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TREATY ON OPEN SKIES SENSOR TECHNOLOGIES WITH POTENTIAL INTERNATIONAL SAFEGUARDS APPLICATIONS

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Abstract

The Treaty on Open Skies is a precedent-setting agreement that allows signatory states to fly aircraft over each other's territory with sensor systems. The purpose of the Treaty is to improve confidence and security with respect to military activities of the signatories. This paper reviews the sensor technology that is currently allowed by the Treaty on Open Skies and potential future sensor technology. The Treaty on Open Skies does have provisions to allow for the improvement of the technology of the current sensor systems and for the proposal of new sensors after a period of time. This can occur only after the Treaty has been ratified and has entered into force. If this regime was to be used for other than Treaty on Open Skies applications some modifications to the allowed sensor technology should be examined. This paper presents some ideas on potential improvements to existing allowed sensor technology as well as some suggested new advanced sensor systems that would be useful for future potential monitoring of safeguard's related activities. This paper addresses advanced imaging sensors and non-imaging sensors for potential use in aerial remote sensing roles that involve international data sharing.

1. Introduction

This paper is intended to help motivate intellectual discussion in the potential uses of aerial remote sensing technology in the ever-increasing monitoring role that is being played throughout the world.

The Treaty on Open Skies is a confidence-building regime that allows the aerial over-flight of participating nations by teams from other nations. The aircraft is allowed to carry suites of sensors in order to monitor military activity. This Treaty was first proposed by President Eisenhower but, due to the poor political climate at the time, was never implemented. During a May 1989 speech at Texas A&M University, President Bush proposed a multilateral Treaty on Open Skies that would permit NATO aircraft carrying various types of sensors to over-fly Warsaw Pact countries and vice versa. The purpose of the proposed agreement was to use aerial surveillance to promote openness and to further reduce tensions in Europe. This proposal led to the current treaty.

Since the initial meetings at NATO headquarters in Brussels, world events have radically changed the initial implementation scenario. Events such as the unification of Germany and the re-organization of the Former

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Soviet Union (FSU) have increased the European community's interest in such a cooperative monitoring regime to further enhance peace and confidence in the international community. A Treaty was signed in March 1992. The ratification process continues today and several nations have already deposited ratification instruments. The US ratified the Treaty on November 2, 1993.

2. Allowed Sensor Systems

In establishing requirements for the Treaty on Open Skies, it was agreed that the sensor technology to be used in the regime would be available to all participants of the Treaty. However, the sharing of advanced reconnaissance sensors and aircraft equipment must be reviewed by the export control authorities of each participating country in order to insure that no militarily significant technology is released without proper approval. This has led to a restriction on the level of sensor technology available for use in the Treaty.

Signatories to the Treaty on Open Skies have suggested various sensor suite configurations. The first list of proposed sensor systems was very extensive and was considered by many nations to be too costly and difficult to implement. After further review by experts from various countries, the list of sensors was reduced to the four categories below:

(A) optical panoramic and framing cameras;

(B) video cameras with real-time displays;

(C) infra-red line scanning devices; and

(D) sideways-looking synthetic aperture radar.

Limitations have been placed on the resolution specifications of the sensors. Currently, the allowed resolution for categories (A) and (B) is 30 cm and for the third category (C) is 50 cm. These three sensor categories have resolution performance that is dependent on the altitude at which the airborne platform is flying. Therefore, for these first three categories of sensors, minimum height restrictions are specified, as verified with certification and demonstration flights. The resolution of sensors in the fourth sensor category (D) does not depend on altitude. The current allowed resolution of 3 meters is verified with a measurement of the system's impulse response (IPR). Future sensors to be used in a Treaty on Open Skies data acquisition activity will also be subject to performance restrictions and will have to be certified with an approved validation methodology. /1/

The Treaty contains provisions to change the sensor technology. It allows for upgrades of sensor capabilities and for the inclusion of other new sensor types. The Open Skies Consultative Commission (OSCC) must approve all changes to the sensor technology, and all signatories must agree to these new proposals. New sensor categories that might be useful for an international safeguard's application, such as air samplers, multi-spectral imagers and laser induced direction and ranging (LIDAR) sensors, have been discussed.

3. Sensor Spectrum Selection

There are many variables that must be matched to the requirements for the selection of the optimal sensor system. The portion of the available sensor spectrum to be utilized is dictated by the characteristic of the target that is to be monitored. In the extreme low-frequency end of the spectrum we may utilize infrasound or acoustic sensors capable of detecting sound waves at great distances and at very low amplitudes. Acoustic waves can propagate in the air and in the water and are available for data acquisition with the appropriate technology. The acoustic frequency ranges are from 0.01 hertz to around 10.0 kilohertz.

The electromagnetic spectrum in a sense overlaps some of the acoustic spectrum, due to some of the electromagnetic energy being non-acoustic, but still at a low frequency. The electromagnetic spectral range is approximately between the ranges of from 1.0 hertz to 300 gigahertz. At the low end, from 1.0 hertz to 2.0 megahertz, magnetic phenomena can be detected. Magnetometer sensors are currently used for this measurement and can detect magnetic anomalies caused by the presence of non-dielectric materials. Imaging and non-imaging radar systems, in the range from 3.0 megahertz to 30.0 gigahertz, are used to detect or image objects on the ground or in the air. An imaging radar system can produce optical-quality pictures of the reflected energy from the radar system. The most common imaging radar system used today is synthetic aperture radar (SAR). The advanced low-frequency types of these imaging radar systems are capable of imaging buried structures.

Non-imaging radar systems, commonly used to detect airborne aircraft, simply paint a bright dot to indicate the presence of a target. In the extreme high frequency spectral range of the electromagnetic spectrum, from 30.0 gigahertz to 300.0 gigahertz, some imaging radar systems and radiometers have been developed and tested. Radiometers measure the amplitude of electromagnetic energy in discrete bands and can be used to determine spectral content of detectable phenomena.

Wavelength and frequency are related by the speed of light and are sometimes used interchangeably when specifying optical systems. The long wavelength parts of the available sensor spectrum from 100 microns to 1 micron are used to monitor heat signatures from objects. These wavelength emissions can be used to image surface features and targets that emit thermal radiation. The heat emissions from target areas can include heating systems for buildings, heated water sources, and burning of materials. For these applications, sensor systems that can be used to measure those heat characteristics include infra-red radiometers, infra-red line scanners and focal-plane arrays of infra-red sensors.

For the wavelength range from 1 micron to 0.5 micron visible light imaging is possible. This is the most frequently used part of the spectrum for observation of activities, since the human eye is sensitive to light in this spectral range. The sensor systems for this part of the spectral range include all types of analog and digital optical cameras. Particular types include panoramic, framing, and video cameras. The ultraviolet spectral range covers from 0.4 micron to 0.04 micron. Ultraviolet signatures from target areas are valuable in determining material composition and content. Sensor systems to collect ultraviolet data include multi-spectral imagers, and laser radar.

4. Small Particle Acquisition

Also to be considered for data acquisition are radioactive and non-radioactive particles. For these small particles that are present in the atmosphere one would use air sampling techniques. The processing of the particles could be done in real-time on the acquisition aircraft or on the ground depending on the requirements. Advanced technology to support real time data processing in the aircraft is of current research interest. Radionuclides from nuclear-related activity can be very good indicators of the process that produced them. Examination of particles is done with equipment such as x-ray detectors, gamma ray detectors, and mass spectrometers. Some detection of nuclear radiation is also done without air sampling. This requires a sensor, such as a gamma ray detector, that must be flown close to the ground.

5. Information Requirements as a Function of Sensor Resolution

When selecting a sensor it is important to consider the resolution requirement. For simple detection of a target a low resolution sensor may be appropriate. If, however, one needs to identify or classify an object as a particular type, then a high-resolution imaging sensor may be required. If the requirement is to detect the presence of a ship, a resolution on the order of 100 meters would be adequate. If, however, the requirement is to classify the ship according to type (e.g., aircraft carrier, battleship), then a resolution of 10 meters or better would be needed.

For non-imaging sensors the sensitivity of the measurement is analogous to resolution, and must be specified on the basis of requirements.

For example, consider the measurement of the variation in magnetic flux using a magnetometer in close proximity to the ground. The sensitivity of the magnetometer will dictate the size of the magnetic flux anomaly that can be measured. Therefore, sensitivity will be specified according to the requirements of the size of the magnetic anomaly to be detected.

6. Resolution as a Function of Sensor Range to an Object

The resolution of optical and infrared imaging sensors is dependent on the range to the object being imaged. This must be taken into account when specifying the data acquisition geometry for these types of sensors. Typically these sensors point straight down from the aircraft platform to image areas below and therefore the image at the center is of higher resolution than the image at the outer edges. Panoramic cameras especially have this distortion. Therefore care must be taken in tasking such range-dependent imaging systems to provide the required coverage.

Imaging radar systems come in three basic varieties, with each having a different resolution as a function of range. For real-beam imaging radar the resolution falls off inversely as the square of the range. These are the simplest of the imaging radar systems and are not used for high-resolution tasks. A second type of imaging radar is one that is called side-looking airborne radar or SLAR. The SLAR systems are also referred to as unfocused imaging radar systems. Their resolution falls off inversely as the square root of range. This type of system is used by aircraft that require medium-level resolution for navigation, and to detect large objects on the ground.

The most sophisticated of the imaging radars that are used today are synthetic aperture radar (SAR) systems. SAR systems are also referred to as fully focused imaging radar systems. The resolution of a SAR system is independent of the range at which the data were acquired. The only range limitation comes from the signal-to-noise level that the radar system can record. Therefore, for SAR systems, impulse response (IPR) is used as a measure of resolution rather than the ability to detect the separation of two objects placed close together on the ground.

One can record digitized raw data from SLAR and SAR systems on high-density digital tape and later process the data to form images. The SLAR raw data requires some first-order phase corrections in order to form the image. The SAR raw data requires higher-order phase error corrections be made to fully focus the image over the entire extent of the area being imaged. The technology to do this in real time may be restricted.

For some non-imaging sensors, resolution is analogous to sensitivity and, therefore, the closer you are to the source the better the results. Examples of such near-range sensor systems are magnetometers and radiation sensors. Air samplers are similar, in that the sensitivity of the analysis is analogous to resolution.

7. Airborne Platform and System Integration Issues

The mission requirements or profiles will dictate the aircraft type best suited for the job, and the specific observable or signature required will dictate the sensor suite to be used. Mission profiles can be broken down into the following four generic categories:

(1) high and fast, e.g.; 30,000 feet altitudes and speeds up to 450 knots.

(2) medium, e.g.; 15,000 feet altitude and speeds up to 180 knots.

(3) low and slow, e.g.; 3,000 feet altitude and speeds up to 150 knots.

(4) local, e.g.; maximum 100 feet altitudes and speeds up to 10 knots.

Once the aircraft has been selected to meet the requirements of the mission profile a suitable set of sensors and an integration configuration must be selected. The sensor technology that is to be selected is dependent on several variables including cost, commercial availability, data-sharing requirements, data-processing requirements, and signature or observable requirements. Some specific examples of aircraft types selected for the use in various aerial remote sensing roles can be found in the Proceedings of the First International Airborne Remote Sensing Conference. /2/

The last thing to specify is the system integration associated with the aircraft and sensor system. Sensors may be placed inside the aircraft fuselage with apertures or windows as required. Alternatively, the sensors may be placed in external stores such as in a canoe or pod configuration. The selection of either system integration option will impact implementation costs and is dependent on the aircraft selected for the mission.

8. International Safeguards Data Acquisition Scenarios

Application of aerial remote sensor technology of the type being used for the Treaty on Open Skies has been examined for monitoring a special nuclear material cutoff regime. /3/ The conclusions from that paper are very encouraging and show that such sensor systems could aid in monitoring other nuclear-related activities.

An aircraft platform offers a unique vantage point for safeguards sensors and data acquisition that can be utilized to great advantage if incorporated into an overall strategy to optimize resources. Features unique to aerial remote sensing are:

1. Rapid coverage of large area
2. Rapid repeat measurements
3. Tip-off for further on-site-inspection (OSI)
4. Screening of large numbers of targets
5. Less intrusive than OSI
6. Wide variety of mission profiles
7. Timely data acquisition
8. Reduces number of OSI visits

Airborne platforms can be upgraded with future sensors systems once they have been matched to future requirements. Advances may include such technologies as:

1. Multi-polarization radar
2. Hyper-spectral scanners
3. Multi-wavelength LIDAR
4. Earth penetrating radar
5. Multi-sensor fusion system
6. Massively parallel processors

The following example scenarios are intended to show some applications that could augment existing or future data collection activities for international safeguards. The addition of new and advanced sensors to the existing allowed categories in the Treaty on Open Skies would make the applications to international safeguards even more valuable.

Imaging Sensors

Consider the periodic monitoring of an exclusion area that has previously been secured by ground personnel and is to be watched for activity. The site has been declared inactive and contains sealed containers that should not be accessed without authorization. The aerial remote monitoring aircraft will be assumed to have only currently allowed sensors for the Treaty on Open Skies. The aircraft can over-fly the exclusion area either on a surprise basis or upon call from a remote alarm system at the site.

With the optical or video cameras the aircraft can over-fly the facility as low as permitted to acquire the best resolution possible. If the flight is at night, infrared cameras are used. If there is enough light to photograph the site, optical cameras are used. If the weather is bad and there is a low cloud ceiling, imaging of the facility is accomplished with the synthetic aperture radar. In any event, with standard change-detection algorithms one can do a pre and post flight comparison to detect any changes in the facility. In addition, one could use data sets from infrared, optical and SAR data in a digitally registered and overlaid process in order to detect features that are not detectable with only one data set.

A strategy could be devised to incorporate an aerial over-flight with routine on-site-inspections in order to optimize resources. If the technologies for these categories of imaging sensors are improved, one could do more sophisticated data processing using multi-sensor data fusion techniques. The improvement of sensor technology in the infrared sensor area can provide more dynamic range in order to detect small temperature differences. The advanced technology associated with spot-light mode SAR data acquisition would allow one to produce very accurate maps of the target areas.

Air Sampler

Consider the proposed addition of an air sampler sensor with either advanced real time data analysis or post-flight data processing. This type of sensor could be used to monitor part of the nuclear fuel cycle process or could be considered for monitoring compliance with the comprehensive test-ban treaty (CTBT). From air sampler data, one might determine the presence or absence of a process by measuring the effluents from the site, whether radioactive or not. These data could be incorporated into an overall monitoring strategy with remote monitoring and on site visits.

Advances in the processing of the data from air samplers will be beneficial in future applications. The ability to do in-flight, real-time processing of samples is a subject of current research interest. The sensitivity or accuracy of post analysis equipment such as mass spectrometers have been improving over the past few years and future improvements in this area will also be beneficial.

Transponder System

A third example involves a sensor technology that is currently not allowed for the Treaty on Open Skies purposes, but might be considered for use in international safeguards. Interrogating transponders that can communicate to an aircraft as it over-flies a safeguarded facility, could be used to save manpower required for on site visits and could also provide large amounts of information in a timely manner. The airborne sensor system would send encrypted signals to seals and tags on safeguarded items. These would then respond with state of health information from a stored item and from the sensor itself. This technique could accommodate a large number of sensor systems on the ground at one time. The data could be compressed or multiplexed in order to allow for large numbers of simultaneous transmissions from seals and tags. This could be done on a routine basis or on a surprise basis and would be relatively less intrusive than on-site-inspection to the facility being monitored.

If transmissions from the aircraft to the ground are not possible, the tags and seals could be designed to start transmitting state-of-health information to the airborne platform on a predetermined schedule. This monitoring technique should also be evaluated for synergy with and augmentation of monitoring strategies in current international safeguards tasking.

Multispectral Sensors

The use of airborne multspectral sensors to monitor a facility can provide large-area coverage in one pass. This type of coverage would not be possible with the limited resources on hand to do OSI. The multispectral coverage can provide environmental data for the facility being imaged. The data can give insight into state-of-health of the surrounding vegetation and can indicate extent of any effects caused by discharge from the facility. In addition, some thermal signatures from the surroundings can provide an indication as to facility operations, if heat is a by-product of the facility's operation.

The current improvement in data processing of multispectral data has demonstrated the value of such information. In addition, the airborne data acquisition activity can be coordinated with Landsat satellite data acquisition in the same spectral bands. The co-processing of both data sets using modern image processing and sensor data fusion algorithms would produce valuable insight in a timely manner. /4/

9. Conclusions

The current sensor suite technology for the Treaty on Open Skies might be useful for some selected international safeguard's scenarios. The use of existing sensors in conjunction with current safeguards activities would be beneficial. The evaluation of a synergy and augmentation strategy to combine conventional and future safeguards activities with an aerial platform would be worth the time and effort. The fact that the current sensor technology has been accepted by twenty-seven signatories to the Treaty on Open Skies makes that technology worthy of consideration in an international monitoring regime. The data and technology sharing aspects of the Treaty required extensive negotiations in order to select the acceptable and available technology levels for all signatories, and some leveraging from this negotiation could be made for international safeguards use.

The proper selection of the sensor technology to be used for a specific set of requirements involves many variables. The scenario or mission profile definition is an essential first step in sensor selection. This paper presented some scenarios that may be beneficial to safeguards-related activities, but discussion and evaluation by those experts is a critical ingredient in finalizing a data collection strategy.

This paper has shown that with some proper selection of new sensor technologies one can acquire relevant data sets for international safeguards. With up-front investment in advanced sensor technology, one could realize savings in the long term.

This paper has shown that the use of aerial remote sensing platforms in safeguards applications have some inherent advantages over other traditional techniques. Aerial remote sensing can provide large area coverage, rapid revisit of an area, timely data acquisition, many mission profile options, and allow screening of a large number of target areas. All these attributes have the effect of reducing OSI visits and they are also less intrusive than OSI.

10. References

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