DEVELOPMENT OF AN IKONOS COVERAGE PREDICTION APPLICATION

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ABSTRACT

Satellite imagery of dynamic environments can only yield precise ground object positional information if temporally accurate ground truthing occurs. Thus, detailed knowledge of satellite overpass characteristics permits ground truthing activities to coincide with imagery acquisition, and also ensures that the deployment of such resources is done in an efficient and cost effective manner. Although the determination of these characteristics is of relative ease for the agencies which control the remote sensing platforms, the current reality of licensing is such that imagery providers are unwilling or unable to guarantee the date/time of data acquisition.

Using orbital models and using orbital data publicly available, an imagery customer could determine the possible dates of data acquisition of their area of interest. In fact, several software packages – ranging from open source to complete commercial solutions – specialize in such predictive scenarios. Unfortunately, a survey of these packages reveals shortcomings in filling the stated needs of the Marine Recreational Vessel Reconnaissance sub-project (part of a Geomatics for Informed Decisions (GEOIDE)) Network of Centres of Excellence research project). The main deficiency identified was the inability to present spatial data which permits ground truth mission planning in a relatively low cost package.

In order to meet the specific requirements of this project, the senior author has undertaken development of an IKONOS-2 coverage prediction application within the Microsoft Visual Basic® development environment using Environmental Systems Research Institute's MapObjects™ software and open source code. In this paper, the authors will outline the development process and implementation of the final product. After briefly describing the overall project requirements, the paper will focus on development challenges and preliminary results.

1. Introduction

As companies with operational high-resolution remote sensing platforms demonstrate financial viability, an increasing number of such systems will continue to be deployed. Thus, the current generation of IKONOS-2 and QuickBird class satellites are at the vanguard of the favourable impact on both the quantity and quality such competition entails. Not only will Space Imaging Inc. (SII) and EarthWatch Inc. continue to provide data to potential users, but with nominal ground resolutions of one metre for IKONOS-2 imagery [Space Imaging, 2002] and 61 centimetres for QuickBird imagery [DigitalGlobe, 2001], such resolutions will undoubtedly improve and become available in the future. The unprecedented availability of quality imagery has rendered possible new applications which simultaneously challenge existing technical limitations. One such project, the Marine Recreational Vessel Reconnaissance (MRV Recon) project, is a Geomatics for Informed Decisions (GEOIDE) sub-project that is intent on creating a working recreational vessel reconnaissance system using civilian technology in support of Search and Rescue marine activity assessment [Pegler, 2001; Pelot, 2001].

While the main challenge of MRV Recon is to implement a sub-pixel detection strategy to detect and identify recreational marine vessels, other constraints exist which impact the viability of such projects. In the past, publicly-funded Earth imaging satellites such as Landsat provided the data at little cost to end users, coupled with a wealth of corollary information [USGS, 2002]. Unfortunately, with a nominal 30 metre resolution, little positional information could be extracted from the imagery. Current and planned privately-held remote sensing platforms however, can readily provide the imagery necessary for such precise value-added positional applications. Thus, the advent of high-resolution imagery has made projects such as MRV Recon possible, but corresponding need by corporations to generate steady revenues has also made imagery acquisition an expensive proposition. In light of such increased expenditures, guarantees regarding data suitability are rightly demanded.

The passive nature of IKONOS-2 complicates this determination, for use of such systems to determine the position of highly dynamic objects requires close coordination between satellite data capture and ground truthing activities. Marine or terrestrial activity does not cease for satellite overpasses, and even a few minutes difference between data collection and ground truthing can lead to unrecoverable errors in positional accuracy. Indeed, an exact determination of the instant of image capture and complementary temporally precise ground truthing are critical to the success of such projects. Therefore, it is imperative that close coordination occurs between the ground truthing elements and data capture to ensure valid and useful imagery.

1.2 Essential Need for a Planning Tool

Indiscriminate purchasing of vast swaths of imagery is no longer a viable option, nor a desirable situation, as little accurate ground truthing could have occurred over such a large area. Therefore, an exact determination of imagery acquisition times of the area of interest is required to permit coordination of ground truthing activities. Space Imaging Inc. (SII) does not currently make any guarantees concerning dates or time of data capture, nor does it make available any tools for the prediction of satellite coverages. With that in mind the user must calculate or interpolate the data. These restrictions permit SII to guarantee delivery of clear imagery, as it does not release any imagery that has more than twenty percent cloud cover over the area of interest [SII, 2001]. However, it is suspected that these restrictions are also the result of SII's business model, as fees increase rapidly for the delivery of higher precision products whose generation can only be guaranteed with clear imagery.

SII does not provide any satellite positional parameters to users, as this would allow relatively low precision (and low cost) products to be easily converted to higher precision products. Despite the fact that such techniques have been developed to increase the precision of low cost IKONOS-2 imagery [Toutin and Cheng, 2000], in order for Space Imaging's business model to remain viable, it must maintain its current licensing policy. Therefore, there exists a clear conflict between the imagery provided by SII and the data required to make a project such as MRV Recon a success. The requirement to establish ground truth nearly simultaneously with satellite overpass, be it by direct observation or by the corollary use of airborne sensors, generates a need for a planning tool that can predict coverages in order to minimize the costs associated with ground truthing activities.

1. 1 Existing Planning Tools

Orbital mechanics is a mature science. Since launching and maintaining an artificial satellite is a costly process, satellite tracking and position prediction is of great interest to governments, militaries and even commercial entities. While such large institutions can justify the costs associated with the development and maintenance of satellite tracking tools, there also exists a large community of amateur radio users and visual observation seekers which relies on such information for their own use. Fortunately, well established channels exist for the dissemination of orbital information, and reference implementations of public domain orbital model algorithms have led to the creation of a large number of software packages. Such programs vary from entertaining (EarthView, [Walker, 2001]) to research grades (ImPredict, [Wu, Brewer and Parker, 2001]), and generally specialize in satellite tracking (WXtrack, [Taylor, 2001]), telescope/antenna control (Satellite Tracker, [Boshart, 1999]), and visual observation prediction (PocketSat, [Berry, 2001]).

During the period May/June 2001, 55 such applications were catalogued and tested for eventual integration with MRV Recon. Targeted at various platforms, and ranging from applications which generated reams of tabular data to those which were visually-pleasing, but ultimately uninformative [Rancourt, 2002]. Generally the applications catalogued either lacked the temporal resolution required by MRV Recon, or failed to present the data in a manner easily accessible and understood by the user. Furthermore, the main limitation proved to be a failure to accurately model the IKONOS-2 agile spacecraft, with in-track and cross-track pointing. Of catalogued applications, Analytical Graphics Incorporated's Satellite Tool Kit (STK) met all requirements but at a price commensurate with its quality [AGI, 2002], was not suitable for integration into MRV Recon.

1. 2 Objectives

In order to permit reasonably accurate planning, the critical components were adequate temporal resolution and accurate platform modelling. Over the course of several discussions/interviews with the primary user, it also became apparent that successful integration also rested with the ability of the planning tool to be easy to use and accomplish its task at minimal expense. As previously mentioned, within the constraints of identified user requirements, existing tools proved either inadequate or overly costly. To permit MRV Recon to coordinate its ground truthing activities with satellite overpasses, the design and implementation of an application focused on the calculation and display of IKONOS-2 coverages was initiated.

2. Development Process

In order to complement the ongoing MRV Recon project process, a software development methodology based on defining and codifying exact and precise user requirements at the start of the project could not realistically be adopted. Thus traditional waterfall and spiral software development methods were bypassed in favour of a Rapid Application Development (RAD) methodology [McConnell, 1996]. Such a methodology permitted the relatively project agnostic decisions to be made, such as those relating to orbital information sources/models and development platform, while still tailoring the tool specifically to MRV Recon by concurrent development with the project. Adoption of existing standards and use of third-party components ensured that the implementation would maintain its utility outside the confines of the MRV Recon project.

2.1 Orbital Information

All artificial satellites, or a significant subset of them, are continuously tracked by several different organizations, each with a vested interest in keeping accurate records concerning orbital characteristics and associated ground tracks, be it for military, communications, research or collision avoidance purposes. Large commercial satellite operators often maintain a tracking capability for platforms under their control, as do the various launching agencies and operating authorities, such as the European Space Agency's Space Operations Centre (ESOC) [ESOC, 2001]. Due to the expensive and extensive global resources required to maintain a continuous tracking network, most of the tracking of space borne objects is carried out by military organizations, such as the United States' Space Surveillance Network (SSN) [USSPACECOM, 2002]. One of the only agencies to make the data available publicly on the Internet in the form of a Space Catalogue is the North American Aerospace Defense Command (NORAD) [USSPACECOM, 2001], in the form of NORAD Two-Line Element (TLE) files [OIG, 2001], which provide mean Keplerian elements for tracked satellites (less United States military satellites).

While the SSN continuously tracks the satellites, NORAD only updates the elements as required. The TLEs provide each satellite's inclination – i, right ascension of the ascending node – Ω, eccentricity – e, argument of perigee – ω, mean anomaly – M_o at epoch t_o, and mean motion – n and generally have no more than five days between updates [Kelso, 2002]. This information is then used to derived the Keplerian elements traditionally used to define the orbit (semi-major axis and eccentric anomaly), and can thus be used to track satellites and predict their locations.

2.2 Orbital Model

Satellite position prediction is not only dependent on the availability of data, but also on the propagation algorithm chosen. With remote sensing applications, determining the exact position of the satellite at the time of measurement of an image element permits the corresponding ground location of the image element to be determined with commensurate accuracy [Dilley and Elsum, 1994]. Therefore, precisely determining satellite positions using mean Keplerian elements requires the use of one of the multitude of orbital models which exist, each with varying applications and precision levels. Those designed for use with the NORAD TLEs were outlined by Hoots and Roehrich [1980], in their seminal report entitled: "SpaceTrack Report No. 3: Models for Propagation of NORAD Element Sets". The Simplified General Perturbations (SGP), SGP Version 4 (SGP4) and SGP Version 8 (SGP8) orbital models differ mainly by the inclusion of a higher number of perturbation correction terms. All are specifically targeted to near-Earth satellites (which NORAD defines as those satellites having an orbital period < 255 minutes [Hoots and Roehrich, 1980]), while the Simplified Deep Space General Perturbations models (SDP4 and SDP8) are used for satellites in 'deep space', i.e. with orbital periods > 255 minutes. The mean Keplerian elements provided by NORAD are generated using the SGP4 model, and thus are intended to be used exclusively with the SGP4/SDP4 model. Fortunately, the majority of Earth imaging satellites have orbital periods of approximately 90 minutes, and thus SDP4 is the most appropriate manner in which to model the IKONOS-2 orbit. Whereas the use of SGP4 versus SGP8 seems to limit accuracy, SGP4 has demonstrated accuracy in benchmarking tests on the order of 0.1 degrees in both azimuth and elevation [Kelso, 1996], even with TLE data several days old. However, a note of caution is warranted, for Alfriend and Paik [2000] have shown that the SDP4 accuracy decreases rapidly when attempting long term predictions (> 30 days). In our case, NORAD TLEs and SGP4, combined with reasonable temporal search windows provide adequately accurate predictions.

2.3 Data Display

Having determined the source of orbital data, and the applicable model, a method of displaying the predicted positions was required. Tabular data, although simple to generate, does not provide the information in an easily understandable format. Options for displaying the generated data were therefore examined, and consisted of implementing either a static graphical representation, a display with minimal functionality, a somewhat interactive display using an Internet Map Server (IMS), or a fully configurable display using an application development framework as the core of the application. The first option, which is favoured by most catalogued applications, is relatively simple to implement. Unfortunately a global map on most computer monitors offers a small scale, with correspondingly little useable information presented. The second option, which essentially consists of developing/implementing a rudimentary Geographic Information System (GIS) was not seriously considered, for reasons which are obvious. The use of an IMS was an intriguing proposition, but as the primary user had not identified multiple-simultaneous usage as an essential requirement, the additional overhead required by such an implementation was deemed unnecessary. Therefore, implementing the application either as an extension to an existing GIS application, or using a some GIS-enabled component was examined closely.

GEOIDE Project ENV#60, whose GIS needs are met mainly by MapInfo's MapInfo™, and the University of New Brunswick's (UNB) Geodesy and Geomatics Engineering (GGE) Department's standardization on Environmental Systems Research Institute, Inc.'s (ESRI) products produced some question as to which framework offered the best solution. However, as the primary user of the application was intended to be MRV Recon, and deployment of the planning tool into the UNB GGE environment was anticipated, targeting the ESRI product line was deemed beneficial. However, at the time the design process was initiated, ESRI's ArcGIS™ 8 had not yet been deployed within the GGE Department. This ruled out the ArcObjects™ architecture, but left ArcView™ 3.2 or MapObjects™ as contenders. ArcView could provide high quality infrastructure within its development framework, but the closed nature of the Avenue programming language, and its planned obsolescence through eventual replacement by ArcObjects, meant ArcView was not the most appropriate development target. MapObjects, an ActiveX control marketed as a lightweight GIS core, offered a robust user-configurable interface ideally suited to this type of development work. As the MRV Recon satellite prediction application is by far not a GIS in the traditional sense, the map display requirements of the implementation could easily be met by MapObjects.

2.4 Development Platform

The NORAD TLE text files are essentially platform independent, as are the algorithms implementing the SGP/SDP family of orbital models. While a reference implementation exists in FORTRAN [Hoots and Roehrich, 1980], the algorithms can be implemented in any programming language, be it Pascal, C, C++, or Java. Since the release of the reference implementations into the public domain in 1988, many authors have re-coded them in several different languages, with much of the available source code considered mature (error-free). Within the context of this project, the use of such a stable code base would provide immediate benefits, as the pitfalls of re-implementation could be avoided. However, as the majority of open source development work is done on and for the Linux platform, the majority of such re-implementations exist in C, and target the *nix platforms. PREDICT, one of the few implementations that is dually implemented in Linux and DOS [Magliacane, 2002], is hosted by the Radio Amateur Satellite Corporation (AMSAT), and as a mature SGP4 implementation serves as the core of several tracking and prediction applications. Relatively platform agnostic, some of the C code is tied to particular versions or types of platforms, through the use of specific code constructs or calls.

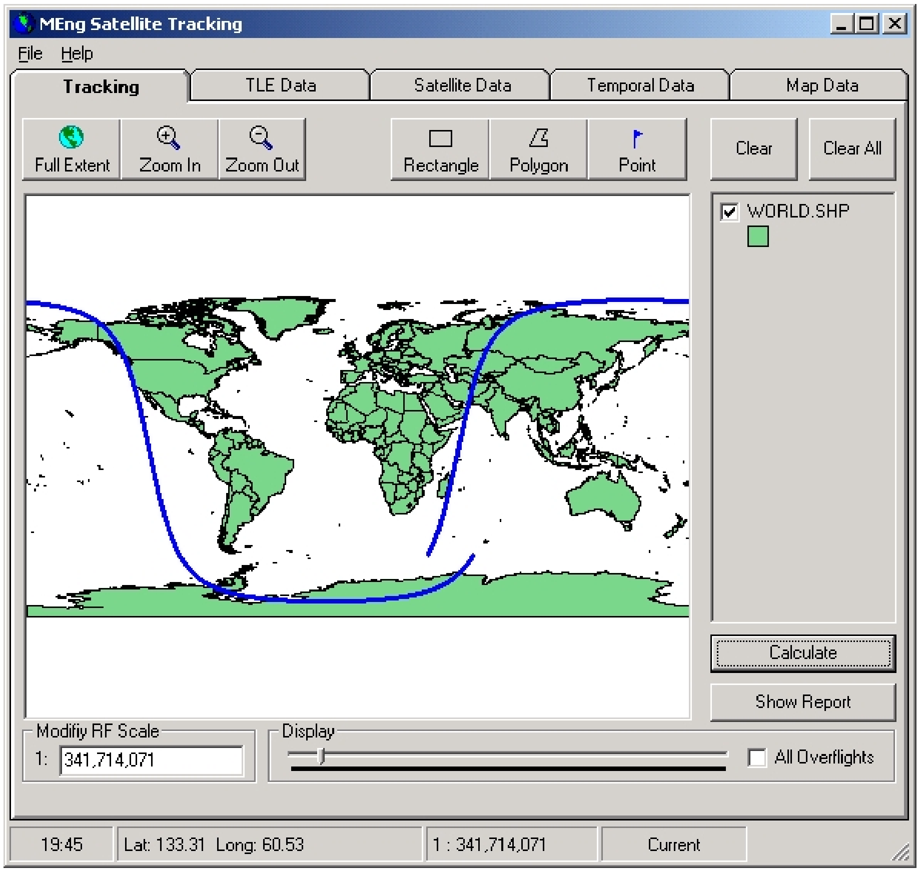
Whereas the development of the MRV Recon prediction application would have most likely proven simpler on the Linux platform, having determined that MapObjects would serve as the basis of the cartographic display imposed some constraints. As an ActiveX component, MapObjects requires a Microsoft® Windows® 32-bit development environment to support it. Fortunately, as the UNB GGE Department is standardized on the Windows operating system, this does not necessarily impose an undue burden. Several development environments are MapObjects-compatible, among them are Borland's C++ Builder® and Delphi 5™ and Microsoft's Visual Studio™ 6. While any of the MapObjects-supported languages could have been used, licensing at UNB is for Microsoft Visual Studio™ only, which left with a choice between Visual Basic and Visual C++.

The RAD implementation methodology chosen favours a Visual Basic approach, as rapid graphical user interface (GUI) development can be accomplished easily. However, Visual Basic is not well suited to heavy calculation loads (as required by SGP4), the PREDICT C code would be integrated into the application as a Dynamic-Link Library (DLL). It was hoped that the choice of Visual Basic could accelerate the development of a usable application, founded on the basis of MapObjects and PREDICT.

3. Preliminary Results

Application design refinement and early RAD iterations revealed some issues which required particular attention. One such issue involves the use of coordinate systems within orbital models. As the SGP4 model algorithms are designed to return satellite position in an Earth-Centered Inertial (ECI) coordinate system, calculation of sub-satellite points required transformation to an Earth-Centered Earth-Fixed (ECEF) system prior to being of use for display purposes. In our case, the World Geodetic System 84 (WGS84) ECEF was chosen as the baseline display coordinate system, mainly for its ease of use with Global Positioning System (GPS) data. While such simple mathematical transformations could be rapidly accomplished in the DLL, the display of disparate coordinate systems in MapObjects proved problematic, for despite the multitude of Geographic and Projection coordinate systems supported, implementation is somewhat counter-intuitive.

The application's main effort is therefore concentrated on sequentially calculating the satellite's position, its sub-satellite point, and finally the predicted coverage based on a buffer around the sub-satellite point. The resultant polygons are then projected onto the display area, which consists of any of the MapObjects-supported data sets. The user therefore controls the selection of satellites tracked (up to a maximum of three), their associated sensor capabilities and the period of time over which to track them. The results, such as those shown in Figure 1, can be displayed at any desired resolution, and with the option of displaying only the overpass with the highest elevation.



☑ WORLD.SHP 🟩

Modifiy RF Scale 1: 341,714,071

☐ All Overflights

19:45 | Lat: 133.31 Long: 60.53 | 1 : 341,714,071 | Current

Figure 1: User Interface

Specified Data	
TLE Date	26 February 2002
Satellite Tracked	IKONOS-2
Dates Tracked	1 March 2002 00:00 – 23:59
Map	World Shapefile
Display	Best elevation only

In order to accurately predict the position of any satellite in near-Earth orbit, large volumes of data must be generated and analysed. In the case of IKONOS-2, which has an orbital period of 98 minutes, determining the sub-satellite point once per minute for one day will only generate 3600 points, but with very low precision (one position calculation per 420 km traveled). Determining position once per second will generate 86 400 points, with a corresponding precision of approximately 7 km. With a claimed revisit rate of 3 days [SII, 2002], IKONOS-2 nadir are much more infrequent, and therefore, a typical temporal search window of two weeks requires 1 209 600 position calculations. Increasing resolution to measurements every ½ or ¼ second for higher precision would generate 2 to 4 times more data. Even though some algorithms offer a higher temporal resolution [Wu, Brewer and Palmer, 2001], such increases always come at a cost of increased processing time. Therefore, acceptable measurement resolution must be at the second-level, if only to maintain reasonable processing times.

The satellite's position is calculated by successive calls from the Visual Basic application to the C DLL. This algorithm performed as expected, exhibiting a roughly linear relationship between the processing time and the number of sub-satellite points to be calculated, which is shown in Figure 2. Although testing did not proceed past the calculation of 30 days worth of data on the test machine (Pentium III 800Mhz, 512MB RAM), it is presumed that the only limitation to permissible calculations is the amount of available memory.

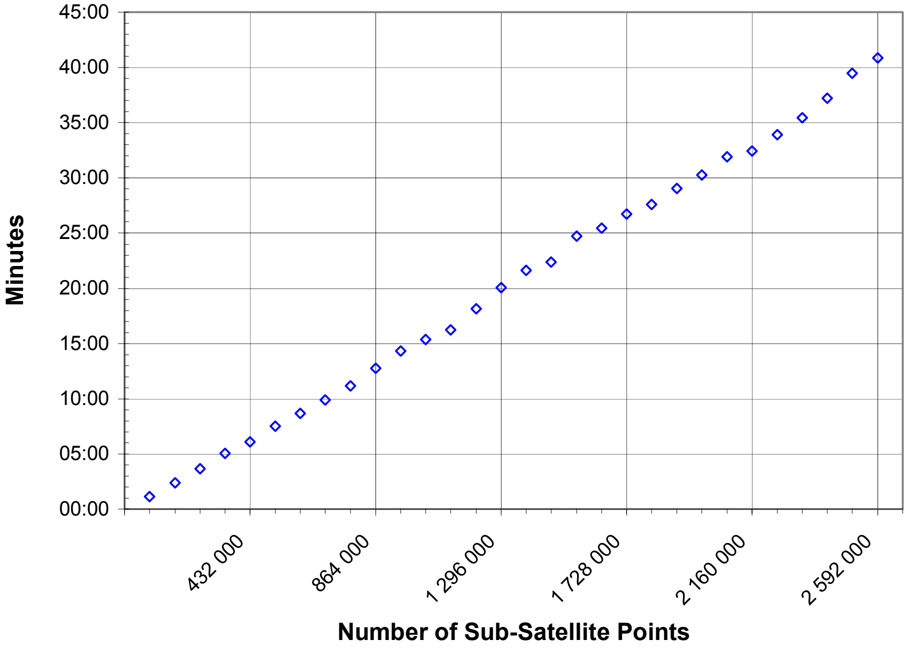


Figure 2: Processing Time Required to Calculate Sub-Satellite Points

Despite these encouraging results, the actual volume of calculations to be performed did not prove to be the largest stumbling block. MapObjects was selected as the main display interface due to its GIS capabilities, which includes spatial functions (point buffering), in the belief that such a capability could be useful in modelling remote sensing imagery swaths. However, further benchmarking revealed that the buffering operation in MapObjects, although similarly of linear order, was much slower than anticipated. As Figure 3 demonstrates, buffering of even a limited number of points (< one day's satellite sub-points) requires twice as much time as the calculations. What is not clearly shown in the Figure below is the severe 'thrashing' which occurred on the test system when more than 4 days worth of points (345 600) are buffered, which added several hours to the calculation completion times.

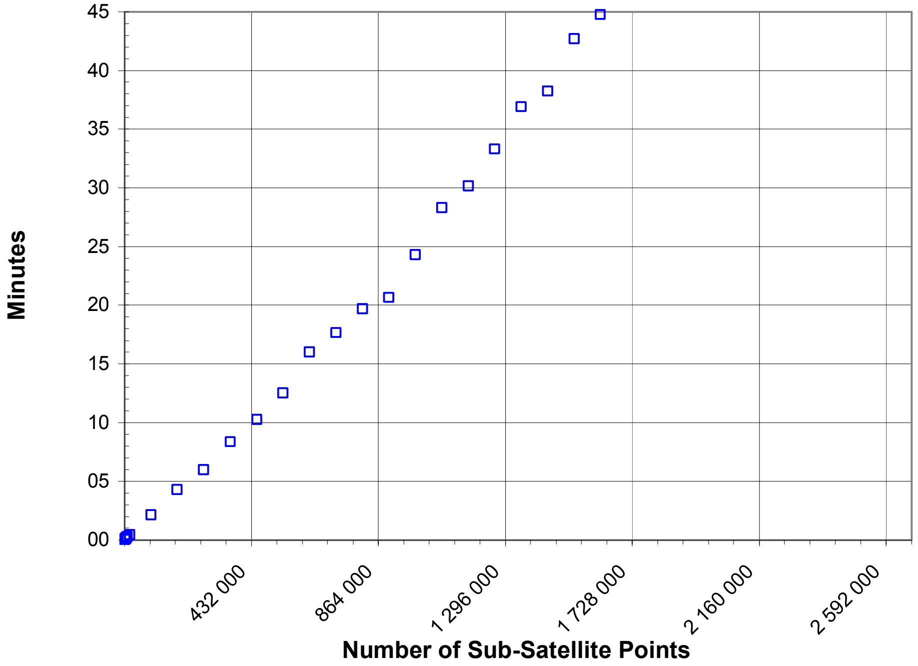


Figure 3: Processing Time Required to Calculate Swaths

While slow point buffering created an application bottleneck, it was assumed that the display of such buffers would be trivial, and thus such delays could be tolerated. However, rendering such a large volume of data in MapObjects proved to be the largest of all problems. Notwithstanding the upper bound on the number of objects which could be displayed on the Tracking Layer (a Visual Basic integer value, or 32 767 objects), which could safely be worked around, informational clarity became an issue. Displaying calculated sub-satellite point data at a temporal resolution of one second, with corresponding overlapping imagery swaths, reduced the display to an unintelligible dense tangle of overlapping polygons. Reducing the number of displayed elements, through the union of overlapping swaths became both a priority and a problem. As Figure 4 shows, despite a similar linear relationship as the previous calculations, simply creating the union of one days' worth of points took an inordinate amount of time. As this situation was clearly unacceptable, optimization of the polygon union loop was begun, and is ongoing.

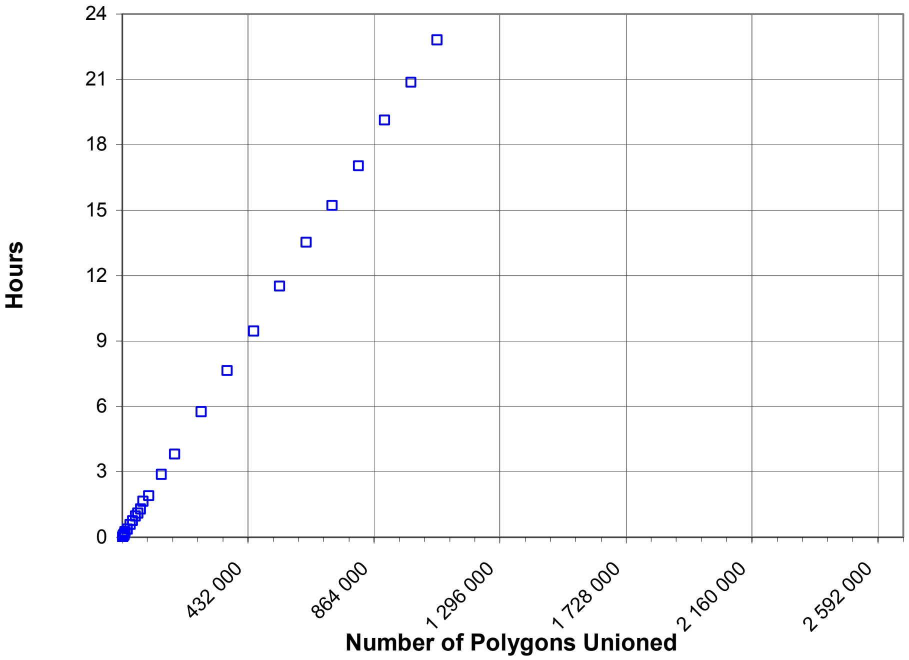


Figure 4: Processing Time Required to Union Swaths

3.1 Limitations

Understanding and exploiting the intricacies of Visual Basic, MapObjects, and the Windows Application Programming Interface, all within the 180 days scheduled for the RAD iterations proved that development projects based entirely on the efforts of a one-person design/development team are prone to frequent and serious setbacks. In order to translate PREDICT's C code into a functional DLL required a through understanding of Unix time representation and the open source DJPP and LCC compilers (required for their Unix-like libraries), despite the implied DOS nature of the implementation. Furthermore, a mixed language development environment rapidly devolved from being an asset into a severe limitation, as data transfer between the C DLL and the Visual Basic application required carefully-controlled, well-defined, and restrictive interfaces. Programming issues of this nature, coupled with the disproportionate amount of time required to debug the GUI have meant that the 1 824 lines of code written have still not reached 100% code-coverage test status.

3. 2 Conclusions

In attempting to implement an effective planning tool to assist the MRV Recon project to focus its ground truthing activities with regards to IKONOS-2 overpasses, the development of an application was undertaken. Through the use of RAD methodology, the serious technical limitations imposed by third party components were addressed in a reasonable time frame. Despite its slow processing speed, the major user requirements were met, and the tool is available for use within the MRV Recon project. Although currently limited in its appeal to a broader public, additional developmental work is being undertaken with the intention to release the application in the near future.

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