THE CANADIAN AUTOMATIC SMALL TELESCOPE FOR ORBITAL RESEARCH (CASTOR) - A RAVEN SYSTEM IN CANADA

Mr. Michael A. Earl and Dr. Thomas J. Racey: The Space Surveillance Research and Analysis Laboratory
Department of Physics, Royal Military College of Canada, Kingston, Ontario Canada

Abstract

Surveillance of space is becoming a more demanding task since the current satellite population is growing at an ever-increasing rate. More efficient means of optically tracking these satellites and analyzing their images is necessary. The hardware and software being sought by the present-day space surveillance agencies must be extremely efficient yet cost effective. This paper describes the Royal Military College of Canada's effort to construct its own autonomous satellite tracking facility known as CASTOR.

Introduction

For the past two years the Space Surveillance Research and Analysis Laboratory (SSRAL) at the Royal Military College (RMC) of Canada has been in the process of obtaining and assembling commercial-off-the-shelf (COTS) hardware and software in order to increase its satellite tracking efficiency. The Remote Maui Experiment (RME), based in Kihei, Hawaii, has been demonstrating its own autonomous satellite tracking apparatus (known as RAVEN) to various military bases in the United States. From July 14 to October 1, 1998 the RMC tested the efficiency of the RME RAVEN apparatus remotely via the Internet. What RMC was most interested in was the efficiency and accuracy of the satellite tracking, and the effectiveness of the image analysis software to adequately detect satellite streaks and to accurately perform the astrometry on the streaks detected.

The RMC then endeavored to obtain the hardware and software that the RME RAVEN employed. In January of this year, the RMC successfully assembled a prototype of the CASTOR system. This system was comprised of hardware that RMC had been using for about a year, and newly acquired astronomical software. CASTOR A, which will be the primary CASTOR apparatus, is currently under construction and will be completed before October 1, 1999. After construction, extensive testing of the system will be carried out in order to ensure that a fully autonomous satellite tracking facility will exist in Canada. The prototype CASTOR system (named CASTOR B) will partly serve as a back-up system in the event that CASTOR A should fail.

Streak detection software is currently being sought to increase the efficiency of the satellite steak detection and analysis at RMC. RMC currently uses a basic Image Reduction and Analysis Facility (IRAF) package that only allows manual streak detection and end-point analysis. Currently, image analysis at RMC is very time consuming. An average time of five minutes is required to obtain all the data from a single image.

Using the Remote Maui Experiment RAVEN Apparatus

During the week of July 13-17, 1998, Mr. Rich Burns, an engineer at the Air Force Research Laboratory (AFRL) at Kirtland AFB, visited RMC to begin the initial setup of the remote link to the RME site. After the first day, he was able to drive the RME telescope remotely using an RMC terminal. He then demonstrated the different modes of operation that the remote system was capable of. The first was a simple point and click mode where the user sees the desired satellite(s) superimposed onto the background of stars that are seen above the viewer's horizon (in this case the sky over Kihei, Hawaii). The user then points and clicks onto the satellite's position and then commands the telescope to slew to that position. The user then can take an image. The second mode of operation is an automatic one in which the user enters the satellite(s) desired in a spreadsheet program along with the exposure time needed for the CCD camera. The spreadsheet program can then be run in "loop" mode where the commands can be executed over and over until the user decides to stop the spreadsheet file from running. The third mode of operation is the FTP mode whereby a user can FTP a ready-made script to be loaded into the spreadsheet to be executed by the RAVEN user at the other end. While operating the remote telescope, Mr. Burns had some trouble downloading CCD imagery. This was due to a slow server somewhere between RMC Kingston and RME Maui. After the first day, that problem no longer occurred. Mr. Burns had effectively shown that the system could successfully track satellites automatically with little human intervention. Later during that week Mr. Burns allowed Mr. Michael Earl to learn the basic functions of the software in order that Mr. Earl could test the RAVEN capabilities at a later date.

On the two days of September 16 and 17, 1998, Mr. Earl, with the help of Mr. Daron Nishimoto, a researcher at Oceanit Laboratories in Kihei, Maui, a Molniya satellite tracking run was done in order to formally test the effectiveness of the RAVEN satellite tracking system. The information gathered from this satellite tracking run would be used to gauge the effectiveness of the RAVEN apparatus and software, and to serve as a reference for the upcoming CASTOR testing to be done when CASTOR A is constructed.

CASTOR A

After RMC completed its evaluation on the RME RAVEN apparatus, it began construction of its own RAVEN-type site (CASTOR A). Brief descriptions of the hardware that CASTOR A will be using is contained in Table 1. All of the major software that will be used with CASTOR A and B was manufactured by Software Bisque. Table 2 briefly describes the software that CASTOR A and B will employ.

Celestron Model CG-14 14 Inch Aperture Schmidt-Cassegrain Reflecting Telescope	This telescope will deliver nearly twice the light-gathering capability that the current RMC satellite tracking telescope of 10 inch aperture can. Its focal ratio is f/11. This will be the Optical Tube Assembly (OTA).
Software Bisque Paramount Model GT-1100 Robotic Telescope Mount	This telescope mount is boasted to be one of the finest and most accurate robotic mounts in the world.
Apogee Model AP-7 Charge-Coupled Device (CCD) Camera	This CCD camera has an 85% quantum efficiency over a wide range of visible wavelengths and has a back-illuminated design.
Datum Inc. Model bc620AT Global Positioning System (GPS) Receiver	The GPS receiver will provide a millisecond accuracy time base for satellite streak end-points.
Ash Manufacturing 10 Foot 6 Inch Diameter Observatory Dome	This dome will house the CASTOR A hardware. A Lanphier shutter system, which is a very well crafted glass shutter, will provide a weather-tight environment for the hardware within.
Pentium II NT Platform PC	This PC will contain the software for the telescope, CCD camera and GPS receiver for CASTOR A and B.

Table 1: The hardware used by CASTOR A.

TheSky Astronomical Software Level IV Version 5	This software will be the main astronomical software. The user will be able to see the simulated sky from any location on Earth for any desired time. Satellite two-line element sets (TLEs) can be loaded to present the desired satellite(s) superimposed onto this simulated sky.
CCDSoft CCD Camera Software	This software can accommodate a wide variety of CCD camera makes and models. It can also perform a wide variety of image analysis and processing functions.
T-Point Telescope Pointing Software	This software automatically corrects for any naturally occurring pointing errors such as those experienced due to an inaccurate polar alignment of the telescope mount.
Orchestrate Scripting Software	This software allows the user to write a script containing specific satellite targets and exposure times for the CCD camera in order to automate the satellite tracking process. It is based on a spreadsheet design.

Table 2: The software used by CASTOR A and CASTOR B
With the exception of T-Point, this software has been tested and used extensively with CASTOR B.

The Paramount GT-1100 Robotic Mount

Both the RME site in Maui and the SSRAL at RMC own this piece of telescope control hardware. The GT-1100 is a German Equatorial robotic telescope mount. The RMC performed tests on the GT-1100 remotely during the RAVEN tests of September 16-17, 1998. RMC was impressed with the GT-1100 maximum slewing speed and pointing accuracy. The GT-1100 had a maximum slewing speed of about 1.5 degrees per second for both Right Ascension (R.A.) and Declination (Dec.) axes and had a pointing accuracy that was within 4 arc-minutes of the actual desired coordinates over the entire sky. The RME Maui site had informed RMC that it had only a rough polar alignment on Polaris and a minimal T-Point model mapping along the Celestial Equator. The pointing errors experienced by the RME RAVEN apparatus during the nights of September 16-17, 1998 are illustrated in Figure 1. The pointing errors contained in Figure 1 are based on the absolute angular difference between the determined coordinates of the center of the image and the destination coordinates that the software had written into the FITS header of the image. The literal values of the pointing errors are not important, since the mount could have been calibrated with a slight error. With a field of view of 27.8 by 27.3 arc-minutes, it would have been easy to calibrate the system with a 2 arc-minute calibration error if calibrated by eye. What is important is the consistency of the errors experienced. The GT-1100 mount successfully navigated throughout the celestial hemisphere without experiencing a pointing error greater than 4.1 arc-minutes. The pointing errors of the GT-1100 can be decreased by performing a more accurate polar alignment of the mount (i.e. on the true North Celestial Pole instead of Polaris) and by using a more thoroughly constructed T-Point model. It may be necessary to employ different T-Point models for different portions of the sky (such as high versus low declinations). RMC will be doing in-depth investigations into the polar alignment and the T-Point modeling when CASTOR A is completed. It is expected that the pointing errors of the GT-1100 can be reduced to 2 arc-minutes or less over the entire celestial sphere using a more careful polar alignment and T-Point modeling.

Since the GT-1100 is a German Equatorial mount, slewing across the celestial meridian is an inconvenient exercise. When slewing across this meridian (whether east to west or west to east) the mount has to slew the telescope through the North Celestial Pole (NCP) in order to prevent the mount from slewing the scope or itself into the mount base or housing.

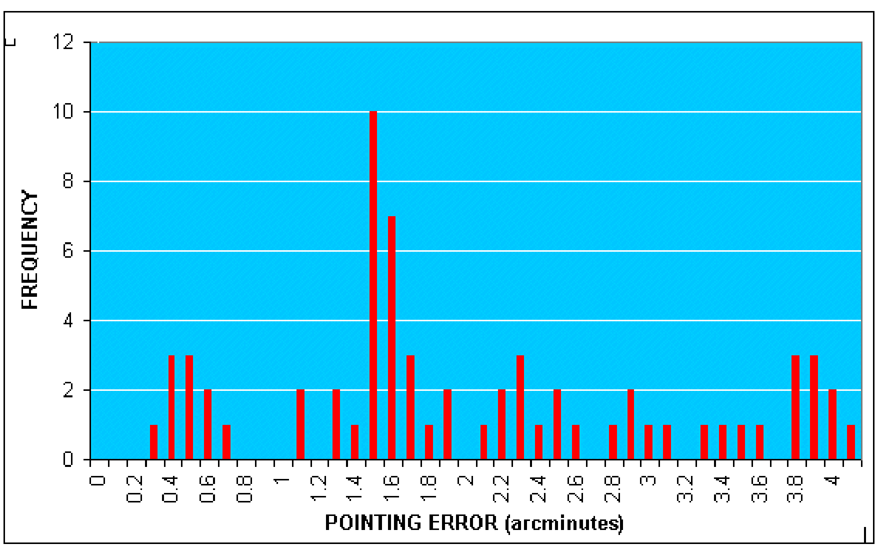

Figure 1: The GT-1100 robotic mount pointing errors experienced during the Molniya satellite tracking session of September 16-17, 1998.

Apogee AP-7 Charged Coupled Device (CCD) Camera

This CCD camera is the camera of choice for both the RME Maui site and RMC. During the nights of September 16-17, 1998, RMC tested this camera remotely and was impressed by its high sensitivity to fainter Molniya satellites (ranges 40,000 km or greater) and its relatively small download time (about 10 seconds using a light frame only). The camera employs a SITe SIA502AB scientific grade 1 chip in a 512 by 512 24 micron pixel array. The RME RAVEN site employed a f/3.75 16 inch telescope which when coupled with the Apogee CCD camera yielded a 27.8 by 27.3 arc-minute field of view (square). The limiting stellar magnitude of this camera when coupled with the RME's telescope was about 19th. When coupled with the RMC's Celestron 14 inch telescope (f/11), the field of view is expected to be about 10 by 13 arc-minutes with a limiting stellar magnitude of about 18th. The limiting satellite magnitude is expected to be about 15th to 16th. This estimate depends on the satellite's angular velocity at the time of tracking. The CASTOR A system is expected to be able to capture any accessible Molniya satellite at any range.

CASTOR B

Before RMC had begun construction on CASTOR A, discussions were made on what to do with its previous satellite tracking apparatus. It was decided to incorporate it into a secondary CASTOR apparatus to be known as CASTOR B. This secondary system would serve as the back-up satellite tracking apparatus to CASTOR A if this primary system met with some kind of serious malfunction. CASTOR B would also serve as the mobile CASTOR system. It could be packed up and moved to any facility to be used for demonstration purposes. CASTOR B was assembled during January, 1999 and was completed in May of the same year. It will be RMC's primary satellite tracking apparatus until CASTOR A is constructed and tested. The primary use for this system has been the tracking of Molniya satellites and surveys of those geostationary satellites accessible to RMC. The Molniya satellite tracking runs have been made to investigate the capabilities of the Software Bisque software using the modest hardware of CASTOR B. This is in preparation for the first CASTOR A operations and testing scheduled to begin sometime in September, 1999. The software to be used with CASTOR B is identical to that of CASTOR A (see Table 2). The hardware for CASTOR B is illustrated in Table 3.

Meade Quartz 10 Inch Aperture Schmidt-Cassegrain Reflecting Telescope	This telescope has been the primary satellite tracking telescope for the SSRAL at RMC since February, 1998.
Quadrant Engineering Coordinate III Telescope Controller	This is the CPU that controls the telescope's stepper motors and serves as the link between the astronomy software (TheSky) and the telescope.
Santa Barbara Instrument Group (SBIG) Model ST-6 CCD Camera	This was the primary camera that RMC used until the Apogee AP-7 replaced it. It can also be used with CASTOR A as an auto-guiding camera.

Table 3: The hardware used by CASTOR B

CASTOR B has been used primarily for familiarizing SSRAL with the Software Bisque software. Presently, all of the Software Bisque software has been used extensively with the exception of T-Point. The main reason for this is that the telescope used has a mechanical or electrical fault in the declination stepper motor assembly that creates a pointing error of 5 arc-minutes at unanticipated times. T-Point cannot compensate for such an error. After CASTOR A is constructed, this declination error will be investigated and corrected. CASTOR B will not be housed in an observatory dome as CASTOR A will be. It will be an open telescope system that can either be controlled from the SSRAL lab or from the roof where the telescope sits. It is also being designed as a mobile satellite tracking facility to be used in circumstances that CASTOR A cannot accommodate, such as a move to a darker site, etc.

CASTOR B is currently employing the Apogee CCD camera for the time being. The Meade telescope coupled with this camera delivers a field of view of 26 arc-minutes by 26 arc-minutes, which is similar to that of the RME RAVEN apparatus. This wide field of view decreases the effect of a natural or mechanical pointing error. In other words, a larger field of view is less sensitive to a specific pointing error.

Preliminary autonomous satellite tracking tests have been carried out with CASTOR B using the Orchestrate scripting software. As many as 10 Molniya satellites have been tracked in a single automatic satellite tracking run using this apparatus, with a 90 percent success rate. This refers to the percentage of images that had the intended satellite contained in it. CASTOR B cannot be automated for long periods of time because of the aforementioned declination pointing error. This pointing error accumulates over time, especially with slews of less than 5 arc-minutes. CASTOR A will be employing the GT-1100 robotic mount, so it will be able to automatically track accessible satellites for an entire night. CASTOR B can be trusted using the Meade's clock drive only i.e. no high-speed slews performed in either axis. Therefore, it is possible to take images of a specific R.A and Dec. and to take images of that specific part of the celestial sphere for the entire night. The active geostationary satellites do not move an appreciable amount with respect to an observer's reference point on the Earth during one observing session. As a result it is possible to scan much of the geostationary belt using the telescope's clock drive to carry the scope along the belt, taking CCD images as it goes along. The result is a survey of geostationary satellites that can be used for regular checks on the position of vital active geostationary satellites and keeping a surveillance on those geostationary satellites that are no longer active (such as Telstar 401). The only drawback is that the trigonometric parallax of one geostationary satellite near the observer's horizon is smaller than that of one on the meridian. This difference is large enough to cause the telescope to track out of the belt eventually. An advantage of this is that the survey can also detect those satellites that have been parked out of the main geostationary belt. Four such geostationary satellite surveys have been carried out by SSRAL on the days of June 11, June 22, and July 14, 1999. They successfully detected a total of 50 active geostationary satellites, including three of the French "Telecom" satellites (Telecom 2B, 2D and 2A) and the Egyptian satellite Nilesat which were only 4 degrees above RMC's south-eastern horizon.

CASTOR B was also tested to determine its single satellite tracking capability. The single satellite RMC chose was Molniya 1-75 (19807). The main reason for this test was to determine if the system could accurately track a single satellite, in both high and low angular velocity cases. Molniya 1-75 (19807) was tracked for a 2-hour time span with CASTOR B. The satellite's range had spanned from 20,000 km (having a high angular velocity) to 35,000 km (having a lower angular velocity) in ascension. A total of 160 images of the satellite had been taken for the 2-hour period with images of a 10-second exposure taken every 20 seconds (the telescope had to slew to the satellite's new position after an exposure had been taken). The results were very promising, and the Software Bisque software performed extremely well.

Image Analysis

As was stated earlier, the image analysis software that RMC currently uses is the Image Reduction and Analysis Facility (IRAF). At the present time RMC can only detect and mark the end-points of the satellite streaks within an image manually, i.e. by eye. RMC is currently investigating obtaining streak detection and analysis software from the U.S. Air Force that RME Maui is currently using called the Steak Detection Algorithm (SDA). SDA automatically detects a satellite streak in an image and determines the end-points. It then uses IRAF to automatically perform the astrometry on those end-points. During the Molniya satellite tracking sessions of September 16-17, 1998, RMC had the opportunity to investigate the capabilities of this software. The resulting end-point coordinates were then checked against those determined by the IRAF facility at RMC. If the absolute angle difference between the two sets of determined coordinates was less than 1 arc-minute, the streak detection was considered a success. Table 4 illustrates the results of the Molniya satellite tracking sessions of September 16-17, 1998. Note the low percentage of successes. This low success rate is mainly due to the fact that many of the images that were taken with the RME RAVEN apparatus had bright diffraction spikes contained within them. Diffraction spikes are caused by the interference of the light entering the telescope tube by the crossed beams supporting the secondary mirror of the telescope. SDA mistakenly labeled these diffraction spikes as satellite streaks, thereby giving false streak detection and therefore worthless end-point coordinates.

Satellite	Images Acquired	SDA Successes	SDA % Success
MOLNIYA 1-52 (13012)	21	3	14
MOLNIYA 1-69 (17078)	19	8	42

MOLNIYA 1-72 (18980)	18	4	22
MOLNIYA 3-19 (13432)	17	1	6
TOTAL	75	16	21

Table 4: Streak Detection Algorithm (SDA) successful satellite streak detection for the Molniya satellite tracking session of September 16-17, 1998.

The telescope that the RME RAVEN apparatus utilizes uses this cross beam design to hold the secondary mirror in place. As a result, if a bright enough star is within the field of view as the image of the satellite is taken, diffraction spikes will occur and will cause a failure in the automatic streak detection process. Figures 2 and 3 illustrate this effect.

Figure 2: MOLNIYA 3-19 (13432)
Bright star with diffraction spikes near top

Figure 3: MOLNIYA 1-69 (17078)
Fainter stars with no diffraction spikes

The streak detection for the Figure 2 image failed due to the bright star and its diffraction spikes. The Figure 3 image resulted in a successful streak and endpoint detection. Note how although the satellite in Figure 2 is noticeably brighter than that contained in Figure 3, the Figure 3 image was the one with the successful streak detection. The Figure 3 image is indicative of a typical image taken by a telescope of the Schmidt-Cassegrain design. A Schmidt-Cassegrain telescope does not utilize the crossed beams to hold the secondary mirror in place. Instead, a corrector plate (a piece of glass that fits over the front of the telescope tube) holds the secondary mirror, thereby eliminating this diffraction effect. The SDA success percentage should increase significantly if the telescope were of a Schmidt-Cassegrain design. The RMC employs this type of telescope exclusively (for CASTOR A and B) and will be investigating the effectiveness of the SDA using images taken with a Schmidt-Cassegrain type telescope.

A second problem encountered when using SDA was its inability to detect two or more satellite streaks contained within the same image. During the Molniya satellite tracking session of September 16-17, 1998, one such image contained two satellites. An image of Molniya 1-52 (13012) also contained an interloper satellite Cosmos 2241 (22954). Both satellites and their endpoints were easily seen within the image. In fact, SDA failed to detect either satellite, probably due to the fact that bright stars were also in the field causing diffraction spikes. Using a Schmidt-Cassegrain telescope would have resulted in the SDA detecting one of the two satellite streaks. Which streak it would have detected depends on which direction the SDA scans the image. In fact, if the SDA could detect multiple streaks, it may be possible to filter out those streaks caused by diffraction spikes, i.e. if a streak is located too near a known star position, delete the detection. This of course would delete some bona-fide satellite streak end points, but SDA would still have a better possibility of detecting the true satellite streaks whether they be single or multiple.

Orbit Determination and Analysis

The images collected by CASTOR A and B will be analyzed by automated streak detection software. That software will produce an output of coordinates corresponding to the satellite streak endpoints. This astrometry data will be used to determine the orbital elements of the satellite in question. The SSRAL at RMC currently uses the Satellite Tool Kit (STK) and its module Precision Orbit Determination Software (PODS) to determine a satellite's orbit given the observations. This orbit determination software was used to analyze the astrometry data from the Molniya satellite tracking session of September 16-17, 1998. The astrometry was performed by both SDA and the IRAF facility at RMC. Two orbits were generated by PODS corresponding to each streak detection method used. The comparison of the osculating orbital elements that were generated by PODS is illustrated in Table 5 below. Molniya 1-69 (17078) will be used for comparison here, since SDA was most successful with satellite detection with this satellite. The 1st Command and Control Squadron (1CACS) mean orbital elements are also included to provide a benchmark for orbital element comparison, except for the mean motion, since the epoch specified for 1CACS is different from that of RMC IRAF and RME SDA.

Orbital Element	RMC IRAF (Osc) Value	RME SDA (Osc) Value	1CACS (Mean) Value
EPOCH (yyddd.dddddddd)	98260.29166667	98260.291666667	98258.09204000
MEAN MOTION (revolutions/day)	2.00668	2.00671	2.00661
ECCENTRICITY	0.6652	0.6651	0.6655
INCLINATION (degrees)	64.17	64.17	64.16
ARGUMENT OF PERIGEE (degrees)	262.83	262.83	262.84
R.A. OF THE ASCENDING NODE (degrees)	185.67	185.68	185.77
MEAN ANOMALY (degrees)	169.74	169.72	023.14

Table 5: Determined PODS orbital elements for Molniya 1-69 (17078) for September 16-17, 1998 observations.

Referring to Table 4, a total of 19 images of Molniya 1-69 (17078) were taken during the September 16-17 satellite tracking session. This translates into 38 individual data points (end-points) using the RMC IRAF facility. There were 9 successful streak detections of the same satellite by the RME SDA that yielded 27 data points. The SDA determines three data points per streak corresponding to the two end points as well as the center of the streak. The compared orbital elements in Table 5 are fairly close, especially when comparing the RMC IRAF and RME SDA values. This confirms that although SDA fails to find most satellite streaks due to diffraction spikes, a successful detection can be trusted for the final orbit determination process. RMC noticed that while determining the orbit of this satellite, the residuals in R.A. and Dec. of the RME SDA orbit were generally negligible compared to those of the RMC IRAF orbit. This is most likely due to the difference between the manual endpoint detection used for the RMC IRAF and the automatic centroiding that SDA employs.

After an orbital determination has been completed, the final determined orbit is used to find the satellite at a later time. More observations are made of the satellite which in turn are analyzed, etc. The STK/PODS determined orbit of Molniya 1-69 (17078) was used to generate look-angles and ranges for epochs of the orbital elements themselves (260), nine days after that epoch (269) and 25 days after that epoch (285). Corresponding up-to-date look-angles were generated using the 1CACS mean element sets corresponding to those same epochs. The look-angles determined from the 1CACS mean element sets were compared to those of the RMC IRAF and RME SDA osculating element sets. The result of these comparisons is shown in Figures 4 and 5. The angle errors were calculated by determining the absolute angular difference between the PODS orbit look-angles and the 1CACS orbit look-angles.

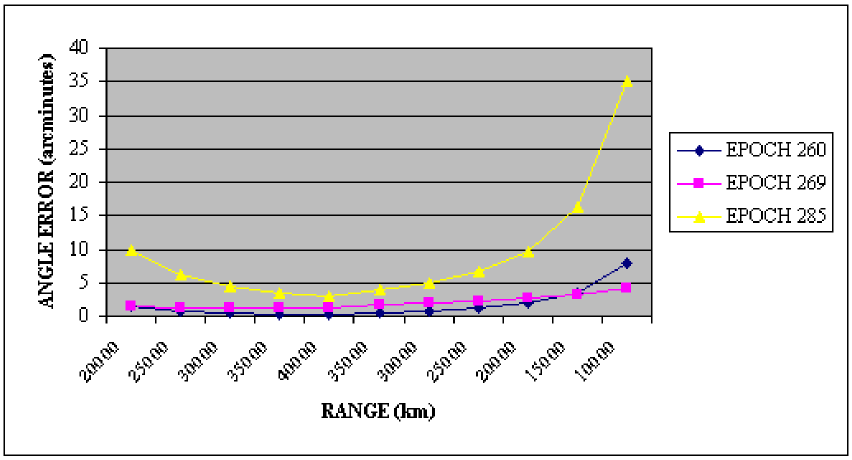

Figure 4: Ascending and descending ranges versus angle error for the PODS determined orbit of Molniya 1-69 (17078): RME SDA look-angles

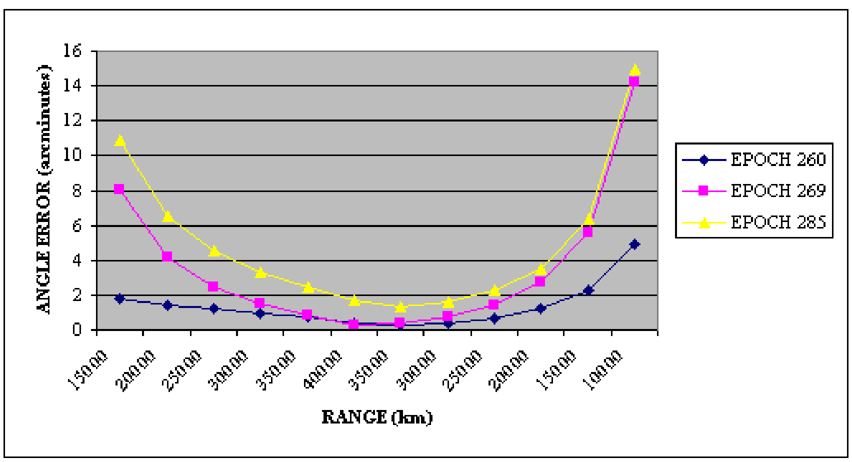

Figure 5: Ascending and descending ranges versus angle error for the PODS determined orbit of Molniya 1-69 (17078): RMC IRAF look-angles

By comparing Figures 4 and 5, one can see that the orbit determined from the RME SDA look-angles is slightly closer to that of the 1CACS mean orbit than that of the RMC IRAF look-angles. Using a 26 by 26 arc-minute field of view, it is theoretically possible to find the satellite again up to 25 days past the orbit epoch using only the original PODS determined osculating element set. Figures 4 and 5 also point out that the satellite needed to be over 20,000 km in range in most cases in order to find the satellite using the element sets generated by PODS. This was expected, since the data collected on Molniya 1-69 (17078) occurred while the satellite was at a range of around 30,000 km. RMC has had the same experiences with its own CASTOR prototype system. In January of 1999, the prototype CASTOR system was used to track the satellite Molniya 1-79 (20949). Approximately 100 images were obtained during that observing session. The resultant PODS generated osculating element set was good for approximately three weeks before the satellite could no longer be found within the predicted field of view. At this time, the prototype CASTOR system was using the SBIG ST-6 CCD camera, which when coupled with the Meade 10 inch telescope yielded a field of view of 11 by 14 arc-minutes. This is about ¼ of the area that the Apogee CCD camera yields using the same telescope.

Intentions for CASTOR A and B

For over two years, the SSRAL at RMC has been investigating the orbital behavior of the Molniya satellites in orbit. This is being done in order to determine a method of orbit determination that would entail using the fewest number of observations possible while maintaining the integrity of the determined orbit elements. The RME RAVEN testing was done in order to obtain an idea of how well the CASTOR A system would perform once constructed and tested.

CASTOR A will be used to continue this study of Molniya satellites. It is hoped that by determining accurate orbital elements for satellites with orbits of high eccentricity (such as Molniya communications satellites) a method of more accurate orbit determination can be achieved for any satellite being tracked optically. CASTOR A could be a Canadian presence in the Space Surveillance Network (SSN) for use as a permanent optical station. There are also plans to make CASTOR A a contributing site in the search for near-Earth asteroids. Geostationary surveys will continue to be carried out using CASTOR A as well as CASTOR B. In the CASTOR A case, small declination corrections can be made at specific times to correct for the trigonometric parallax difference as the telescope tracks through the geostationary belt. It is hoped that by using this system and a more efficient method of image analysis (such as SDA) the entire geostationary belt can be monitored weekly in order to provide a warning system for any potential “renegade” satellites, such as Telstar 401.

CASTOR A will be just one of a trio of planned CASTOR type facilities across Canada. One is planned for the western and the other for the eastern portion of the country. The resulting array of CASTOR facilities will ensure that satellite tracking will be possible somewhere in Canada (it is seldom that the country is completely cloud-covered). This trio of research facilities will also make it possible to conduct range finding via parallax measurements using two or all three facilities. It is hoped that CASTOR A will be gathering images on every clear night of the year, regardless of temperature. The Lanphier shutter system will allow heating and air conditioning of the telescope dome in order to keep the temperature of the hardware near room temperature.

A CASTOR-type system is also being built at the Defense Research Establishment Valcartier in the Province of Quebec to be used with a hyper-spectral camera to carry out space object identification (SOI) research via spectral signatures of satellites in orbit. The first test objects that it will be using are Molniya satellites. This camera may also be able to detect the doppler broadening of the spectral lines of a tumbling (inactive) Molniya payload in order to determine its rate of tumble. Using tumble periods of inactive Molniya satellites is another proposed method of satellite identification.

As was mentioned earlier, CASTOR B will be used primarily as the secondary system to CASTOR A. It will not be as versatile as CASTOR A, but it can be used for geostationary surveys and simple automatic Molniya satellite tracking. Once its shortcomings are corrected, it is hoped that CASTOR B will be nearly as efficient as CASTOR A will be. CASTOR B has an advantage over CASTOR A of being a mobile satellite tracking facility in the sense that it can be moved from one site to another for demonstrations or other purposes. CASTOR B can also be used as a training facility in order to familiarize new users of CASTOR with the hardware and software without taking satellite tracking time from CASTOR A.

Conclusions

The prototype of the CASTOR system was the first automatic optical satellite tracking facility in Canada. Every time it has run on automatic, it has performed admirably with few errors. It had successfully tracked Molniya 1-75 (19807) for a total of two hours without an error. Plans are underway for a 20 Molniya satellite automated tracking session for CASTOR B. Molniya 1-79 (20949) was manually tracked using the “point and click” mode of TheSky. IRAF and STK/PODS was used to obtain an osculating element set that was used for up to three weeks after that element set epoch. The camera used at that time was the SBIG ST-6 CCD, which when coupled with the Meade 10 inch reflecting telescope, only gave a field of view of 11 by 14 arc-minutes.

The RAVEN demos of September 16-17, 1998 yielded extremely useful information regarding the capabilities of a future CASTOR A facility. The GT-1100 robotic mount performed admirably, especially with its laudable pointing accuracy consistency despite its minimal polar alignment and minimal T-Point model. A better polar alignment (to the NCP instead of Polaris) with a better and more carefully mapped T-Point model is needed for improved pointing accuracy. This will be accomplished when CASTOR A is completed and tested in September of 1999. Its maximum slewing speed is excellent for such a mount. The only drawback is the case where the user needs to cross the celestial meridian. The Apogee AP-7 CCD camera was able to detect the accessible Molniya satellites of ranges 40,000 km and greater with ease. This was also the case for satellites with high phase angles. The Streak Detection Algorithm (SDA) did not perform well as far as streak detection is concerned, but when it did successfully detect a genuine satellite streak, its automatic end-point detection was better than that of a manual one performed with RMC IRAF. This was proven when the orbits generated by RMC IRAF and RME SDA were compared for angular errors against the mean orbit determined by 1CACS. Provided that the satellite tracking is performed when the satellite is greater than 20,000 km in range, it is possible to find the satellite within the predicted field of view (27.8 by 27.3 arc-minutes) using only the initial PODS generated element set. The same satellite can be theoretically found again for up to 25 days from the element set epoch. This may not be true for every Molniya satellite, but it was true for Molniya 1-69 (17078) during the RAVEN demo. It must also be stressed that the elements sets generated by PODS were osculating, and not mean. At present, PODS does not generate mean orbital elements only osculating ones. RMC is presently obtaining a module to STK/PODS that will convert the determined PODS state vectors into mean orbital elements to be converted into mean two-line element sets to be used with TheSky and STK. It is hoped that with CASTOR A, as well as a better streak detection software, RMC will be able to provide optical observations and element sets to both 1CACS and the U.S. Navy in order to provide further assistance in the realm of mid to high Earth orbit satellite tracking. CASTOR B can also be used for this purpose, but in a smaller capacity.

RMC has learned that RME Maui has since corrected the problems experienced with its SDA. It is using better transforms in order to avoid diffraction spike detection. SDA can now also detect more than one satellite streak within a single image. RMC hopes to obtain a copy of this SDA in order to test its capabilities with CASTOR A and CASTOR B images.

The CASTOR project should be capable of providing satellite tracking information to Canadian and American interests alike. It is hoped that the CASTOR system will make a uniquely Canadian presence in the Space Surveillance Network possible.