SOLAR SYSTEM OCCULTATION PREDICTIONS USING AUTOMATED MICRODENSITOMETRY TECHNIQUES

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1. Introduction

The development of automatic, computer-controlled, electronic equipment, under the direction of an intelligent user, has significantly affected the output of scientific knowledge from astronomical research. This increased output is as much a result of the easing and/or elimination of heretofore tedious tasks as it is a result of vast increases in data acquisition rates via observing systems which make more efficient use of in-coming electromagnetic radiation. One such automated system (Shelus et al, 1977) has been implemented by the present authors to predict occultations of stars by Solar System objects. In the past these predictions have been a time consuming task which was made even more onerous since only a very few observable phenomena were found. Perhaps of even more importance is that, since candidate objects to be occulted typically were obtained from star catalogs, such a search was incomplete. Note that phenomena involving stars fainter than normal catalog limits are certainly relevant in the cases of Uranus, Neptune, Pluto, minor planets and the natural satellites of the major planets.

Hardware consists of a Boller and Chivens (Photometric Data Systems) 1010A microdensitometer, controlled by a Digital Equipment Company PDP-8/e computer with 20K words of core memory; peripherals are two 830K word capacity disks and a fast floating point processor with extended precision capability. A description of an early realization of the hardware can be found in Wray and Benedict (1974). Wide-field photographic plate material is a set of glass copies of the National Geographic Society-Palomar Observatory Sky Survey (Minkowski and Abell, 1963). Reference stars are obtained from the Smithsonian Astrophysical Observatory Star Catalog (Smithsonian Institution, 1966). Planetary ephemerides are obtained from the various Developmental Ephemerides exported regularly by the Jet Propulsion Laboratory (Devine, 1967; O'Handley et al., 1969; Standish et al., 1976). Note that the system is completely independent of the source of plate material, reference star positions and/or ephemerides. The present specific

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choices are a result of ready availability.

2. ESTABLISHMENT OF THE BASIC ASTROMETRIC REFERENCE SYSTEM

To outline the occultation prediction process a typical session will be described. The first step consists of determining how many and which reference stars lie on a selected wide-field plate; these objects will form the basic reference frame to be impressed upon the plate. One provides the right ascension and declination of the region of interest and the Palomar Sky Survey plate or plates on which the area of interest resides are identified and a machine-readable list of SAO stars contained in the selected region is produced. This list contains right ascensions and declinations as well as rectangular (x,y) coordinates of each object with respect to the plate center. These data establish a disk file of standard stars. A plot of the selected area is also generated. Typically, 50-150 SAO stars are provided over an approximately 25 cm square.

By inspection of the standard star list or of the plot a pair of stars widely spaced in x and at nearly the same y are identified. The plate is aligned on the microdensitometer platen using these two stars as a baseline; alignment is not critical to less than 50μ. The PDS is driven by the PDP-8/e to the position of every nth (n is nominally 5 or 10) reference star on the disk file of standard stars. A single hand measurement is made at each location and an on-line step-wise regression program provides preliminary standard astrometric plate constants.

Using these preliminary plate constants, the PDS is then driven to every reference star, usually to within the image of the star on the plate. This provides easy identification in crowded fields and, for all stars, relieves the operator from any identification worries. Depending on the operator's assessment of any star image he may (a) skip measuring it altogether (image too large or excessively comated, image too close to another), (b) hand position n times and average (image too large for automatic raster scanning), or (c) allow the PDS to scan the image and obtain a "first-moment" position (this is essentially a simple center of gravity technique, where the image density is substituted for mass). When all stars have been measured the regression program provides final plate constants. The solutions and (o-c) residuals are presented for operator review. The R.M.S. error of a single SAO position for such a reduction is usually on the order of 0.3-0.6 arcsec in both right ascension and declination. Seven plate constants, including the so-called Schmidt term, are used for the Sky Survey astrometric reductions. The time required to align the plate, perform the measures and obtain final plate constants is of the order of two hours.

Once a final reference frame has been obtained and the operator has deemed it to be a satisfactory one, the system prompts the user

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for additional information. The two possible tasks in our current programs are the prediction of stellar occultations by Solar System objects and the establishment of secondary reference star systems for the astrometric reduction of small field plates. The former task will be dealt with here; the latter has been discussed elsewhere (Benedict et al., 1978).

3. THE STELLAR OCCULTATION PREDICTION PROBLEM

Having impressed a standard reference frame upon a wide-field photographic plate as described in the previous section the PDP-8/e drives the microdensitometer across the plate in a path which mimics the Solar System object of interest and inventories the area of that path for occultation candidates. For this task a polynomial representation of the astrometric right ascension and declination is continually evaluated. Going from (α,δ) to standard coordinates (ξ,η) by standard techniques (Smart, 1960) and then to measured (x,y) through the plate constants formerly derived provides the information needed to drive the microdensitometer. A preliminary pass generates 40-micron x-positions and 500-micron y-positions for every candidate object with a transmission less than some user input limit. This limit for stars fainter than about 10th magnitude is proportional to magnitude. A second pass, made only at the positions obtained from the first pass, produces 40-micron positions of each candidate object in two coordinates. The microdensitometer then is driven to each candidate object for final measurement. These measurements are made in a manner identical to that used for the original measurements of reference stars outlined in the previous section.

The output from this last step is a list of candidate objects which are typically within 35 arcsec (when using Sky Survey plates for scanning purposes) of the Solar System object and an approximate time of closest approach. These candidates are then scanned to produce instrumental magnitudes. When two color plates are available, the scanning of the second plate will provide, in addition to improved coordinates of each candidate object, an instrumental color. If faint $(V>10)$ standards can be found on a plate, these instrumental magnitudes can be transformed to give V and B-V with an accuracy of about ±0.1 magnitude. The list of candidate objects is then processed to give a time history of separation for each event.

4. RESULTS

Since, in practice, faint local standards are not generally available, at the present time our final results consist of astrometric positions of each candidate star, time of closest approach, and a photographic finding chart centered on the candidate star. We feel that for fainter stars such a finding chart is much preferable to a simple position and an uncertain magnitude and color estimate. The

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production of finding charts involves the use of a system designed, built and implemented by our Radio Astronomy group (Hemenway et al., 1977). As an example of the results obtainable with this system we present four objects to be occulted by Saturn and several of its satellites in the 1979-1980 time frame. Geocentric positions, times of closest approach and minimum center-to-center separations are presented in Table I; the associated finding charts are given in Plate I. A complete list for the interval 1979-1985 will appear elsewhere.

5. DRIFT

All measuring engines suffer from a lack of positional stability. Extensive testing of our microdensitometer has shown the instrument to suffer from a drift which is monotonic and reasonably linear in nature, the problem being more severe on the Y-axis than on the X-axis. Two types of drift checks are used, the first being an edge position algorithm (Wray and Benedict, 1974) and the other uses the same first moment digital centering techniques as found in the system described above. Exhaustive mechanical and electronic diagnosis has reduced the rate of drift to about 2 microns per hour in Y and less than one quarter of a micron per hour in X. We have adopted the following procedure to allow results of the stated accuracy and precision to be obtained routinely. Just after the preliminary reference frame has been measured, the operator selects a magnitude 14 or 15 star near the center of the plate. The system measures the position of this star ten times and derives an average to be used as a zero point. As the occultation prediction procedure is carried out, this zero point star is monitored at intervals of about twenty minutes. After each check the position is compared with the zero point and the read out registers of the microdensitometer updated (if necessary) to bring the measured position back into coincidence with the zero point. The zero point correction is seldom more than one micron in either x or y. This dynamic correction process has proven to be quite effective even for lengthy runs involving meal breaks or other computer/operator malfunctions.

6. REMARKS

The high speed with which this task can be performed is due mainly to the following factors. Star images on the Palomar Sky Survey plates are not Gaussian; they tend to be flat-topped or even doughnut shaped. This justifies the use of faster, relatively unsophisticated first moment methods to derive positional information. Next, the operator is not required to do any bookkeeping or spend an inordinate amount of time in star identification and/or plate marking; the PDP-8/e does this for him. Set up time is kept to a minimum since one has the ability to generate preliminary plate constants to take care of mis-alignment. Finally, the fast floating point processor previously

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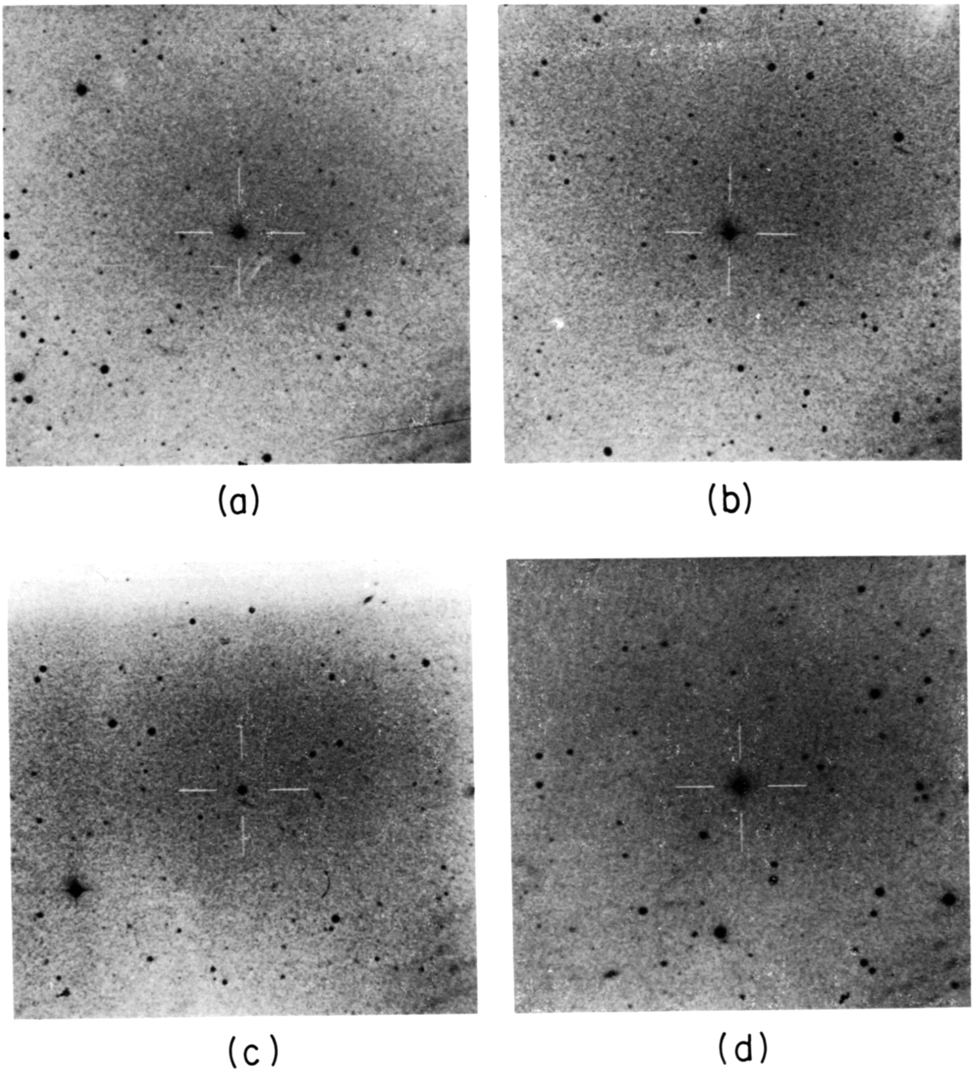

Figure 1. Selected occultation candidate finding charts (each reticle mark is 50" long).

Table 1. Geocentric phenomena of selected Saturn events.

	$\alpha_{1950.0}$	$\delta_{1950.0}$	Universal time	Δ	P.A.
a.	$11^{h}01^{m}29^{s}.61$	$+8^{\circ}17'15''.5$	1979 Jan $08^{d}09^{h}50^{m}$	$5''.0$	$326^{\circ}.9$
b.	$10^{h}59^{m}18^{s}.60$	$+8^{\circ}34'59''.0$	1979 Jan $23^{d}22^{h}28^{m}$	$9''.4$	$153^{\circ}.6$
c.	$10^{h}59^{m}03^{s}.02$	$+8^{\circ}37'08''.9$	1979 Jan $25^{d}07^{h}56^{m}$	$22''.6$	$153^{\circ}.9$
	(possible Tethys event)		1979 Jan $25^{d}12^{h}44^{m}$	$0''.9$	$321^{\circ}.7$
d.	$10^{h}47^{m}18^{s}.98$	$+9^{\circ}41'18''.6$	1979 Jul $08^{d}10^{h}50^{m}$	$6''.7$	$157^{\circ}.1$

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mentioned is indispensable; its extended precision facility allows plate solutions identical to those obtained with a CDC 6400/6600 system to be generated in about 30 seconds.

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8. REFERENCES

Benedict, G. F., Shelus, P. J., and Mulholland, J. D.: 1978, "Astron. J." (accepted for publication, August).
Devine, C. J.: 1967, "JPL Tech. Rept. 32-1181."
Hemenway, P. D., Torrence, G. W. and Wolf, C. S.: 1977, "Bull. American Astron. Soc." 9, 598 (abstract).
Minkowski, R. L. and Abell, G. O.: 1963, "Stars and Stellar Systems (Vol. III)", ed. by K. Aa. Strand, 481-487.
O'Handley, D. A., Holdridge, D. B., Melbourne, W. G., and Mulholland, J. D.: 1969, "JPL Tech. Rpt. 32-1465."
Shelus, P. J., Benedict, G. F., and Evans, D. S.: 1977. "Bull. American Astron. Soc." 9, 439 (abstract).
Smart, W. M.: 1960, "Text-Book on Spherical Astronomy," Cambridge University Press.
Smithsonian Institution (1966) Positions and Proper Motions of 258,997 Stars for the Epoch and Equinox of 1950.0 (Vol. I-IV), U.S. Gov't Ptg. Office, Wash., D.C.
Standish, E. M. Jr., Keesey, M. S. W., Newhall, X. X.: 1976, "JPL Tech. Rept. 32-1603."
Wray, J. D. and Benedict, G. F.: 1974, "SPIE," 44, 137.

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