MEDSAT: A Small Satellite for Malaria Early Warning and Control

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This paper presents the design for a low cost, light satellite used to aid in the control of vector-borne diseases like malaria. The 340 kg satellite contains both a synthetic aperture radar and a visual/infrared multispectral scanner for remotely sensing the region of interest. Most of the design incorporates well established technology, but innovative features include the Pegasus launch vehicle, low mass and volume SAR and VIS/IR sensors, integrated design, low power SAR operation, microprocessor power system control, and advanced data compression and storage. This paper describes the main design considerations of the project which include the remote sensing task, implementation for malaria control, launch vehicle, orbit, satellite bus, and satellite subsystems.

Introduction

The idea of a medical satellite (MEDSAT) developed over the last five years within the National Aeronautics and Space Administration's Biological Monitoring and Disease Control Program (DI-MOD) at the Ames Research Center (NASA--Ames). The MEDSAT concept centers on using remote sensing information obtained from a space-based platform to aid in the control of vector-borne diseases. NASA--Ames researchers, encouraged by the DI-MOD studies, supported the University of Michigan (Winter term 1991) in conducting a satellite systems design course to determine a preliminary design for MEDSAT.

The MEDSAT project course was organized to foster an interdisciplinary research approach. The project involved collaboration between students and researchers from various disciplines including: engineering; natural resources; biology; public health; and other sciences (e.g., atmospheric, environmental, and space). This interdisciplinary research approach went significantly beyond the design of the MEDSAT satellite bus. The MEDSAT design project included investigation into: the feasibility and design of the remote sensing systems; vector-borne diseases; primary test site selection; data reduction techniques; implementation considerations; and other end-to-end system design problems.

The MEDSAT project focused on a light satellite design incorporating sensors developed to provide information that could be used to aid in the control of malaria. Malaria and other vector-borne diseases are serious health problems which affect approximately half a billion people worldwide. Malaria is the vector-borne disease where the vector, or carrier, is the Anopheles mosquito--a common mosquito found throughout the world[14].

The MEDSAT system works by combining information from satellite sensors and ground sources to assess the malaria risk in a particular region. The satellite sensors are used to detect and measure the large scale environmental and cultural features associated with malaria transmission. For instance, some of the data collected to assess malaria risk would be: the extent and mutual proximity of pastures with standing water (source of mosquitos); migrant worker camps that contain some malaria infected people (source of parasites); and nearby towns (source of uninfected persons). Maps can then be constructed that delineate the spatial distribution of malaria risk in the region. Regular observation of a particular region will allow researchers to map the temporal and spatial change in the region's malaria risk.

In developing tropical countries, the control of vector-borne diseases is inadequate due to limited available resources[22,31,38]. Hence, as reported by the World Health Organization in March of 1990, the threat of vector-borne diseases to the world population is increasing. The information obtained from the MEDSAT system will allow the disease control community of the particular region to more effectively use their limited available resources. The MEDSAT system will provide earlier warning of a malaria outbreak to disease control community allowing them to use pro-active rather than reactive control measures when dealing with the disease.

The rest of this paper describes the various design considerations of the MEDSAT project. First, the remote sensing task of the MEDSAT project is presented, followed by a description of the intended launch vehicle. Then, the satellite bus and subsystem designs are presented. The paper ends with the project conclusions and appendices on SAR and VIS/IR sensor designs. This paper is a summary of the MEDSAT satellite design project report[30]. The reader is referred to the text cited above for a more detailed discussion of the MEDSAT project design reasoning.

Remote Sensing Requirements

The primary test site was determined to be the county of Soconusco located in southern part of Chiapas, Mexico based on the region's high incidence of malaria cases coupled with a public health program that can take advantage of the MEDSAT information. The system is designed to collect 250 km by 50 km image data twice daily over this area.

The most important fundamental attribute of the MEDSAT sensors is their ability to be used to create imagery in which the target classes associated with malaria transmission can be detected, discriminated, and measured. The MEDSAT remote sensing task is defined by imaging, environmental, and temporal factors.

The imaging factors consist of the ability to distinguish the various target classes corresponding to mosquito habitats and human habitation within the resulting imagery. The mosquito habitats basically tend to be vegetated areas with underlying standing water[13,37]. Within the MEDSAT target area of southern Mexico, migrant workers are believed to be a significant risk factor due to the high incidence of malaria among such workers and their close proximity to the mosquito habitats[3]. Therefore, in addition to knowledge pertaining to locations of mosquito habitats, spatial and temporal distribution of migrant worker camps is also highly desirable. Knowledge of the spatial distribution of stable communities like towns and family villages is also required.

A visual and infrared (VIS/IR) multispectral scanner system can be used used to fulfill the imaging factors of the MEDSAT project's remote sensing task. Research by NASA--Ames in California rice fields has shown that VIS/IR multispectral scanners can be employed to create imagery used to correlate biomass and standing water on the fields with the abundance of Anopheles mosquitos[37]. Other research has shown that space based VIS/IR multispectral scanners can be employed to produce imagery used in the detection, classification, and measurement of mosquito larval habitats[13]. Imagery from Landsat VIS/IR multispectral scanners has also been used to detect and measure land use which may be of use in determining human habitation.

We found that SAR systems have been successfully employed to create imagery used to remotely: classify and measure vegetation; identify and measure soil moisture/standing water, even through moderate vegetation canopies; and identify man-made structures [13]. Hence, the deduction was made that a SAR system would complement the VIS/IR sensor in fulfilling the imaging factors of the MEDSAT project's remote sensing task [24].

The environmental factors indicate that having at least one sensor with the ability to penetrate through clouds and rain is important for the fulfillment of the MEDSAT project remote sensing task. The reason being that the malaria problem is typically the worst in tropical parts of the world--like Chiapas, Mexico--where there are long rainy seasons and high percentages of cloud cover.

The temporal factors indicate that, in order to fulfill the MEDSAT project remote sensing task, at least one sensor must be able to remotely sense the target area independent of solar illumination conditions. There is indication that acquiring remote sensing data during low sun illumination periods may provide necessary information to aid in the determination of malaria risk in the region of interest. This may be especially true since the anopheles mosquitos, which are the vectors of concern in the transmission of malaria, tend to be most active during dust, dawn and at night[14,22]. Another reason for sensing at night would be because the environmental conditions in vegetated areas tend to be more constant at that time than during daylight hours[6].

There is still uncertainty as to when the best time would be for collecting the SAR image data for the MEDSAT project (i.e., time of day or time after a rain fall). The planned orbit of the MEDSAT satellite--besides having a period of 94.1 minutes, a repeat cycle of 24 hours, and a second target overpass on an ascending node 6 hours after the first descending node pass--has a precession rate, which will cause the satellite to pass over the test site of

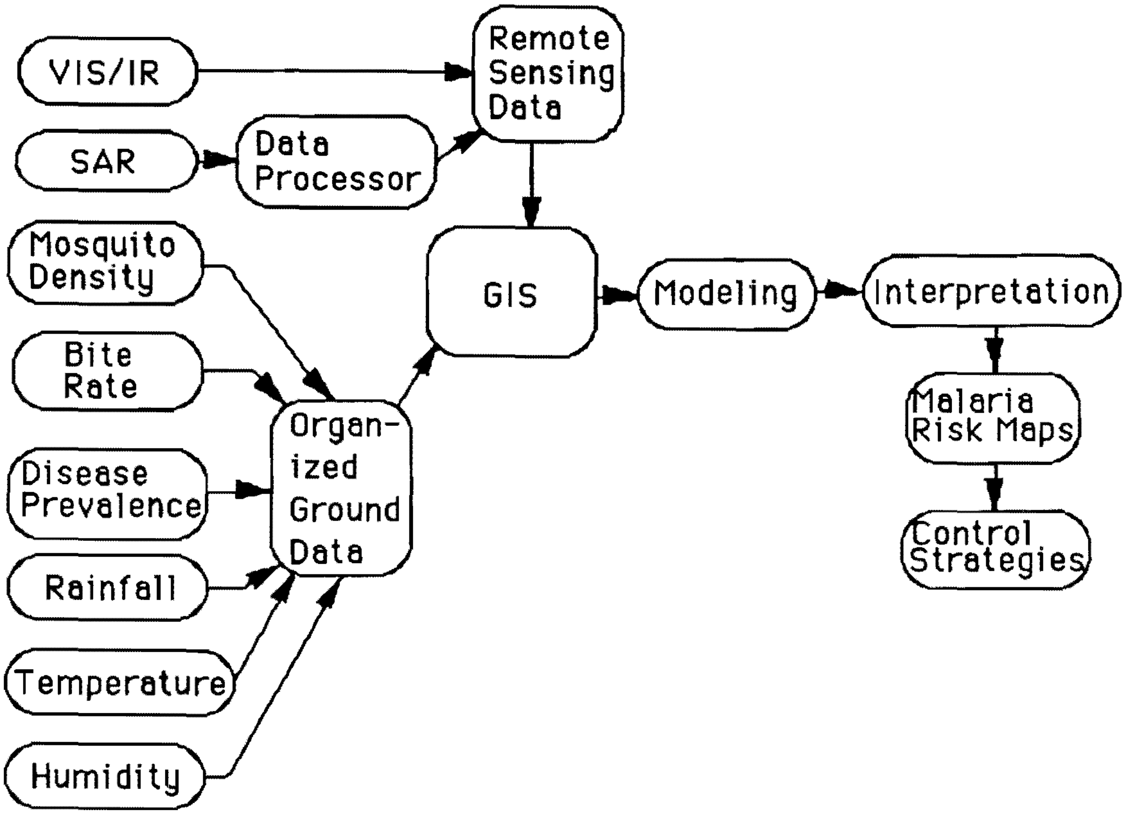

Figure 1: Information Flow Diagram

Chiapas, Mexico 25-30 minutes earlier each day. This precession rate will actually help in the determination of the optimum time of day and after a rain fall to collect the SAR image data, but it also dictates that sensing sessions will need to be undertaken at night--even with the twice per day coverage of the target.

SAR systems are operationally independent of both solar illumination and weather conditions. VIS/IR multispectral scanners (excluding thermal infrared) require sun illumination and fairly cloud free sky in order to collect acceptable imagery data. Hence, the deduction was made that a SAR system would greatly improve the remote sensing capability of the MEDSAT project by eliminating the effect of the two important environmental and temporal factors of the remote sensing task. The two Appendices at the end of this paper provide summaries of the designs for the two sensors.

Once the remote sensing data is obtained, it will be fed into a geographic information system (GIS) along with other ancillary data and used to assess the malaria risk in the region (see Figure 1)[5,18,21]. The malaria risk assessment will most likely be accomplished through application of a structured mixing model that is similar to other epidemic transmission models [16,19,22]. Other possible modeling schemes include neural nets and expert systems.

The variables that should go into such a model can be divided into two categories--ground and satellite imaging systems. The variables that can be measured on the ground include: mosquito density estimates (larval counts); bites per person per night; number and location of malaria cases; rainfall; temperature; and humidity. Ground measurements will also be made in order to provide ground truth for the remote sensing instruments.

The variables that can be measured by the satellite imaging systems can be further divided into those that can be provided by a particular sensor. The VIS/IR multispectral scanner imagery can be used to measure: ground surface temperature (estimate); vegetation/crop type; standing ground water; vegetation biomass; and land use. The variables that can be measured from the SAR imagery include, but are not restricted to: moisture content; vegetation type; vegetation canopy measurements; land use (including human population

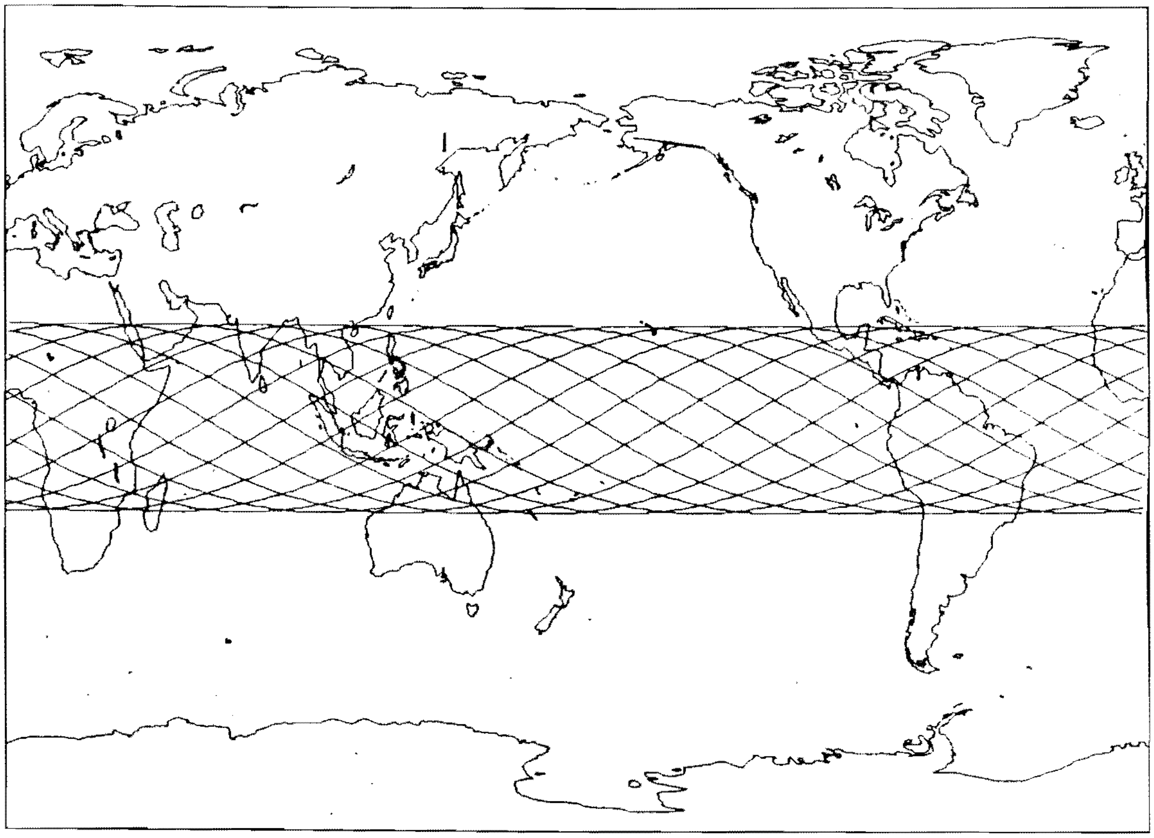

Figure 2: MEDSAT Ground Track

estimation); standing water; water level in streams and rivers; crop development; and rainfall.

Launch Vehicle and Orbit

The reason for choosing a light satellite design was to reduce the cost of the satellite so as to increase the probability of its implementation. The Pegasus air launch system, developed by Orbital Sciences Corporation, was chosen as the launch vehicle for the MEDSAT light satellite [27]. The main advantages of the Pegasus launch system are the reduced cost and increased flexibility in choosing the launch time and place[30]. The launch window flexibility of this system allows the user to choose any combination of orbital inclination and ascending node when launching the satellite. The Pegasus is fired from a special pylon under the wing of a B-52 or other similar size airplane. At launch, the airplane is in cruise flight conditions, flying at about Mach 0.8 and at an altitude of 12,000 m.

The selection of a light satellite platform for MEDSAT placed strict limitations upon the power, volume, mass and data rate of the two remote sensing instruments. The Pegasus launch vehicle can place payloads with a mass and volume of up to 410 kg and 7.2 m^3 respectively into low earth orbit. The orbital parameters chosen for the MEDSAT satellite are as follows:

Altitude = 477 kilometers circular
Period = 94.1 minutes
Inclination Angle = 21 degrees
Satellite Mass = 340 kilograms
Revolutions/Day = 15
Coverage Frequency = Twice per day
(of Chiapas)

This orbital period and altitude will allow the satellite to cover the target site of Chiapas twice every day--first on a descending node then about six hours later on an ascending node. In addition, this orbit covers the entire equatorial region and will allow remote sensing information to be acquired for most of the world's tropical countries (see Figure 2)[11].

However, because the precession must be taken into account when determining the orbital period, the time of day of coverage will vary. Each day the satellite will pass over Chiapas 27.74 minutes ear-

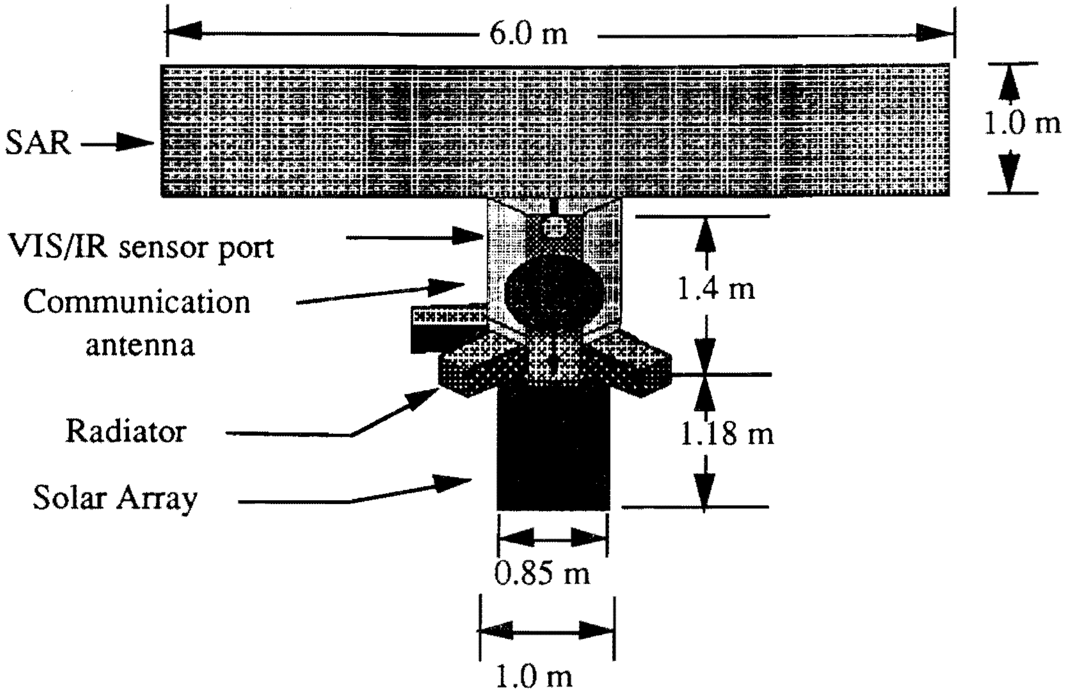

Figure 3: Bottom view of the MEDSAT satellite

lier, local time, than the previous day's pass. This leads to the inevitability of some nighttime coverage of the target. The use of twice per day coverage of the test site means that only for a few days at a time will both passes be in darkness. This will allow for the maximum benefit from the VIS/IR multispectral scanner.

The atmospheric drag associated with the low MEDSAT orbit requires that the satellite fire thrusters to maintain the orbit over the planned four year satellite life. A Hohmann transfer maneuver will be performed every 54 days to keep the satellite within a ± 2 km tolerance of the planned 477 km orbit.

Satellite Bus and Subsystem Designs

The design presented to NASA--Ames and NASA--Lewis in April 1991 features a 340 kg satellite with VIS/IR and synthetic aperture radar (SAR) sensors in a low inclination orbit observing a primary site in Chiapas, Mexico. This section of the paper presents the main design parameters of the MEDSAT satellite bus. A more detailed description of this design can be found in the MEDSAT project report that was submitted to NASA--Ames [30].

The satellite is roughly a 1.4 m by 1 m octagonal cylinder of aluminum honey comb panels (see Figure 3). The shape of the satellite bus was determined by the size and shape of the Pegasus payload bay, the remote sensing instruments, and the attitude control system. Six components of the satellite are extended from the main structure: on top is the 1.18 m by 0.85 m solar panel; from the bottom is the 6.0 m by 1.0 m SAR antenna (see Appendix A); from the side walls are the 0.75 m diameter parabolic dish communications antenna and three thermal radiators. During launch, the solar panel is folded and stored on top of the octagonal cylinder. The SAR antenna is folded and stowed within the satellite bus during launch. The communications antenna is folded at two hinge points during launch, and held securely to three of the side walls of the satellite bus. During launch, the thermal radiators are folded up and projected into the forward section of the Pegasus faring.

Attitude and position sensing are accomplished using the Solar Aspect Sensor (SAS), Global Positioning System (GPS), and TRILAG laser gyros. The satellite is three axis stabilized with attitude and position adjustments made via three reaction wheels and 10 external hydrazine thrusters (see Figures 4 & 5). The thrusters will be used for orbit insertion, downloading reaction wheel momentum, providing redundancy for the reaction wheels, and performing the Hohmann transfer maneuvers necessary to prolong the lifetime of the satellite. The disturbance torques expected with the low earth orbit of the

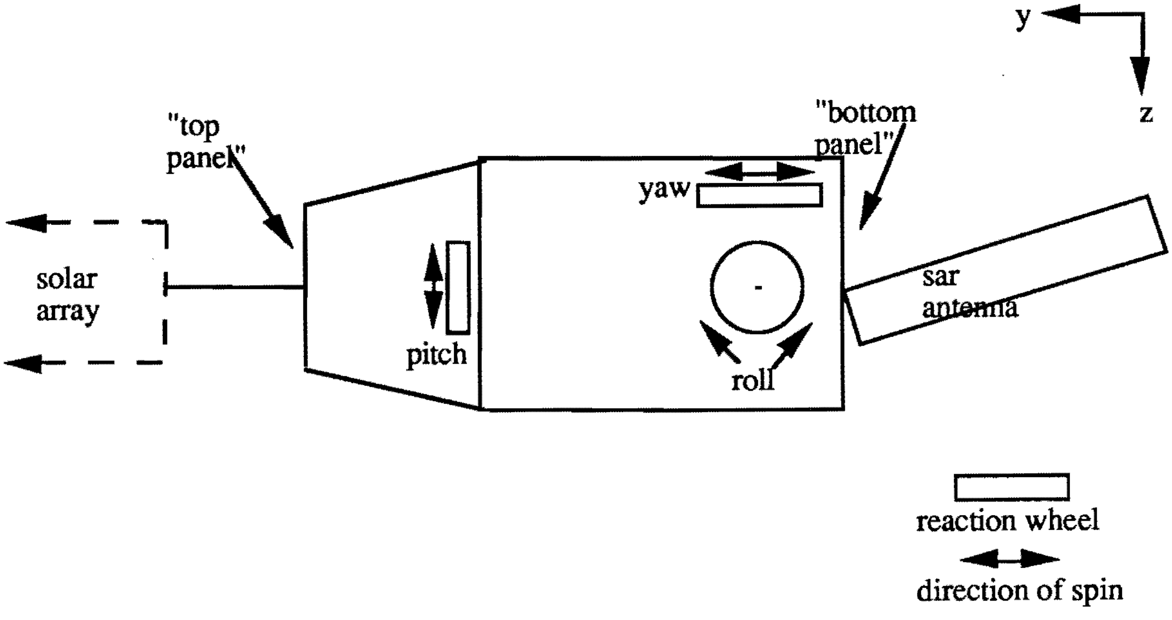

Figure 4: Reaction wheel orientations

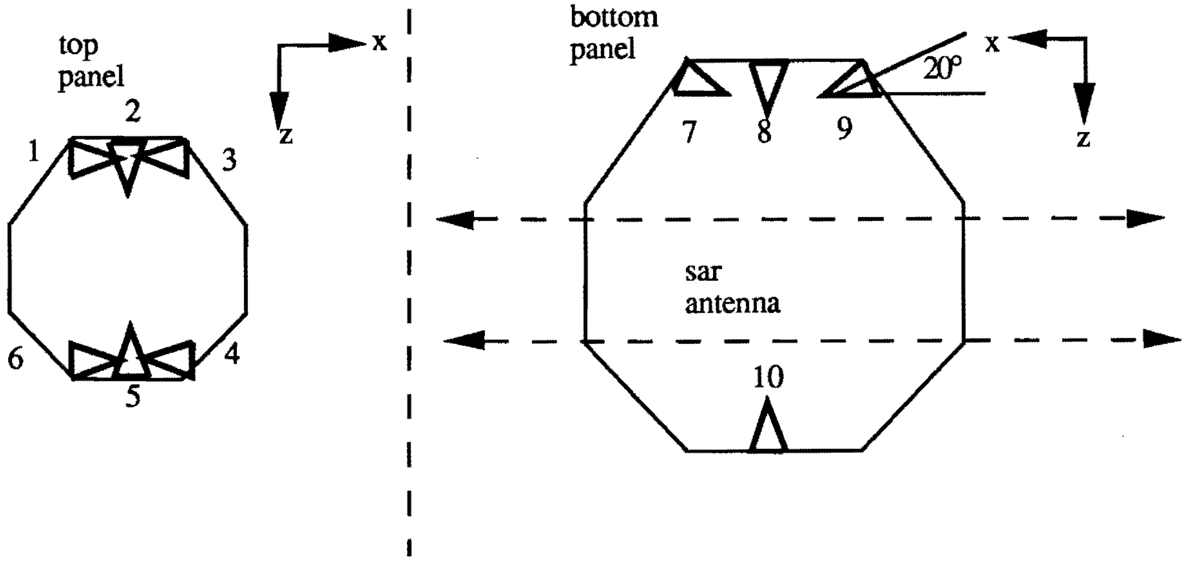

Figure 5: Thruster orientations

MEDSAT satellite will consist primarily of gravity gradient, aerodynamic drag, and solar radiation.

The control system will utilize an on-board microprocessor to coordinate sensor and actuator information. Position information from the GPS receiver will be used to determine when the scientific instruments and communications antenna must be turned on, and to determine when the Hohmann transer maneuver is required. The TRILAG laser gyros (inertial sensor) will provide attitude informa-tion needed to maintain the Nadir orientation of the spacecraft and point the scientific instruments to within 0.3 degrees of the target. The sun position information from the SAS will provide a reference for the solar array and the inertial sensor. The microprocessor will also be used to control the thrusters while the Hohmann transfer is performed, and while downloading momentum in order to unsaturate the reaction wheels.

Thermal control and cooling are required for both the satellite electronics and the detectors of the VIS/IR multispectral scanner. The cooling is accomplished using insulation and three active radiators pointed to deep space (see Figure 3). The insulation employed to shield the interior components from the temperature extremes experienced by the satellite is aluminum Kapton. The insulation is a 1 cm thick blanket made up of 30 separate layers of Kapton. The coefficient of conductivity for the blanket is 0.00029 watts/meter-Kelvin.

The three radiators have shielding to prevent absorption of radiation from the Earth and sun. Two of the radiators (surface area 0.647 m^2) are dedicated to the VIS/IR sensor components, and will provide cooling down to 95 K at a rate of 2.25 w. The other radiator (surface area 0.218 m^2) is used by the batteries and other electronics, and will provide cooling within the range of 273-283 K at a rate of 55 w. The heat from the various components is transferred to the radiators through heat pipes, con-ducting rods or thermoelectric devices. The work-ing fluid used by the radiators and heat pipes dedi-cated to the VIS/IR sensor is liquid nitrogen, while working fluid used by the radiator and heat pipes dedicated to the electronics is liquid ammonia.

The difficult task faced by the power system is that of providing high power levels to the scientific instruments for short durations in the low earth orbit environment. The power system must supply a maximum of 353 w during the 36 sec data collection pass, and 58 w of continuously to the other subsystems of the satellite (see Figure 6). The MEDSAT power system requires a battery with a large charge capacity, and a pulse modulator to feed the SAR with the required burst pulse power (see Appendix A).

The power system of the MEDSAT satellite em-

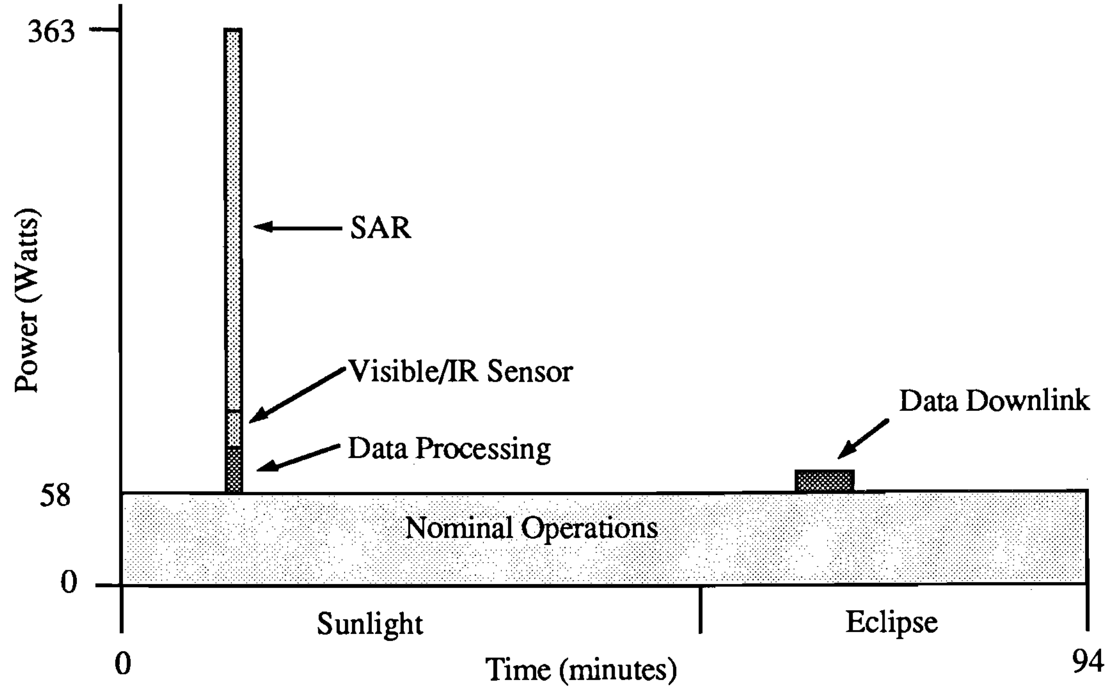

Figure 6: Typical power requirement profile

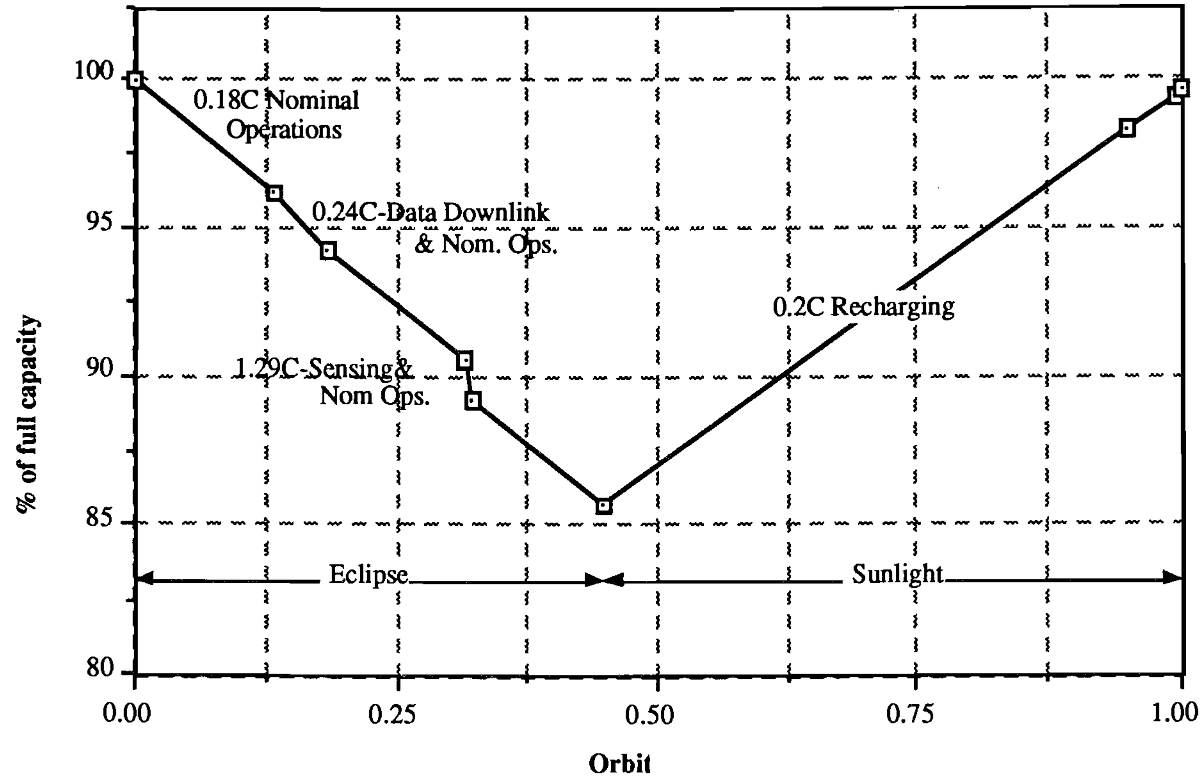

Figure 7: Battery charge status for the worst case orbit

ploys proven technology gallium arsenide (GaAs) solar cells and 24 Nickle Cadmium (NiCd) batteries. The system also uses the on-board microprocessor to increase the power system efficiency, prolonging the life of the batteries and reducing the overall weight of the power system. The microprocessor continually monitors and adjusts the satellite power system, including the battery voltage, solar array current, and battery charging rate. The microprocessor can also carry out instructions received from the ground.

The GaAs solar array has an efficiency of 18% (compared to 12% for an array of silicon cells) which means a smaller array size as compared to a silicon solar array. The smaller array means a reduction in drag, and hence the amount of propellant needed for station keeping. The efficiency of the GaAs cells is also more thermally stable than that of silicon cells. The cells will be mounted on aluminum honeycomb sheet, the back side of which is laminated to improve the radiation of heat generated by the cells into space. The array is single axis controlled (i.e., the y-axis from Figure 4), and depends on the Solar Aspect Sensor to determine the direction to pivot the array in order to obtain maximum solar illumination of the cells. The power output of the GaAs solar array--taking into account temperature, season (sun angle), array assembly errors, and other losses--is expected to be between 135 and 174 w.

Satellites in low Earth orbit (LEO), like MEDSAT, spend a considerable portion (~45%) of their orbital period in the shadow of the earth. During this darkness or occultation, the solar array cannot produce power and the satellite subsystems must depend on the stored electrical energy in the batteries. The NiCd battery cells used will provide 1.2 V, with a series of cells employed to supply the satellite with 28 V. The battery will provide enough energy to allow both a sensing session and a downlink during the eclipsed part of the satellite orbit, and still remain charged to above 85% capacity. The power system is then able to recharge the battery to almost 100% capacity before the next orbital eclipse begins (see Figure 7).

The satellite is designed to handle 1 Gbit of remotely sensed image data on a single pass over the target area. This information is stored on a 2.4 Gbit optical disc which allows room for data from two sensing sessions to be recorded before the need to downlink[33].

The data handling capacity of the satellite required an innovative SAR sensor design since SAR systems typically have very large data rates. The MEDSAT SAR design incorporates a data compression technique that has been proven on the Magellan and Cassini SAR systems (see Appendix A for more details)[30]. Through the application this data compression technique, in conjunction with other operational attributes of the system, the SAR data rate to the recorder is reduced from 272 Mbits/sec to about 6.5 Mbits/sec. This means that the total recorder memory capacity needed for the 250 km by 50 km SAR image is only about 234 Mbits. The optical image data is recorded first and then compressed prior to transmission to the ground station. The 500 Mbit optical image data will be compressed and recorded, during the ten minutes after data collection, by a factor of 5 to 10 using a vector quantization encoding technique.

The compressed image data is then direct downlinked on K_u-band using a 0.75 m diameter parabolic dish antenna to a ground station in Hawaii. The Hawaii station then sends the data, via the NASCOM satellite communications system, to both NASA--Ames and and a ground/field station in Chiapas, Mexico. At the field station, which could be simply a van or trailer, the data is decompressed and the images are processed, interpreted and assimilated with the ground information into the GIS system. The information is then used to assess the malaria risk in the region.

Conclusions

We conclude from this study that an effective, low cost satellite for malaria control is feasible. Both the synthetic aperture radar and visual/infrared multispectral scanner sensors can be include in a 340 kg spacecraft compatible with a Pegasus launch vehicle. Twice daily coverage is allowed for a single site in Chiapas, Mexico with an option to observe various other tropical, equatorial sites. Most of the design incorporates well established technology, but innovative features include the Pegasus launch vehicle, low mass and volume SAR and VIS/IR sensors, integrated design, low power SAR operation, microprocessor power system control, and advanced data compression and storage. Although this design is specifically concerned with malaria, the MEDSAT system can also be used in the control of other vector-borne diseases such as African sleeping sickness, filariasis, dengue, schistosomiasis, yellow fever, and Japanese encephalitis.

Acknowledgements

This work was performed at the University of Michigan with funding and direction provided by the National Aeronautics and Space Administration's Ames and Lewis Research Centers. The members of the MEDSAT research project thank NASA for its technical and financial support, and also thank the various other the people from the Jet Propulsion Laboratory, Environmental Research Institute of Michigan, The University of Michigan, and numerous other private companies who shared their time and knowledge with us.

Appendix A: Synthetic Aperture Radar Design

In order for the MEDSAT satellite to be an effective tool used in determining areas of high malaria risk in the tropical equatorial regions of interest, it must possess a sensor capable of remotely sensing mosquito habitats and human habitation through rain and clouds, and independent of solar illumination conditions. The all-weather and day/night operational attributes of a synthetic aperture radar (SAR) system, coupled with the ability to utilize the output imagery in identifying, classifying, and measuring the terrain parameters that are of key importance to the this project, make the SAR ideal for use on the MEDSAT sensing platform. This appendix highlights the key design parameters of the SAR followed by a tabulated summary of the SAR design (see Tables 1, 2 &3). The SAR sensor chapter of the MEDSAT project report has a more detailed discussion of the reasonings behind the choice of the various sensor design parameters[30].

The best discrimination of target classes on SAR images would be obtained by using a radar sensor that employs two or more frequency bands (e.g., a high frequency like X-band along with a lower frequency like L-band). The second best attribute that a SAR sensor could have to improve the target class distinction problem would be the ability to exploit the multipolar return signatures of the target area [6,23,24,34]. The MEDSAT SAR design is constrained--due to the power and size requirements of present technology devices--to employing only one frequency band. However, the increase in system power, data rate, and antenna complexity associated with going to a fully polarimetric SAR design is manageable with present technology devices[25]. Therefore, the MEDSAT SAR sensor will be fully polarimetric (i.e., quad polar) in order to gain an increased ability to distinguish various target classes from each other in the resulting imagery, where a fully polarimetric SAR is a system that has the ability to measure the complete phase and amplitude information of the target/ground returns.

Since it was desired to have a system that was able to detect vegetated areas with underlying standing water, the frequency band chosen had to be one that provided sufficient vegetation canopy penetration. This factor narrowed the choice to either P or L-band. There is substantial research supporting the employment of L-band SAR systems in the detection of soil moisture and standing water under vegetation canopies [6,15]. There has not been as much research documented on similar usage of P-band systems. There was also concern from various researchers in the radar remote sensing field [6,34] that the effect of large Faraday phase rotations (worst at low frequencies like P-band) on the radar return signals due to passage through the ionosphere would severely alter all the polarimetric information. An even more deciding factor for the choice of L-band over P-band for the MEDSAT SAR system was the size of the antenna required for P-band simply to acquire an acceptable antenna gain. Thus, the current information indicates that the optimum frequency band for MEDSAT SAR sensor is L-band (1.275 GHz / 0.23 m). The SAR chapter of the MEDSAT project report submitted to NASA--Ames has a more detailed discussion of the reasonings behind the choice of L-band as the frequency for the MEDSAT SAR[30].

The MEDSAT SAR will be employing burst mode operation, in order to reduce the operational data rate and power draw of the sensor. This mode of operation has been well developed by JPL on the Magellan and Cassini SAR systems [9,17,26,35,]. This technique works by simply turning the radar on and off in specific timed bursts during the imaging time over the target. The duration of the "burst on" time is calculated to create a synthetic aperture (antenna lengthening) of sufficient length to satisfy the azimuth resolution specification. In the MEDSAT design, the "burst on" duty cycle works out to be 17%. This corresponds to an 83% reduction in the number of transmitted pulses as compared to a traditional continuous mode SAR.

The MEDSAT design incorporates a proven adaptive quantization scheme similar to that used by the Magellan and Cassini SAR systems. This approach allows the system to retain a large dynamic range while using fewer bits. The quantization scheme provides a data compression to compliment the data reduction obtained by the burst mode operation. Applying these two techniques to decrease the amount of SAR data means that the system will operate at a much lower data rate and require substantially less memory than traditional SAR systems. In the MEDSAT SAR design, the incoming data will be initially quantized to 8-bits per sample (i.e., 8-bit dynamic range). This 8-bit data is then passed through a device similar to Magellan's block adaptive quantizer where the input 8-bit data is returned in 2-bit form[20].

The very large instantaneous data rate of the MEDSAT SAR is reduced to a more manageable value through the three data reduction steps of time expansion buffering (stretch processing), burst mode operation, and block adaptive quantization[4,9,17,20,26,35]. The instantaneous data rate for the MEDSAT SAR is about 272 Mbits/sec. After application of the data reduction steps, the final MEDSAT SAR data rate to the recorders is about 6.5 Mbits/sec. This means that the total recorder memory capacity needed for an image of 250 km by 50 km is about 234 Mbits.

The 6 m X 1 m antenna design will employ T/R module technology in an active phased array design. Each T/R module will control two radiating patch elements, one for horizontal polarization and the other for vertical. A more detailed discussion of the advantages and disadvantages of using this small antenna design, along with calculations to determine the patch spacings, can be found in the MEDSAT design report[30].

The average radiating power required by the MEDSAT SAR antenna (assuming a 6 m by 1 m antenna size) is 275 w (RF) which corresponds to a peak radiating power of about 2710 w (RF). The required DC input power from the satellite's power supply to the antenna is about 860 w during the "burst on" time, and 0 w during the "burst off" time. This means that by utilizing burst mode operation, the average power draw from the satellite's power supply is only 145 w, which is a substantial savings in power [30].

Table 1: SAR Geometric Imaging Requirements

Radar Frequency (wavelength)	1.275 GHz (0.23 m)
Radar Band Designation	L-band
Nominal Range to Target	520 km
Satellite Altitude (nominal)	500 km
Ground Equivalent Velocity	7000 m/s
Azimuth Resolution	75 m
Range Resolution	75 m
Incidence Angle	15 degrees
Ground Swath	250 km X 50 km
Polarization	HH, VV, HV, VH

Table 2: SAR System Design Specifications

Thermal Signal-to-Noise Ratio	8 db
System Losses	4 db
Noise Temperature	500 K
Noise Floor	-23 db
Pulse Repetition Frequency	5047.95 Hz
Transmitted Pulse Length	20 µsec.
Chirp Pulse Bandwidth	7.727 MHz
Burst Repetition Frequency	1.4 Hz
Number of Pulses per Burst	571
"Burst On" Time	113 msec.
Integration Time	3 sec.
Data Reduction Ratio	16 %
Power Reduction Ratio	17 %
Final Average Data Rate to Data Storage System	6.5 Mbits/sec
Recorded Data Volume per Image	234 Mbits
Number of Looks	4
Antenna Dimensions	6 m X 1m

Table 3: SAR Power and Mass Estimates

Antenna Radiating Peak Power	2710 w (RF)
Antenna Radiating Average Power	275 w (RF)
"Burst On" Power Draw From Power Supply	860 w (DC)
"Burst Off" Power Draw From Power Supply	0 w (DC)
Average Power Draw From Power Supply Over the Burst Period	145 w (DC)
Antenna Mass	40 kg
Electronics Mass	30 kg

Appendix B: Visual and Infrared Multispectral Scanner Design

The visual and infrared multispectral scanner is proven tool for use in the detection and measurement of mosquito habitats and man-influenced topography. This appendix describes the channels and detectors used for the MEDSAT multispectral scanner and ends with a tabulated lists of the design for this sensor (see Tables 4 & 5). The VIS/IR sensor chapter of the MEDSAT project report has a more detailed discussion of the reasonings behind the choice of the various sensor design parameters[30].

The visual and infrared multispectral scanner has been determined to be a four channel (wavelength band) device. This means that the device will measure the electromagnetic radiation of four distinct wavelength bands as depicted in Table 4.

The measured intensity values for the visible red and NIR radiation are used to calculate the Normalized Difference Vegetation Index (NDVI):

$$\text{NDVI} = (\text{NIR} - \text{RED}) \;/\; (\text{NIR} + \text{RED})$$

The NDVI is well documented as an indicator used for determining health and biomass of vegetated areas. The mid-infrared radiation intensity measurement can be used to obtain a measure of the water content in the leaves of the vegetation. The intensity value obtained for the thermal infrared radiation is actually a measure of the thermal radiation of the target surface. Thus, the information from the thermal channel can be used to estimate the surface temperature of the target area. The thermal infrared channel is the only one of the four multispectral scanner channels that does not require direct sun illumination of the target in order to produce an image.

The multispectral scanner design that can meet our spatial and spectral resolution needs is called a line scanner, or "push-broom" imager. This type of scanner acquires reflectance data from the target area one line at a time on a one-dimensional linear array detectors.

The detectors we suggest for Channels 1 and 2 of the MEDSAT multispectral scanner are recently developed charge coupled devices (CCD's). Each detector consists of a 2 x 1024 array with a 30 μm x 30 μm pixel size. For Channel 3, we recommend two Palladium Silicide (Pd_2Si) Schottky Barrier arrays (each a 2 x 512 with a 30 μm x 30 μm pixel size) developed by Walter Kosonocky at the David Sarnoff Research Center. Two of these arrays can be butted together to accommodate the instantaneous field of view (IFOV) requirements. This detector operates at 125K, which can be controlled using a thermal conducting rod connected to the MEDSAT passive radiator cooler. The detector we suggest for Channel 4 for is Platinum Silicide (PtSi) which is similar to the previous array in that it is a 2 x 512 with a 30 μm x 30 μm pixel size. This detector operates best at 77K, and may require active cryogenic cooling if the results obtained with the radiative cooler system--which can cool the device to 95K--are found to be unacceptable.

Table 4: VIS/IR Multispectral Scanner Channel Designations

Channel	Descriptive Name	Wavelength Band
1	reflected visible (red light)	0.62-0.69 μm
2	reflected near infrared (NIR)	0.77-0.9 μm
3	reflected mid-infrared	0.77-0.9 μm
4	radiated thermal infrared	4.0-5.6 μm

Table 5: VIS/IR Multispectral Scanner Design Parameters

Number of Channels	4 (see Table 4)
Nominal Range to Target	520 km
Satellite Altitude (nominal)	475 km
Ground Equivalent Velocity	7000 m/s
Instantaneous Field of View (IFOV)	0.05 milliradians
Aperture	20 cm
Effective Focal Length	570 mm
Effective f Number	4
Field of View (FOV)	6 degrees
Ground Instantaneous Field of View (i.e., Azimuth and Range Resolution)	50 m x 50 m
Look Angle	15 degrees off Nadir
Ground Swath	50 km X 250 km
Data Volume per Image	500 Mbits
Signal Encoding	12 bit
Power Draw From Power Supply	25 w
Total Mass	27 to 33 kg
Calibration	Blackbodies at two different temperatures
Cooling System	Radiative Cooler via heat pipe, conducting rod or thermoelectric device

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