"Drift-Scan Imaging the Search For Near-Earth Asteroids"

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An exciting new area of CCD Astronomy just starting to be explored by amateur astronomers is that of "drift-scan imaging" or Time-Delay Integration (TDI). This a powerful imaging technique that is useful for automating the search for faint asteroids, comets, and supernova's. Scan mode imaging is been made possible by recent advances in CCD camera technology and computer data storage systems. This new scanned imaging mode is being used to replace more traditional ∕ time consuming methods that Astronomers have used for decades of mechanically "blinking" photographic plates of the night sky taken several days or weeks apart. These techniques are performed in an attempt to identify new types of stellar objects. (This is the technique used to discover Comet Schumaker-Levy 9 in 1993.)

TDI techniques are usually implemented by recording (from a CCD camera) a continuous image or "movie" of a particular part of the night sky, and then capturing the same "strip" of sky using the same process several days or weeks later. Scan mode imaging creates long continuous images of the sky located in the field-of-view of a particular telescope ∕ CCD camera system. With this technique two star field image sequences (taken on different nights) are can be compared for new or moving objects within in a background reference star field. This is usually done by fixing (or greatly slowing down) the CCD camera ∕ telescope optical system as compared with a normal equatorial drive system that would be used to take conventional CCD images. A variation of this technique is used by the SpaceWatch telescope at Kitt Peak Observatory to search for Near Earth approaching objects. TDI techniques are also used to perform sky survey's of portions of the sky for specialized astronomical research purposes.

The professional and amateur astronomy community's interest in Near-Earth approaching objects was peaked last December when asteroid XM1 passed 105,000 KM from the earth. (This is less than half of the distance from the earth to the moon). An image of it was captured by James Scotti using the Space Watch telescope at Kit Peak as well as by several amateur astronomers. An image of XM1 was shown in the March issue of Sky and Telescope taken by John Rogers of Camarillo, California using a 10" telescope and a ST-6 CCD camera. This demonstrates that amateurs with the right equipment and forethought can make a significant contribution in this particular area of Astronomy. Knowing where to look for such objects is not always easy and drift-scan techniques are now within the reach of the amateur astronomy community. With the right combination of equipment and a little imagination amateurs can now automate their equipment to search for such Near-Earth approaching objects.

SEE Drift1.GIF Image

The above image shows asteroid XM1 captured last December by the SpaceWatch telescope at Kitt Peak Observatory.

The technique employed to implement drift-scan imaging is quite simple and straightforward. With a telescope (and attached CCD camera) in a fixed position (or one that is moving at a rate that is greatly slowed from the sidereal-rate) a star moves across the CCD camera (while staying on the same column). The objective is to synchronize the readout rate of the CCD image detector (one line at a time) with the rate the star moves across that column. For example if the telescope has a 1 arc second per pixel scale, and the telescope is in fixed position, a star will move across the CCD camera at a rate of 15 line per second rate. (The sky rotates at a rate of 15 Arc seconds ⁄ per second at the Celestial Equator. The sky drift rate varies as the cosine of the declination angle. (Thus at or near the Celestial Pole there would be very little star movement). The readout of each line from the CCD camera must be precisely timed to coincide with the drift rate of a single star across one column of the CCD camera's image detector. One significant problem with this technique (at high declination angles) is that of "differential trailing" of an star's image across the CCD chip. This is caused by the fact that the scanning speed is proportional to the cosine of the declination angle. When the field of view is wide enough (this depends upon the declination angle and the distance from the Celestial Pole) the required scanning speed can be significantly different between the top and bottom of the CCD camera detector. Usually it is not possible to compensate for differential-trailing by adjusting the readout speed of each line of the CCD camera. If the speed at which one line is read out from the CCD camera is set for drift rate at the middle of the CCD image chip, the stars at the top and bottom of the chip will trail. This is caused by the fact that the stars at the bottom will move faster and the stars at the bottom will move slower. "Differential trailing" can yield this technique unusable at all but low declination angles or narrow fields of view. Another problem with this technique is the huge volume of data that is generated (many megabytes of data can be generated from one evenings drift-scan imaging run). The data (to be useful) must be also accurately "time-stamp" so that drift-scan image time sequences can be accurately time-correlated from one night to the next. This is normally considered to be a "Wide-Field" imaging technique and it is desirable to cover as large an area of the sky as possible.

To compensate for the "differential trailing" associated with drift-scan imaging, a technique used in the Sloan Digital Sky Survey (under development at the FERMI National Laboratory) is to scan the telescope and CCD camera along "great circles" of declination (i.e. any circle whose plane intersects the center of the celestial sphere, and is oriented along any declination line). With such a setup the motion of the CCD camera is at a "paragallactic angle" (the angle between the CCD camera and the north celestial pole). Using this technique the columns of the CCD chip are aligned in the North-South direction, and the telescope mount tracks in RA, and a constant rate motion is put into the Dec drive. This makes it possible to go anywhere in the sky (all circles of constant RA are "great circles") and then to arbitrarily set the scanning exposure time by the rate of telescope scan in Declination. The rate at which the telescope scan's in Declination determines the limiting magnitude that's possible to achieve with a drift-scan exposure. The use of this technique permits "drift-scan imaging" to be performed at any Declination angle in any part of the sky as long as the telescope and CCD camera are attached to an equatorial mount that is capable of scanning (at a fixed rate) in Declination as well as tracking at the usual sidereal rate in Right Ascension.

Glenn became interested in this technique last fall when he and John Chumack were involved with hunting down and imaging faint comets as a part of our

involvement with NASA's ULYSSES project (see Fall 94 issue of CCD Astronomy). He began to investigate this technique to see if it was possible to put together a drift-scan imaging set-up with "off-the-shelf" components that are readily available to most advanced amateurs. This project posed a real challenge because very little has been written about utilizing this technique in the amateur realm and we felt like that it was a "star from scratch" operation. With some research into the components that might make up such a system it turned out that we could put together an "Amateur Sky Survey System" out of components that we currently had to work with, along with some custom software that had to be developed to support this type of CCD camera scanning mode. We were interested in using "off-the-shelf" components as much as possible so that it would be within the realm any advanced amateur to duplicate. A project like this would be something that could be undertaken by a number of amateur's / club's so that the results could be compared from a number of different efforts at differing locations.

Early last fall he contacted Richard Schwartz (President Santa Barbara Instruments Group makers of the ST-6 CCD camera) and inquired as to whether SBIG had thought about implementing a "drift-scan" imaging mode in their ST-6 camera control software. (He and John had been using an ST-6 camera for the last year to combined with John's homemade 16" F/4.5 Newtonian telescope to take black and white as well as tri-color CCD images.) Richard said that they had several requests from Universities for such an ST-6 camera imaging mode, but stated that they did not presently have the personnel available to undertake such a development effort. Glenn volunteered to undertake such a software development with some technical assistance and advice from SBIG personnel. Richard Schwartz agreed to allow Matt Longmire (developer of the ST-6 camera control and image processing software) to answer questions and assist with the software development. Matt also agreed to provide a special version of the ST-6 control program which had ST-6 camera program debugging features. This served as the starting point for development of specialized P.C. based software to collect and store ST-6 drift-scan images. It was decided to make the initial version of the drift-scan imaging software DOS based to keep the program execution speed as fast as possible (without the unnecessary overhead) of a Windows based programming environment. Drift-scan imaging mode necessitates a fast down-load time between the CCD camera and the host computer. A special file format need to be defined to store drift-scan lines in a predetermined manner. It was decided that each drift-scan image file should be no larger that 1.44 Mbytes (so that it could be transferred to a standard 31/2" floppy disk). It was also decided to make each sequential file 1024 scan lines long (using the standard ST-6 image compression format), which would make each drift-scan image file approximately 425 Kbytes in length (including a 2048 byte header file similar to the current ST-6 image format).

The Borland C++ programming language was selected as the application development language. (This is the programming environment that Matt used to develop the ST-6 CCD camera control software.) Several software packages had to be selected to develop the drift-scan software for the ST-6 CCD camera. One is a high speed interrupt driven serial communications package, the other is a good super VGA graphics library that supports a number of different graphics boards in 800 X 600 (256 colors) super VGA mode. These two packages were found in the public domain after several nights of scanning the appropriate Internet news groups and FTP sites. These two packages formed the basis for the ST-6 drift scan software developed for this project. During the development of the ST-6 drift-scan software Matt provided invaluable technical assistance in the answering questions and offering ideas on how to best store the data, without his assistance this project would not have been possible. As the project progressed it became apparent that the data storage needed to be addressed "up front" in order to insure the long term success of the project.

The ST-6 CCD camera downloads images over a serial communications port to the host computer. Its maximum download rate is 115K baud. This means that it would download "full size" ST-6 image (242 X 374) resolution in about 16 seconds (providing that the host computer can keep up). Thus it takes about 0.066 seconds to download one complete line into the computer. The average throughput is about 15 lines / second which is more than adequate to support drift-scan imaging which most amateurs would be interested in doing. The ST-6 also supports automatic dark-frame subtraction as an option when it is operated in conventional image acquisition mode. It is also possible to subtract previously stored dark-frames on a "per-line" basis which turned out to be a very important feature for the development of our drift-scan imaging application. Another handy feature built into each P.C. is a very accurate clock timer module which can be used to generate system timing information for timing drift-scan download times as well as "time stamps" of the 1024 image lines. The built-in "clock" in most P.C.'s is accurate to 100 microseconds (0.0001 second) and provide all the accuracy needed to "time-tag" drift-scan image sequences.

It is possible to program the exposure time of the ST-6 very precisely (down to 0.01 second) which turned out to be a very useful feature for precisely programming drift-scan exposure times. A table of exposure times vs limiting stellar magnitudes is shown below (this was provided by Alan Holmes of Santa Barbara Instruments Group). It shows using an integration time of only one second would produce a limiting stellar magnitude of approximately 14.5 and an integration time of 10 second would produce a limiting stellar magnitude of approximately 16.5. Thus with short exposure times using the ST-6 it is possible to get very good limiting magnitudes with which to detect faint moving objects.

Initial tests of the drift-scan software with the ST-6 were using a one second integration time with the camera mounted on a stationary camera tripod attached to a Celestron 500mm F5.6 telephoto lens. The camera was pointed at low declination angles. In this part of the sky the circum-polar rotation rate is fairly small and it served as a good starting point to experiment with drift-scan techniques. Because the images area of the sky moved at a fairly slow rate the timing of the readout from the ST-6 was not as critical as it would be when the camera is pointed further toward the celestial equator (where the drift rate is 15 arcseconds / second). A deep read (#92 Kodak filter) was used in initial testing to block out as much light pollution as possible from the light polluted back yard where the initial testing was done.

It is desirable (from a faint object search standpoint) to make the limiting magnitude of the drift-scan image as faint as possible to attempted to locate new / moving objects. The following table of limiting magnitudes vs exposure times was generated by Alan Holems. It estimates the limiting magnitude's that are achievable with an 8 inch telescope and a F6.3 focal reducer for various exposure times ranging from .1 to 50 seconds in duration. Also included is a table of readout noise and associated parameters that were used to estimate the limiting detection magnitudes for several different types of SBIG CCD cameras.

Exposure Times vs Limiting Magnitudes for SBIG ST-6 Camera*

Integration Time: (Sec)	ST-6 Camera	Readout Noise: ST-6 (Electrons)

0.1	12.15	35.5
0.2	12.90	35.6
0.5	13.88	36.1
1.0	14.61	36.8
2.0	15.32	38.1
4.0	16.01	40.7
8.0	16.64	45.5
10.0	16.83	47.6
20.0	17.38	57.4
30.0	17.67	65.7
40.0	17.87	73.0
50.0	18.02	79.7
60.0	18.14	85.8

Note: The above able represents a estimates for a normal CCD image exposure and is included to give an idea of what could be excepted to be achieved with a typical short drift-scan exposure.

Currently a Losmandy G-11 mount that has been used with 6 inch and 8 inch Newtonian telescopes for conventional CCD imaging. The controller for the CG-11 mount allows driving the mount in Declination at various multiples of the sidereal tracking rate (0.3, 0.5, 1.0, 2.0 , 4.0, 8.0 and 16.0). Commanding the G-11 mount to move in Dec (while tracking in R.A.) would allow the telescope to be moved in a "great-circle" pattern about the North Celestial Pole. The optical system used to collect drift-scan images is a home made 6" F4 Newtonian with an attached ST-6 CCD camera. The field of view obtained with the 6" F/4 Newtonian is almost 1 degree across the diagonal of the CCD. Initially to try out this technique the lowest driving rates (0.3 and 0.5 times the normal sidereal rate were used) to allow the faintest possible limiting magnitude to be collected.

Also a recent computer upgrade was performed. A 720 megabyte hard-drive was added so that long strips of the sky could be imaged and saved away on the hard drive. A future upgrade planned to the present system is to store data onto 8mm tape (the same kind that is used in hard-disk backup systems) this should allow several gigabytes of data to be stored from an evenings imaging secession and saved for future comparison with a subsequent night of imaging. The low cost of 8mm tape ($8-$9.00 per tape) make it an affordable low-cost way to store / archive many evenings observing secessions. This seems like the ideal medium to store the huge volumes of data that will be collected when operating a "Amateur Sky Survey System" over a period of weeks and months.

Initial results that have been achieved with the system are shown as a part of this article. The system is still in the process of being "fine-tuned" for optimum performance. The combination of the software for the ST-6 to allow "drift-scan" readout from the ST-6 TI-241 CCD chip along with an accurate mount that can be driven in Declination (as well as R.A.) allows amateurs to put together a drift-scan imaging system that will rival performance of instruments used at professional observatories with "off-the-shelf" commercial components that are easily within the reach of any advanced amateur / astronomy club. This combination opens up a whole new area of serious research for

amateur astronomers. With a ten second exposure time and an 8 inch F6.3 telescope it is possible to reach a limiting stellar magnitude of approximately 16-17. This is well within the parameters necessary to allow amateurs to perform serious searches for Near-Earth approaching objects.

Presently efforts are on a program in Visual Basic to time align and compare two image sequences that were taken on different evenings and compare them for new ∕ moving objects. A future planned addition to the present computer data acquisition system is the development of an 8mm archival tape system that will allow images to be saved (and played back from low cost magnetic tape). The future in amateur astronomy looks more and more exciting all the time with more powerful tools that are now within the reach of amateur astronomers. This will allow amateurs to partake in "Sky Surveys" of parts of the sky that are professional astronomers do not have the time ∕ budget to undertake and hopefully advance the science of Astronomy with the new tools that they soon will have at their disposal!