UNBSAT: A Digital Recording System for the CMA-722B Transit Doppler Receiver

SEE HEAN QUEK
RICHARD B. LANGLEY
Department of Surveying Engineering
University of New Brunswick
Fredericton, New Brunswick

The United States Department of Defense (DoD) Navy Navigation Satellite System (NNSS), commonly known as Transit, has been used extensively since 1967 for civilian geodetic surveying and navigation. With the advent of the Global Positioning System (GPS), the DoD will have no further need for Transit and plans to shut down the system in 1994. GPS receivers are still expensive and Transit Doppler receivers purchased today, according to the planned schedule, would have a limited life span of less than ten years. In this paper we present an economical method of acquiring the capabilities of modern Transit receivers by upgrading a popular old receiver. We have interfaced a standard Apple II microcomputer to a Canadian Marconi CMA-722B. The Apple microcomputer provides the added data processing and storage capability found in more modern Doppler receivers and obviates the need for "user unfriendly" paper tape or expensive data cassettes. Dubbed "UNBSAT", our system allows established survey organizations to expand their Transit positioning capabilities by reactivating their moth-balled CMA-722B receivers, allows developing nations to carry out Doppler surveys economically, and provides an educational tool for training surveying engineers in satellite positioning techniques. The hardware and software configuration of this system is described and an outline of its capabilities is given. The direction of current and future development of the system is also discussed.

Le système de satellites de la Navy Navigation (NNSS) du Département de la Défense (DoD) des États-Unis, mieux connu sous l'appellation du système Transit, a été largement utilisé depuis 1967 pour des fins de levés terrestres et comme moyen de navigation. Avec l'apparition du système de positionnement global (GPS), le DoD n'entrera pas plus avant dans le système Transit et propose de la fermer en 1994. Les récepteurs GPS sont présentement très coûteux et les récepteurs Doppler du système transit qui appartiennent à des firmes d'arpentage auront tout au plus une limite pratique de vie d'environ 10 dans selon le programme Transit projeté. Dans cet article, on présente un moyen économique de modifier un bon vieux récepteur en lui donnant les mêmes capacités que les récepteurs plus modernes. Par exemple, nous avons interfacé un micro-ordinateur Apple II de type standard à un récepteur manuel Canadian Marconi CMA-722B. Le micro-ordinateur Apple fournit la posibilité de traiter et emmagasiner les données captées et de rendre ainsi l'appareil aussi efficace que les récepteurs automatiques, ce qui évite l'utilisation d'un lecteur à bande perforée « plutôt encombrant » ou d'un lecteur à cassette lequel demeure très dispendieux. Mieux connu sous le sobriquet de « UNBSAT », notre système permet aux organisations œuvrant dans le domaine de l'arpentage terrestre d'étendre leurs possibilités de positionnement Doppler en réactivant leurs bons vieux récepteurs CMA-722B;

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permet aux nations en plein développement d'effectuer des levés satellites Doppler de façon économnique; et fournit un outil éducatif aux ingénieurs en arpentage pour leur formation sur les techniques de positionnement par satellites. La configuration du matériel et du logiciel de ce système est décrite et l'on donne un aperçu de ses possibilités. On termine par une discussion sur l'évolution présente et future du développement de ce système.

Introduction

The Transit system [*Stansell* 1978] has been in commercial use since its release to the public in 1967. A number of companies have manufactured Doppler receivers for the system ranging from the low-accuracy single-frequency navigation receivers to the more precise two-frequency geodetic receivers. One of the receivers in the latter category is the CMA-722B NNS Receiver/Signal Processor [*Canadian Marconi Company* 1975].

The Canadian Marconi Company first produced the CMA-722 series of Transit receivers in 1971. The geodetic version, the CMA-722B, was introduced in 1973 and continues to produce useful data for many users worldwide. It was designed simply as a high precision receiver and signal processor for the Transit signals with no built-in data processing capability. The receiver may be used "offline" with postprocessing of the collected data, or "online" with direct connection to a computer for near real-time position determination.

In the offline configuration, the incoming signals are decoded into bit streams and these are output by the receiver to an external recording device. The receiver provides 9-digit Doppler data (i.e., to an accuracy of 0.01 cycle of the 400 MHz Doppler frequency) for a paper tape punch, a data cassette drive, or a teletype. For the online configuration the receiver is interfaced directly to a minicomputer, such as the Hewlett-Packard HP 1000, to provide the necessary data processing capability. The CMA-722B computer interface, however, only provides 7-digit Dopplers (i.e., to an accuracy of 1 cycle). This accuracy is insufficient for most geodetic applications. Hence for geodetic work the cassette drive (and earlier the paper tape punch) were used extensively to record the more precise 9-digit Dopplers for later processing.

The data cassette records raw, unmajority-voted and unverified data. Consequently longer field observation sessions must be scheduled to ensure that a sufficient number of passes remain after the initial data filtering to delete passes with an insufficient number of Doppler counts or bad broadcast satellite messages. The more modern receivers, for example, the Canadian Marconi CMA-761 or the Magnavox MX 1502, have built-in microprocessors to do the majority-voting of raw Doppler data and to perform data quality checks in the field. Furthermore, data cassettes are expensive and their limited capacity restricts unattended operation of the receiver.

Many CMA-722B receivers are still in use today, providing output on data cassettes or paper tape. More are gathering dust, having been abandoned in favor of modern receivers. In this paper we describe a system to breathe new life into these receivers. By interfacing a standard Apple II microcomputer to the receiver, we have been able to create a system with most of the features of modern Transit receivers and with the flexibility for customization of the controlling software as needs dictate. The complete system, exclusive of the CMA-722B, can be assembled for under $3000.00 with most of this cost for the purchase of the Apple II microcomputer. This is a small fraction of the cost of a modern Transit or GPS receiver. No modifications to the receiver itself are necessary. The system has been dubbed "UNBSAT".

Historical Development

The initial conceptual design and hardware experimentation for the UNBSAT system were carried out at the University of New Brunswick (UNB) in 1982 [*Lord* 1982]. Several microcomputers were evaluated for their ability to act as a data processor and auxiliary storage device for the Doppler data, with consideration given to their hardware reliability and expansibility. The Apple II+ microcomputer was the logical choice at that time.

Software for the Apple II+ was written to validate and test the hardware and overall system design. In 1983, the system software was further improved to provide real-time preprocessing of data output from the receiver [*Quek* 1983]. This preprocessing included the majority-voting of the broadcast satellite message, accumulation of dual frequency 30-second Doppler counts, and validation of the satellite message. By the summer of 1984, after switching from the receiver's computer parallel interface output to the serial (teletype) interface output, we had the capability of acquiring Doppler data from the receiver at a precision of 0.01 of a Doppler count [*Vu* 1984]. Either the Apple II+ or the newer IIe microcomputer may be used with the present system.

At the time of writing, the present version of the UNBSAT sysem has been in operation at UNB for more than a year. Two CMA-722B receivers have been outfitted with microcomputers and used by students for point positioning as well as differential positioning using translocation.

UNBSAT System

The UNBSAT system is made up of the following hardware components:

- Canadian Marconi CMA-722B NNS receiver/signal processor
- Canadian Marconi portable NNS antenna
- Apple II+ or IIe with the following accessories:
  - Disk controller and two disk drives;
  - 16K language card (needed for Apple II+ only);
  - California Computer Systems Model 7424 calendar/clock module; and
  - Apple Super Serial Interface Card.
- Video monitor
- Teletype to RS-232C signal converter.

A conceptual diagram of the hardware is shown in Figure 1. All of the computer-related items are commercially available, with the exception of the teletype to RS-232C signal level converter. This is a simple integrated circuit device to convert the teletype output signals of the CMA-722B to RS-232C voltage levels for input to the Apple via the Super Serial Interface Card. Although it is possible to incorporate this device inside the receiver, we purposely chose not to carry out wiring modifications in the receiver itself in keeping with our "low-tech" approach. Processed data is recorded at the end of

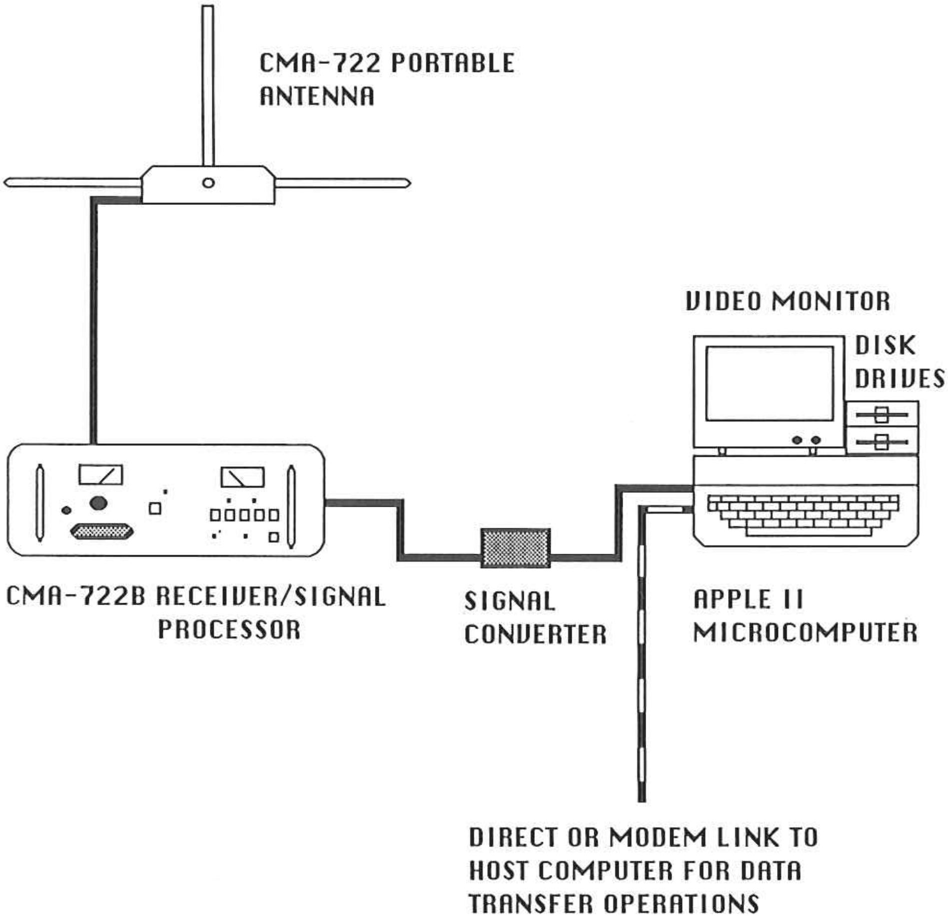

Figure 1. UNBSAT hardware components.

each satellite pass on a diskette. The calendar/clock module is used to time stamp the data files.

Our software has been configured to operate with the specific interface cards listed above. Cards from alternative suppliers may be substituted requiring, at most, minor modifications to the software.

Most of the operating software is written in Pascal under the Apple Pascal Operating System [*Apple Computer* 1980] which allows for structured and modular programming. Device interface subroutines are written in assembly language to increase flexibility and execution speed.

The software preprocesses and records the Doppler data coming from the receiver. Among its capabilities are real-time majority-voting of the broadcast satellite message; real-time accumulation of 30-second Doppler counts; real-time verification of satellite being tracked; post-pass verification of broadcast satellite message; storage of the identity of the majority-voted message and dual frequency 30-second Dopplers only or with raw

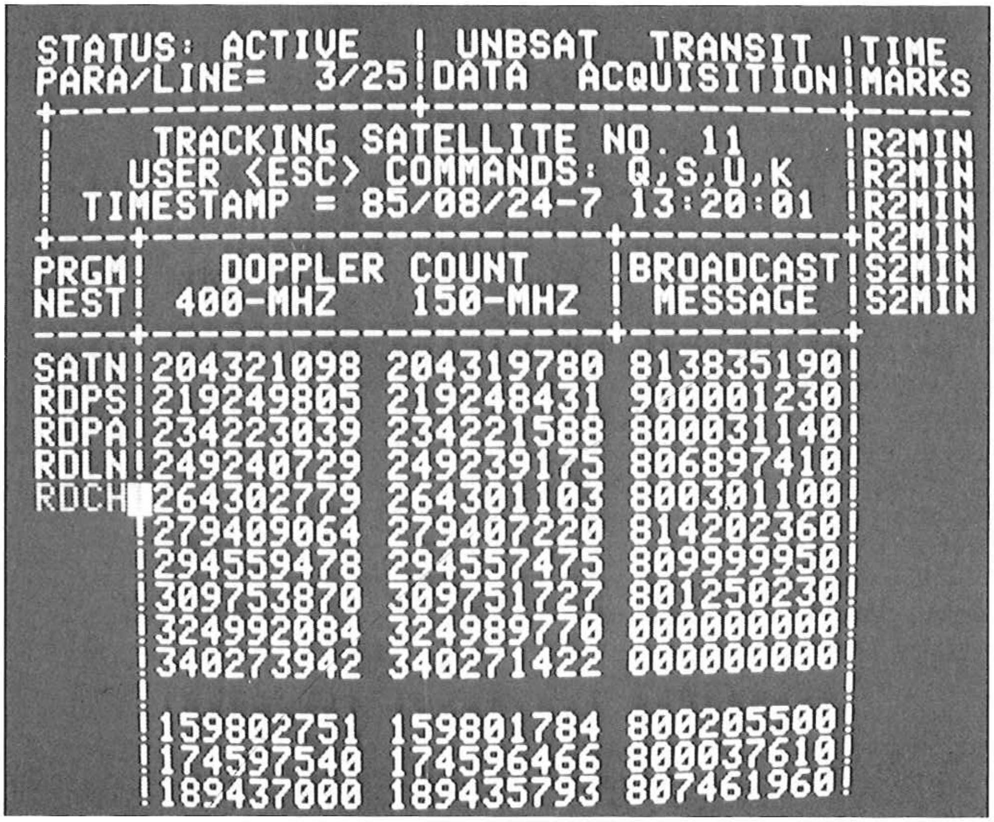

Figure 2. UNBSAT screen display during data acquisition.

4.6 second Doppler data; and optimization of data storage by the rejection of passes with corrupted satellite messages or insufficient Doppler data for position computations.

On start-up, the UNBSAT software requests the operator to choose the desired options for the recording session. These options include the minimum number of received 2-minute paragraphs of Doppler data required before a pass will be recorded on diskette; the minimum number of dual frequency 30-second Doppler counts acceptable for a pass; whether passes should be rejected if they fail the message verification tests and whether both the raw data and majority-voted data or majority-voted data only should be saved on the diskette. Once this information has been fed into the Apple, the program goes into a wait state; waiting for the next available satellite pass. As soon as the receiver locks on to a rising Transit satellite, the program goes into the active state (see Figure 2) and begins storing the Doppler counts and broadcast message in a buffer. The majority-voting of the satellite message and the accumulation of the dual frequency 30-second Doppler counts are done as the digits arrive from the receiver. The program displays the identity of the satellite tracked when a valid satellite identification number is decoded. The operator can then accept or reject the satellite pass if so desired. Upon the completion of the satellite pass, denoted by a loss of signal from the receiver, the program begins to decode and test the validity of the majority-voted satellite message. The number of "healthy" dual frequency 30-second Doppler counts is also determined. If the data in the buffer passes all the previously chosen constraints signifying a good pass, the majority-voted data and the raw observed data from the receiver (with the latter being saved only if requested) are written as separate files on the diskette. The program then reverts to the wait state.

The majority-voted file stored on the diskette contains a 31 by 4 matrix of numbers with a time stamp at the top. An example of a majority-voted file is shown in Figure 3. The variable majority-voted ephemeris parameters recorded span from $(t - 4)$ minutes to $(t + 22)$ minutes, where t is the lock-on-time of the satellite signals. Bad satellite messages occasionally occur when an observed satellite has a low elevation and insufficient 2-minute paragraphs of data are received to properly majority-vote the satellite message. Poor signal quality would also have the same effect.

With two floppy disk drives and under optimal selection criteria, i.e., saving only majority-voted data, a minimum of 10 dual frequency 30-second Doppler counts and at least five 2-minute paragraphs of Doppler data, the system can be left unattended for up to five days before the diskettes must be replaced. This is based on the assumption that 30 good qualifying passes are tracked per day. The actual length of unattended operation would however ultimately depend on the number of good satellite passes recorded each day. Each diskette can hold up to a maximum of 77 majority-voted data files (limitation imposed by the capacity of the diskette file directory). This number drops down to 18 data files when both the raw and majority-voted data are kept on the diskette.

83/02/11-5 16:51:55

081197057	081198312	090010014	0
151452765	151456123	600130134	0
234337398	234343356	610250334	0
307294432	307303035	620350593	0
085282947	085286658	630410894	0
159683084	159689088	640451231	0
248259931	248270243	200451580	0
326995234	327007535	210372147	0
092972231	092974152	220342470	0
174875914	174879622	230282744	0
273238823	273243714	240202965	0
361277233	361282351	250103090	0
104383983	104383358	060013145	0
196419922	196418143	000000000	0
306655017	306649052	039300580	0
404747482	404736632	637537250	0
115330658	115326258	818388360	0
216014491	216005531	800199840	0
335331000	335316437	800047520	0
440383400	440364835	807449856	0
000000000	000000000	813016500	0
000000000	000000000	900005250	0
000000000	000000000	800131180	0
000000000	000000000	823901100	0
000000000	000000000	800301400	0
000000000	000000000	817200420	0
000000000	000000000	809999140	0
000000000	000000000	802060000	0
000000000	000000000	000000000	0
000000000	000000000	121004105	0
000000000	000000000	511110031	0

Figure 3. Example of a majority-voted data file. The majority-voted file consists of a 31 by 4 matrix of numbers with a time stamp at the top. The first two columns are the accumulated 400 MHz and scaled 150 MHz 30-second Doppler counts respectively. The third column of the matrix holds the 14 fixed and 14 variable majority-voted ephemeris parameters. The last three lines of the third column are used to store pertinent user and site information, and selected options for the recording session. The 4th column is used to describe the 'health' of the majority-voted broadcast satellite message. A detailed description on this file is given in *Quek* [1983].

Additional disk drives or use of a hard disk will increase the unmanned operational time. Based on the figures given above, each additional disk drive allows approximately two extra days of unmanned operation. The software can accommodate more floppy disk drives and will seek each drive in turn to record data.

The accumulated data files are processed on a mainframe (e.g., IBM 3081) or a minicomputer (e.g., HP 1000). The UNBSAT system includes a program called LINK which is used to transfer the data from the Apple diskettes to the processing computer via the Apple Super Serial Card. LINK is a general communication package that can transfer raw and majority-voted data files. The program was written for 300 or 1200 baud communications with the host computer via an RS-232C link, directly or through a telephone line with the aid of a modem. Currently file transfer operations are adapted for the IBM 3081 Virtual System Personal Computing (VSPC) operating environment. Link can easily be modified to accommodate a different mainframe environment or protocol procedure. This customization to the host protocol makes it possible to transfer a diskette full of Doppler data to the host unattended. This operation can be carried out from a field site if there is access to a telephone or radio modem. The program also allows for two-way transfer of ordinary text files, for example, weather and operator site information from the remote site to a base station or further operational instructions from the base station to a remote site.

After the transfer, the host Doppler adjustment program can be used to process the Doppler data. At UNB, the suite of GEODOP programs [*Kouba and Boal* 1976] available from the Geodetic Survey of Canada is used. The incompatibility between the GEODOP data input format and the UNBSAT majority-voted data output format is handled by VSPC software. The software automatically converts the format of the data and concatenates the majority-voted data files into one large file as required by GEODOP. The processing thereafter follows normal GEODOP processing procedures.

Field Tests

UNBSAT has been used in a number of student exercises over the past two years. These exercises included both point and relative position determinations. Translocation was demonstrated over a short 5 km baseline with the second receiver at an unmanned remote site. With the exception of diskette changes, the system was left to operate on its own. Doppler data recorded and processed from the two sites demonstrated the ease of operation of the system and the advantage of the improved recorded data format. The system has also been operated in the field at near freezing temperatures with no degradation in data quality (see Figure 4).

UNBSAT has been installed at the Wuhan Technical University of Surveying and Mapping in the People's Republic of China and was used by the Geodetic Survey of Canada in its 1985 field season. Software and documentation are available to others who may wish to use the UNBSAT system with their own CMA-722Bs.

Current and Future Developments

The UNBSAT system is continually being enhanced. Present developments include microcomputer control of the receiver for automatic pass rejection, use of the CP/M

Figure 4. UNBSAT system in the field.

operating system on the Apple for increased speed of operation and for use on other microcomputers, development of a primitive Doppler point positioning program under the CP/M operating system for near real-time positioning, and remote continuous unattended station operation with automatic data transfer.

Conclusion

The UNBSAT system is an economical alternative to the purchase of a new Transit or GPS receiver. For a few thousand dollars existing CMA-722B receivers can be rejuvenated to extend the satellite Doppler positioning capabilities of established survey organizations or to provide a new capability to survey organizations, such as those in developing nations, operating on limited budgets and with limited technical resources. UNBSAT is also an ideal tool for teaching students about satellite positioning systems.

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See Hean Quek graduated from the North East London Polytechnic, United Kingdom, with a B.Sc.(Hons) in land surveying sciences in 1980. He subsequently enroled in the postgraduate program at the University of New Brunswick (UNB) and graduated with a M.Sc.E in surveying engineering in 1983. In 1984 he joined the research staff at the Department of Surveying Engineering, UNB, where he is currently involved in software development pertaining to the areas of extraterrestrial positioning and navigation. He has also acted as a software developer and consultant on a number of projects at Universal Systems Ltd., a digital mapping company based in Fredericton, New Brunswick.

Richard Langley is an associate professor in the Department of Surveying Engineering at the University of New Brunswick (UNB), where he has been teaching since 1981. He has a B.Sc. in applied physics from the University of Waterloo and a Ph.D. in experimental space science from York University, Toronto. After obtaining his Ph.D., Dr. Langley spent two years with the Department of Earth and Planetary Sciences of the Massachusetts Institute of Technology involved in research in lunar laser ranging and very long baseline interferometry. He subsequently joined the faculty of UNB where he continues his interest in extraterrestrial positioning techniques.