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AN EXPERT SYSTEM FOR SHUTTLE AND SATELLITE RADAR TRACKER SCHEDULING

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Abstract:

This expert system automates and optimizes radar tracker selection for shuttle missions. The expert system is written in the Fortran and C languages on an HP9000. It is portable to any UNIX machine having both ANSI-77 Fortran and C language compilers. It is a rule based expert system that selects tracking stations from the S-band and C-band radar stations and the TDRSS east and TDRSS west satellites under a variety of conditions. The expert system was prototyped on the Symbolics in the ART and ZetaLisp. After the prototype demonstrated an acceptable automation of the process of selecting tracking stations to support the orbit determination requirements for Shuttle missions, the basic ART rules of the prototype were ported to the HP9000 computer using the CLIPS language. CLIPS is a forward-chaining rule-based expert system language written in "C". Prior to the development of this expert system the selection process was a tedious manual process and, expensive in terms of human resources. Manual tracking station selection required from 1 to 2 man weeks per mission; whereas the expert system can complete the selection process in about 2 hours.

Introduction:

Expert system technology is a major subset of Artificial Intelligence (AI) and has been aggressively pursued by AI researchers since the early 1970's. In the last few years, both government and commercial application developers have given expert systems considerable attention as well. Expert systems have a number of characteristics which make them an attractive solution to problems which require complex expertise: they don't quit, retire, or become ill; they always work at their highest level of capability; they can be applied to hostile environments or repetitious problems; and they potentially offer a computer-based solution to problems that previously required a human expert.

This paper describes an expert system that automates the laborious and time-consuming process of selecting radar tracking systems prior to each Shuttle flight. The tracker selection is necessary in order to insure that the mission has adequate tracking coverage to provide required position and velocity information. The data obtained from these trackers provides the information for the orbit determination process in the MCC and therefore is crucial for performing maneuvers.

This development expert system also served as a case history for the development and delivery of expert systems. The initial prototype of TRACKEX was developed in ART on a Symbolics machine in three weeks. There were approximately one hundred ART rules with an average length of twenty lines. There were also five hundred lines of LISP code, primarily providing a user interface. The target machine for the delivery system was an HP9000. The conversion of the one hundred ART rules to CLIPS took one week, and three weeks were spent in converting the LISP to FORTRAN.

EXPERT SYSTEM OPERATION:

The expert system TRACKEX is a rule-based software package written in the C and FORTRAN languages. The rules are coded in the production rule language CLIPS. The use of CLIPS was driven by the choice of the target machine: a unix-based HP9000, inputting the C and FORTRAN compiler. FORTRAN subroutines and C functions were developed to replace the LISP I/O interface of the prototype. The released product consists of 295 rules, 52 FORTRAN subroutines and 23 user-defined C functions.

TRACKEX assigns the best possible group of tracking systems from the total set of trackers available during each orbit. This selection is made with consideration given to geometry, no two stations from the same geometric area; to expense of operation, some sites are always active and are therefore more economical to use than a site that has to be manned specially for the mission; and to subsequent orbit coverage, especially for a Target vehicle. Once a tracker is assigned to a Target, it is assigned in subsequent orbits until its elevation angle, with respect to the tracker's local horizontal, falls below an acceptable limit.

TRACKEX will make tracker selections for up to four vehicles for batches of ten orbits at a time. The user defines the preferred priorities when more than one vehicle is to be considered and this priority ordering is maintained throughout the entire selection process unless the user modifies the priorities during the run. TDRSS and S-band systems can track multiple vehicles during the same orbit. However, most Targets will not have S-band transponders and will therefore be skin tracked. Skin tracking prohibits the tracking of more than one vehicle at a time. Therefore, multiple Targets may mean sparsity of available trackers, making the assignment of vehicle priority very important.

The number of user inputs are minimal and are menu driven thus, training a user to use the system is quickly accomplished. The expert system can be run in a completely automatic mode after the program has been properly initialized and all user required inputs are made.

The tracker selection matrix table is described in the appendix, and the included table is an example of the expert system's output using simulated data. The table is formatted according to the users' specifications and is intended to be adequate for insertion into all documentation requiring it's information content.

TRACKEX has proven to be both accurate and fast. During the verification phase, it was found to be correct in these cases where the initial human expert solution differed from the expert systems selection.

The verification for TRACKEX was an exhaustive case-by-case comparison of human expertise versus TRACKEX automation. This was possible since there are only four groups of ground stations, each containing a limited number of specific tracking sites. The verification cases were designed so that each tracker would be selected at least once at the appropriate time and under a variety of conditions. Each of the three tracking phases, non-critical, critical, and complex were exercised to the fullest extent.

The human expert designed the test cases to cause every rule in the expert system to be fired at least once. The expert then made independent tracking system selections per case prior to running TRACKEX. When there was a difference in the selections, TRACKEX was ultimately found to be correct.

In addition to being accurate, TRACKEX is capable of making the tracker selection for an entire Shuttle Mission in about two hours of computer time, whereas the manual method takes from one to two man weeks and is subject to error (a less than optimal selection) because it is very difficult for a person to remember and constantly apply 295 rules.

Conclusion:

Although an entire industry has grown to support the development of expert system tools and applications, with a wide variety of both hardware and software products now available, expert systems have generally failed to make a major impact in application environments where there is a requirement for specific hardware or integration with procedural languages such as ADA, C, or FORTRAN. The problem of delivering a functional application, especially in embedded systems, has proven to be a major stumbling block.

This stumbling block was avoided in this project by using the CLIPS language for the delivery of TRACKEX.

The CLIPS language provides expert system technology in a conventional language with the capability of complete integration with conventional procedural languages.

Acknowledgments:

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References:

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Appendix:

DESCRIPTION OF THE TRACKER SELECTION MATRIX

The output tables containing the tracker schedule are stored in permanent files for inclusion in documentation requesting the trackers to be scheduled for a particular orbital mission.

The following is a description of each entry to the table:

a) Title---Tracker Support Matrix
The table is a matrix of the selected tracker site (row) vs the orbit in which it is available (column).

b) Sub-titles
Flight: The flight acronym is picked up automatically from the visibility files which contain the flight's predicted tracker acquisition and loss of signal profile.

Orbits: The ten (10) orbits over which the current table extends are indicated by their starting orbit number and the end orbit number for quick reference purposes.

Cycle: This is an integer that indicates the version number for documentation purposes.

The full date and time of the table's creation is included again, for documentation and referencing purposes.

c) The table entries
The column titled "SITE" contains the Tracker acronym for a Tracker (S-band, C-band, or Tdrss) selected at least once during the ten-orbit period. For instance the first acronym is TDRE and it has entries in all ten orbits.

The entry itself is coded such that the following information is revealed:

a) The first single symbol (C, X, or *) indicates the vehicular phase for that particular vehicle. (see note at bottom of table)

b) The next 2 character symbol is a user input, defined at run time, and indicates the vehicle to which the data pertains. Thus, the user can tailor this entry to best describe the vehicle name and/or type. For example, an OA entry could signify Orbiter A.

c) The last symbol is an two-digit integer indicating the maximum elevation angle for that tracker during the orbit of interest. For example, the ninth row contains a selection for BDQC in orbit 2. BDQC is the acronym for a C-BAND tracker on the island of Bermuda. The entry indicates that the Orbiter vehicle, OA, is in Complex tracking phase (X) and had a maximum elevation angle of 25 degrees.

The symbols are completely defined in a post-script to each table.

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Tracker Support Matrix

Flight:FLT1
Cycle: 1

Orbits: 1 - 10
Thu Mar 24 10:14:14 CST 1988

SITE	1	2	3	4	5	6	7	8	9	10	SITE
TDRE	XOA00	XOA00	XOA00	*OA00	*OA00	*OA00	*OA00	*OA00	*OA00	*OA00	TDRE
TDRW	XOA00	XOA00	XOA00	*OA00	*OA00	*OA00	*OA00	*OA00	*OA00	*OA00	TDRW
KMRC		XOA25									KMRC
KMTC			XOA25								KMTC
KMAC	XOA25										KMAC
KPTC		XOA25									KPTC
PTPC		XOA25									PTPC
WLPC	XOA25										WLPC
BDQC		XOA25									BDQC
ANTC			XOA25								ANTC
ASCC	XOA25										ASCC
ASTC			XOA25								ASTC
SITE	1	2	3	4	5	6	7	8	9	10	SITE

Vehicles: OA = Orbiter TA = Target OB = Orbiter TB = Target
Selected Sites: * = Non-critical C = Critical X = Complex