal/cm²/hour; internally generated power density
- Slop: deg; slope angle between surface normal and zenith
- Azmh: deg; azimuth angle between vertical plane of surface normal and North

Typical parameter values for surface materials, buildings, vegetation, water, metals, etc. can be found from a variety of sources such as physics reference tables or the AIRSIM handbook² used here. For IR image simulation, IG database modeling breaks up each object (area) into polygons and assigns constant parameter values to the polygon face or vertices. While such interactive manual polygonization and assignment is feasible for a small number of discrete objects and small area patches, the process becomes impractical for large background areas. Furthermore, material and object identity is nearly impossible to determine for every pixel or even polygon covering large areas. Therefore, a process for automatically estimating the thermal IR parameter values over the gaming area was developed.

The question arose as to which parameters should be estimated and from what sources. To simulate diurnal variations, such as contrast reversals, the knowledge of visible emissivity simultaneously with thermal mass is most critical, followed by thermal conductivity and thermal emissivity. While estimating these parameters for a terrain surface from imagery is difficult, fortunately the most important, visible emissivity and thermal mass, can be obtained from correlated thermal IR and visible panchromatic imagery acquired at specific times of day, such as shortly after sunrise.

An IR image taken an hour or two after sunrise contains useful information about the thermal properties of the image when combined with a visible image taken at the same time. To a first approximation, an IR image can be obtained by a black-to-white inversion of a visible panchromatic (pan) image because dark surfaces readily absorb and emit heat, while light surfaces do not. High thermal mass dark objects heat up slower in the morning sun, appearing dark in a white-hot thermal IR image. The result is a difference between the bright (hot) pixels in the inverted pan and dark pixels in the actual thermal IR image. Therefore, the difference can be considered as a first-order indicator

of thermal mass, while the visible pan value can be considered as an indicator of the visible emissivity.

Questions arise as to why make predictions of object parameters if we already have a thermal image. There are two reasons for this. First, we would like to predict the changes in the image with changes in time of day or weather after the thermal image was acquired. Second, we would like to be able to predict the thermal image at higher spatial resolutions than available from the one originally taken — the resolutions usually available from visible-band imagery.

Further specific simplifying assumptions were made. Because

$$\text{Thermal Mass} = \text{Density} * \text{Specific Heat} * \text{Thickness},$$

an assumption of constant Thickness and Specific Heat in the AIRSIM Object File results in Density as an indicator of Thermal Mass. Furthermore, these indicators can be computed from Landsat TM bands 1, 2, 3 (visible) and 6 (long-wave thermal IR) shown in Figure 3-1. The thermal mass Difference Radiance indicator, Diff, was computed for a 4431-pixel x 3751-line TM image in four spectral bands:

$$\text{Diff} = \text{Integrated In-Band Radiance} [\text{Band 6} - \text{Inverted (Pan)}]$$

The estimate of Visible Emissivity, Pan, was approximated by the In-Band Integrated Panchromatic Radiance from the digital levels of bands 1, 2, and 3 as:

$$\text{Pan Radiance} = \text{Integrated In-Band Radiance} [\text{Band 1} + \text{Band 2} + \text{Band 3}]$$

The Diff and Pan indicators were scaled and quantized into 8 bits.

In order for 'therm' to use the indicators, an Iso-Clustering classification algorithm was applied to the Diff-and-Pan 2-band 16-bit image. The algorithm reduced the 16-bit image containing $2^{16} = 65,536$ possible indicators of thermal mass and visible emissivity into only 16. The result was a 16-class (4-bit) thermal mass/visible emissivity Pointer Image used to construct an AIRSIM Object File and predict weather-dependent diurnal IR imagery



(a) Visible Landsat TM1



(b) Visible Landsat TM2



(c) Visible Landsat TM3



(d) Long-Wave IR Landsat TM6

Figure 3-1 Terrain Imagery in Four Landsat TM Bands

4. DIURNAL WEATHER-DEPENDENT IR IMAGE PREDICTION RESULTS

Geospecific weather-dependent diurnal IR image predictions were achieved using the Landsat TM-derived AIRSIM Object File parameter values and actual weather data from the geographical area of the Landsat TM imagery.

4.1 AIRSIM OBJECT FILE

Figure 4.1-1 shows the AIRSIM Object File contents determined from the Landsat TM-derived thermal mass and visible emissivity indicators, Diff and Pan, respectively.

The specific heat (SpHt) was set to 0.2 cal/gram/degC and thickness (Thick) to 5 cm based on a typical range of values in the AIRSIM surface material tables². Since $0.2 * 5 = 1.0$, the value of Density was used to store the thermal mass indicator, Diff. A largest thermal mass of 25.5 for the heaviest objects expected on terrain surface was assumed to correspond to the largest absolute value, 4.4403638, of the Difference indicator. This value in turn determined the maximum Density from the iso-clustering to be

Density	Split	ThmCond	Thick	EmV	EmTh	XpA	dPw	Slop	Azml	Name / IRCode
10.700	2000	10.00	5	.20	.99	-.5	0.	0.	0.	'25E3F47'
9.100	2000	10.00	5	.20	.99	-.5	0.	0.	0.	'35E3F47'
7.200	2000	10.00	5	.26	.99	-.5	0.	0.	0.	'44E4F47'
6.600	2000	10.00	5	.26	.99	-.5	0.	0.	0.	'54E4F47'
5.500	2000	10.00	5	.33	.99	-.5	0.	0.	0.	'6375F47'
4.600	2000	10.00	5	.33	.99	-.5	0.	0.	0.	'72E5F47'
3.600	2000	10.00	5	.40	.99	-.5	0.	0.	0.	'8246F47'
2.700	2000	10.00	5	.40	.99	-.5	0.	0.	0.	'91E6F47'
1.200	2000	10.00	5	.40	.99	-.5	0.	0.	0.	'10A2E6F47'
0.200	2000	10.00	5	.53	.99	-.5	0.	0.	0.	'12A2E6F47'
0.900	2000	10.00	5	.53	.99	-.5	0.	0.	0.	'13A9E6F47'
2.400	2000	10.00	5	.59	.99	-.5	0.	0.	0.	'14A9E6F47'
4.300	2000	10.00	5	.73	.99	-.5	0.	0.	0.	'152E6F47'
6.100	2000	10.00	5	.79	.99	-.5	0.	0.	0.	'163DC6F47'
7.600	2000	10.00	5	.86	.99	-.5	0.	0.	0.	'174C6F47'

Figure 4.1-1 Landsat TM-Derived AIRSIM Input Object File

10.7 grams/cm³ and resulted in the range of Densities shown in the Figure 4.1-1.

Similarly, setting the maximum possible Visible Emissivity (EmV) to be 0.99 in the Panchromatic indicator image, the Iso-Clustering algorithm determined the range of Visible Emissivities shown in Figure 4.1-1. Thermal conductivity (ThmCond), thermal emissivity (EmTh), and surface exposure area (XpA) took on typical values of surface materials from the AIRSIM handbook²; zero values were assumed for internally generated power (dPw), slope angle (Slop), and azimuth heading angle (Azml). Note the comment field, Name/IRCode, containing a 24-bit hexadecimal encoding of the Object File parameters for future IR DB generation and IG use. Negative value of XpA directed AIRSIM to disable internal heat convection.

4.2 AIRSIM WEATHER FILE

AIRSIM uses the following 13 parameters as inputs from the Weather File:

- Time: Local time of day (hours:minutes or hours.100ths)
- AirTm: Air temperature (deg. C)
- AirPr: Air pressure (millibars)
- RelHu: Relative humidity (fraction; if -1, calculated by AIRSIM from the Dew Point)
- DewPt: Dew point (deg. C)
- WndSp: Wind speed (meters/sec)

- DirIn: Direct visible insolation on a surface orthogonal to sunrays (Langley/hour; if -1, calculated by AIRSIM)
- DifIn: Diffuse visible insolation on a horizontal surface (Langley/hour; if -1, calculated by AIRSIM)
- SkyEx: Sky exposure (fraction; 0=100% cloud cover)
- ic: Cloud type (0=none; 1-8, Tables in AIRSIM handbook²)
- ip: Precipitation type (0=none; + / - 1=rain)
- pRate: Precipitation rate (cm/hour)
- pTemp: Precipitation temperature (deg. C if Precipitation Type=1; fraction of wet bulb temp. if Prec. Type=-1)

The USAF Wright Laboratory Meteorological Office provided geospecific weather data used for calculation of the AIRSIM weather parameters. The data provided was in the Data Save (DATSAV) format defined by the USAF Environmental Technical Applications Center (ETAC) and mapped into the AIRSIM parameters as in Figure 4.2-1 ("-1" directs AIRSIM to internally calculate the value).

An AIRSIM Weather File must contain at least 24 hours of data for initialization prior to a temperature prediction run by AIRSIM. A file extracted from the ETAC ground-level meteorological observations at Nellis AFB, Las Vegas, Nevada (36:14 North latitude, 115:02 West longitude) consisted of 48

ETAC DATSAV PARAMETERS	AIRSIM Parameters
- Day time (hour, minutes)	- Time
- Dry bulb temperature (tenths deg. K)	- AirTm
- Station Pressure (tenths millibar)	- AirPr
- N/A	- RelHu = -1 (from DewPt)
- Dew-point depression (tenths deg. K)	- DewPt
- Wind speed (tenths meter/sec)	- WndSp
- N/A	- DirIn = -1
- N/A	- DirN = -1
- Total sky cover (codes)	- SkyEx
- Cloud classification	- iC
- Cloud Type	- iC
- 6-Hour precipitation (millimeters)	- iP, pRate, pTemp

Figure 4.2-1 Correspondence of DATSAV and AIRSIM Parameters

for hours (lines or records) of data at one-hour intervals 00:00 to 23:00 hours local time on 30 and 31 May 1987. Figure 4.2-2 shows an excerpt from the AIRSIM Weather File used in the simulation

4.3 AIRSIM TEMPERATURE PREDICTION

The Landsat TM geographic area used for diurnal predictions was located at 37:47:58 degrees North latitude and 116:46:50 degrees West longitude. While not directly positioned over this area, the location of the ETAC weather observations shown in Figure 4.2-2 was considered as the nearest approximation of the local weather conditions.

AIRSIM was initialized with the Landsat geographical location and the date of 31 May 1987 to

be simulated. The Weather File in Figure 4.2-2 and the Object File in Figure 4.1-1 were used as inputs to produce the predicted Temperature File shown in Figure 4.3-1.

The ASCII-text Temperature File contains 14 lines summarizing the geographic location, date, and initial weather conditions from the Weather File. Sixteen real and radiometric temperature pairs corresponding to sixteen lines in the Object File are output by AIRSIM across the page and down. The time of day (e. g., 9.00) for each prediction is represented by hour, period, and hundredths of an hour within a 24-hour period and appears to the left of each series of temperature pairs. The time of day corresponds to a time in the Weather File used for the AIRSIM run. Finally, the Temperature File was used to generate Look-Up Tables (LUTs) for

Time Hrs	AirTm degC	AirPr mbars	RelHu frac	DewPt degC	WndSp m/sec	DirIn Lhr	DirN Lhr	SkyEx frac	iC 1	iP 1	pRate cm/hr	pTemp degC
23.00	18.30	1013.21	-1.	20.40	1.50	-1.0	-1.0	.80	1	0	.00	90
0.00	18.30	1013.21	-1.	20.40	1.50	-1.0	-1.0	.80	1	0	.00	90
1.00	18.30	1013.21	-1.	20.40	3.10	-1.0	-1.0	.80	2	0	.00	90
2.00	18.90	1012.87	-1.	18.90	2.60	-1.0	-1.0	.80	2	0	.00	90
3.00	17.20	1013.21	-1.	17.20	1.00	-1.0	-1.0	.99	2	0	.00	90
4.00	16.10	1013.65	-1.	15.00	0.00	-1.0	-1.0	.80	1	0	.00	90
5.00	13.90	1014.22	-1.	13.30	0.00	-1.0	-1.0	.80	1	0	.00	90
6.00	15.60	1014.90	-1.	14.50	0.00	-1.0	-1.0	.80	1	0	.00	90
7.00	17.20	1015.24	-1.	15.00	0.00	-1.0	-1.0	.40	2	0	.00	90
8.00	22.80	1015.24	-1.	20.60	1.50	-1.0	-1.0	.40	2	0	.00	90
9.00	26.10	1014.90	-1.	22.20	3.10	-1.0	-1.0	.80	2	0	.00	90
10.00	27.80	1014.90	-1.	25.00	1.00	-1.0	-1.0	.80	4	0	.00	90
11.00	27.80	1014.96	-1.	25.60	0.00	-1.0	-1.0	.80	4	0	.00	90
12.00	30.00	1013.89	-1.	29.40	2.10	-1.0	-1.0	.40	4	0	.00	90
13.00	30.00	1013.21	-1.	31.00	1.50	-1.0	-1.0	.40	4	0	.00	90
14.00	31.10	1012.19	-1.	31.60	1.00	-1.0	-1.0	.60	4	0	.00	90
15.00	31.10	1011.18	-1.	32.70	0.00	-1.0	-1.0	.60	4	0	.00	90
16.00	31.70	1010.50	-1.	33.30	1.50	-1.0	-1.0	.60	4	0	.00	90
17.00	31.10	1011.85	-1.	32.70	0.50	-1.0	-1.0	.60	4	0	.00	90
18.00	30.60	1009.82	-1.	32.70	2.10	-1.0	-1.0	.60	4	0	.00	90
19.00	28.90	1010.16	-1.	31.60	1.50	-1.0	-1.0	.60	2	0	.00	90
20.00	27.80	1010.50	-1.	30.50	1.00	-1.0	-1.0	.60	2	0	.00	90

Figure 4.2-2 AIRSIM Input Weather File

TIME		AIR TEMP				
Sunrise:	5:29	14.72 deg C	Date:	870531		
Peak Temp	16:00	31.70 deg C	Latitude:	37-47.58 N		
Sunset	20:01		Longitude:	-116-46.50 E		
INITIAL CONDITIONS						
Air Pressure:	1013.2 mbars					
Relative Humidity:	100 %					
Dew Point:	20.40 deg C					
Wind Speed:	1.50 m/sec					
Sky Exposure:	80 %					
Cloud Type:	Cirrus					
Precipitation:	None					
23.01	27.96 27.46	27.29 27.19	27.52 27.41	27.11 27.01	27.10 27.00	26.53 26.44
	26.00 25.92	24.92 24.84	23.52 23.45	21.95 21.89	21.41 21.35	21.95 21.91
	24.93 24.85	23.32 23.21	20.55 20.42	22.23 22.09		
0.00	21.35 21.27	21.34 21.25	21.31 21.22	21.28 21.19	21.25 21.16	21.21 21.12
	21.16 21.07	21.08 21.00	20.95 20.87	20.65 20.56	19.87 19.79	20.65 20.56
	21.05 20.95	21.20 21.11	21.27 21.18	21.31 21.22		
1.00	18.96 18.88	18.94 18.85	18.90 18.81	18.85 18.77	18.81 18.72	18.75 18.67
	18.68 18.59	18.57 18.48	18.38 18.29	17.93 17.84	16.68 16.60	17.93 17.84
	18.52 18.43	18.74 18.65	18.84 18.75	18.90 18.80		

Figure 4.3-1 AIRSIM Output Temperature File

converting the 16 input Object File pointer's into grey-level intensities for each time of day.

4.4 SIMULATED DIURNAL WEATHER-DEPENDENT IR IMAGERY

Figure 4.4-1 shows the 4431 x 3751 pixel, 133 x 113 km, area overview simulated for six times of day. A smaller, 640 x 480 pixel, 19 x 14 km, area is shown simulated at full resolution in Figure 4.4-2. The images contain 16 grey levels linearly stretched into 0-255, 8-bit, display intensity range. Black-white or white-black contrast reversals of terrain surfaces are notable as the time of day varies from midnight to 20:00 hours (8 P.M.).

5. SUMMARY AND CONCLUSIONS

A process has been demonstrated that allows physics-based diurnal weather-dependent geospecific IR background image generation when detailed thermal characterization of terrain surface is not feasible.

The key to the process is the estimation of thermal model parameters from remotely-sensed thermal IR and visible panchromatic Multi-Spectral Imagery (MSI). The MSI source can be a commercial platform such as the Landsat TM satellite used here or a reconnaissance (recc) platform permitting simultaneous image acquisition in panchromatic visible and thermal IR bands.

Thermal mass and visible emissivity indicators were estimated here. However, more accurate thermal IR image calibration and knowledge of ground truth at selected sample areas could also permit estimation of thermal emissivity and internally-generated power. In addition, estimation of additional IR parameters may be possible from multiple MSI bands using other automatic parameter estimation techniques such as artificial neural networks^{4,5}.

The IR simulation results were demonstrated using non-real-time Look-Up Table (LUT) image processing software to map AIRSIM-predicted radiometric temperatures into image intensities. For real-time Image Generation (IG) systems, either IR codes or IR pointers stored in an IG run-time database could be mapped in real time into display intensities using multiple LUTs implemented in hardware. Furthermore, using polygonal terrain elevation representation in its run-time database, the IG could project three-dimensional terrain perspective IR scenes in addition to the overhead geometry imagery shown here.

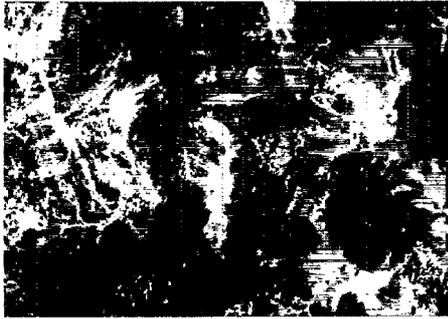
The IR Simulation process developed under McDonnell Douglas independent Research and Development (IRAD) was applied to Landsat TM MSI data used for War Breaker F-15E Weapons and Tactics Trainer (WTT) visual and radar IG database generation. The WTT simulator included navigation, targeting, and missile IR image generation. 24-bit IR codes were defined, their values determined from the



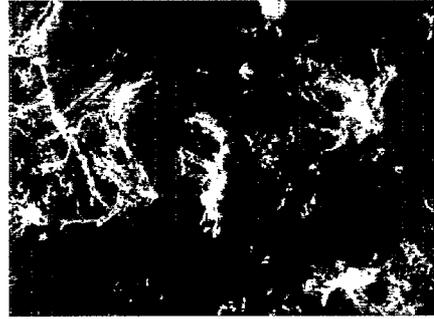
(a) Midnight



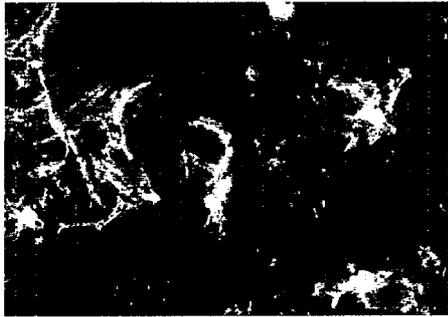
(b) 04:00



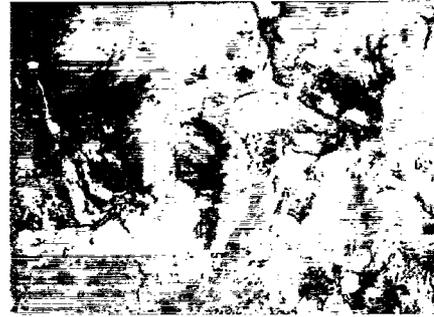
(c) 08:00



(d) 12:00



(e) 16:00



(f) 20:00

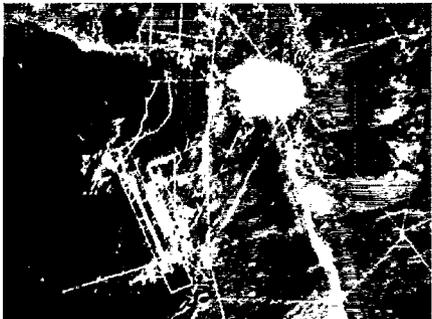
Figure 4.4-1 Thermal Imagery at Six Times of Day - Large Area Overview (Local Time Indicated)



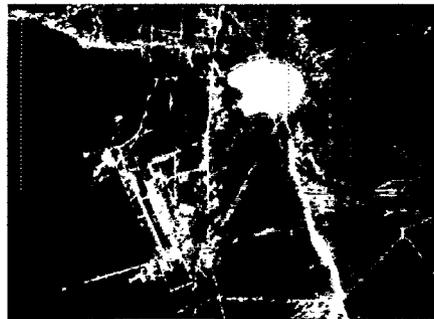
(a) Midnight



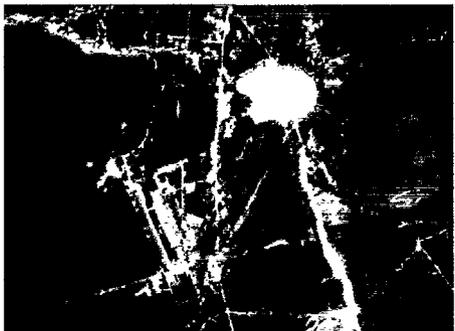
(b) 04:00



(c) 08:00



(d) 12:00



(e) 16:00



(f) 20:00

Figure 4.4-2 Thermal Imagery at Six Times of Day - Full Resolution (Local Time Indicated)

TM MSI data and stored in the run-time database, and an IR code-to-intensity LUT for 20:00 hours. Because of the IG software architecture, the LUT was only used to pre-compute an IR intensity database prior to simulation rather than to switch multiple LUTs in real-time.

Irrespective of the IG architecture, we succeeded in generating a database containing all basic thermal parameters necessary for any physics-based weather-dependent diurnal IR modeling and simulation. Furthermore, the database was produced cost-effectively from available sources of data, without extensive and labor-intensive IR modeling, and the predicted thermal imagery demonstrated diurnal variations driven by geospecific weather and terrain data.

Follow-on efforts could include accuracy validation of the predicted imagery against real IR imagery accompanied by weather and ground truths, experiments using Defense Airborne Recce Office imagery sources, addition of atmospheric propagation and sensor models, and simulated IR image fidelity evaluation by training, mission planning, and mission rehearsal personnel.

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