The Fault Induced Document Officer: A Case Based Response System for Unmanned Complex System Operations.

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ABSTRACT

Knowledge acquisition from experts is an inefficient and painful process for most automation implementation projects. The knowledge acquisition phase is often so wrought with difficulty, that the success of the automation project as a whole is jeopardized. Here we describe an alternative approach and its implementation called the Fault Induced Document Officer (FIDO). FIDO is an automated system which assists in expert knowledge acquisition, access, and publishing capabilities for safely managing complex systems under staffing reductions and "lights out" operations.

We propose the integration of several "off-the-shelf' products to comprise a casebased, computer-mediated response information system which will assist operators to validate and capture the knowledge necessary to allow fewer and less specialized operators to safely operate the complex systems.

The FIDO approach provides a mechanism to index the relevant documentation in the search space and produce additional highly specific documentation at the time of an anomalous event. FIDO can mitigate the effects of down-sizing, reduce response time, reduce the cost for anomaly resolution, increase the effectiveness of team or collaborative solution thinking, and provide a permanent repository for mission knowledge.

1.0 INTRODUCTION

Day-to-day complex system operations tasks have been identified as an area for high return on investment of automation [1]. Several recent automation implementation projects on older scientific satellites at NASA Goddard Space Flight Center (GSFC) have resulted in significant day-to-day operations cost savings [2]. These older, human-mediated missions have been retrofitted to comply with the automated "lights out" operations mode—an operations mode in which daily operations tasks are routinely performed by an autonomous computerized system.

Additionally, human-mediated complex system operations are frequently being replaced by intelligent software systems in the design or fabrication stage of the mission [e.g. 3]. The drivers for these changes remain reduced costs and increased performance and process execution reliability.

The typical mission enjoys the highest concentration of expert knowledge during proposal and fabrication stages through deployment and initial testing. During this critical period, mission specific information development is at a peak, but often remains in the heads of experts or is captured in obscure documentation. Documentation production in the form of proposals, reviews, quality assurance, and testing also typically peak during this period. The FIDO approach exploits this window of production. FIDO provides a mechanism to acquire, index, and publish information relevant to assist ing operators and experts responding to events.

Trends in human-machine systems suggest that these problems will only become more severe as operations budgets are further decreased [4] and staffs are further reduced, less specialized, and less familiar with the systems in the emergency state.

2.0 BACKGROUND

FIDO was developed at the Center for Extreme Ultraviolet Astrophysics and the Jet Propulsion Laboratory (JPL) to address requirements arising from the "lights out" operation for the ***Extreme Ultraviolet Explorer*** (EUVE) satellite. EUVE is an orbiting telescope facility [5] technologically based in the late 1980's. The science payload and platform are operated from CEA at the University of California, Berkeley (UCB).

EUVE was launched aboard a Delta H rocket in June, 1992, and remains functional beyond its planned 3.5 year mission. It is currently operating in an "extended mission" phase under a reduced budget but with virtually uncompromised science return.

Prior to launch, the decision was made to monitor the EUVE science instrument with staff controllers at CEA in the same method as other missions: 24 hours a day, 7 days a week. It required that two people, generally a staff controller and a student controller-aide, be available in the EUVE Science Operations Center (ESOC) at all times to monitor telemetry as it arrived.

In an effort to reduce EUVE'S operating costs and to increase the mission's competitiveness, CEA and NASA Ames Research Center (ARC) developed an autonomous monitoring system for the payload. A discussion of the factors that went into this decision can be found in [1] and [6].

The resulting system allowed the science payload to be operated in a "lights out" mode for 16 hours of every day.

3,0 A STATEMENT OF THE PROBLEM

Complex Systems have anomalous events: Resolving these events require the knowledge of experts, in the form of either expensive human beings or their documented knowledge.

The FIDO system was designed to provide solutions to system-related events that occur on the ESOC operations network. The importance of an automated system to augment a human-mediated operations center is increasing due to several noted trends in human-machine systems: I) Humans are used to complement automated systems by resolving exceptions [7]; 2) Automated systems remove operators from the "firing" line [8]; 3) A Popular technique for accommodating decreases in staffing budgets is to require a single staff person to monitor multiple complex systems [9].

FIDO was developed to address these trends by providing a knowledge acquisition, organization, and presentation mechanism that is timely, non-intrusive, and stable.

FIDO was constructed with re-use and portability as paramount development criteria. Every effort has been made to use free, public domain software which is supported by widely accepted standards. The major components of FIDO have been borrowed from "freeware" repositories and commercial developers distributing free licences. Additional "glue" code was written by CEA to provide functionality not inherent to the generic borrowed components.

3.1 **Requirements**

The FIDO system requirements were derived from an operations center review of an early FIDO prototype in 1996. The overall concept was very well received by EUVE operations personnel, but the application domain and several features were re-engineered for the *full-release-1 (R1)* release. The following is a list of the features requested as a result of the initial review:

- Supported by SunOs 4.1.3
- Easily incorporated into current network
- Minimize a priori knowledge engineering
- Supports multiple document formats
- Single window interface
- Display is passive (will not crowd work space)
- Supports retrieval refinement
- Search box available at all times
- Ground system network is the application domain

4.0 FIDO DESIGN PHILOSOPHY

The FIDO team focused on the design and development of software which provides a system state summary (a configurable engineering summary which displays the state of the ground systems and observatory) and documentation for diagnosis of potentially failed components.

The FIDO design specified tools for the conversion and delivery of complex sets of static documentation to operators involved in real-time ground and spacecraft activities. This activity, coined knowledge publishing [10], delivers the high quality knowledge layer of FIDO known as the "casebase." Knowledge publishing, Feigenbaum reports, is the conversion of normal passive books into a knowledge publishing system that delivers knowledge in active books to the user specifically in the context of a user's need or request [11]. The FIDO system supports the HTML formatting specification for the "book" delivery system.

One of the analytical strategies that FIDO uses to diagnose faults and retrieve their associated documents is based on using the Kolodner Case Based Reasoning (CBR) paradigm. Kolodner's research focuses on the use of previous experience as a learning resource for responding to subsequent anomalous events [12]. CBR maintains a casebase of earlier events and solutions in order to solve future problems. CBR is defined as a model that incorporates problem solving, problem understanding, and problem learning.

FIDO follows Kolodner's CBR model by incorporating previous search results into its current search criteria. Kolodner's model of CBR maintains: 1) references to old cases are advantageous, and references to similar situations are necessary for adequate queries, 2) understanding or interpreting a situation is a necessary part of the reasoning cycle, and 3) old cases need to be adapted to new situations [1 1].

In addition, "weak" relevance feedback is used to enhance retrieval and make it more context sensitive. FIDO queries the operator to optionally specify the relevant ground system and spacecraft state attributes that are necessary to justify the retrieval of this particular set of documents [13].

5.0 FEATURES LIST

The FIDO system makes the following functionality available for the operator of complex systems.

- Event log monitoring
- E-mail notification
- Display of critical systems status (before and during the event)
- Knowledge capture
- Knowledge indexing

- Knowledge retrieval
- Knowledge publishing
- Bookmaking
- Personnel Paging (optional see 6.1)

6.0 IMPLEMENTATION

FIDO differentiates between two qualities of knowledge: 1)the casebase and 2) the search space. The casebase is the initial corpus retrieved and displayed for *understood* action events. The casebase requires initial population by hand if the mission is to be safely operated in "lights out" mode. The search space is the entire base of knowledge available on the file system. This is mainly comprised of documents and drawings found throughout the network. The search space requires no preparation and is largely a by-product of mission development and operations,

FIDO provides a system that watches system log files and responds to specific event entries or exceptions by paging and sending e-mail to a list of appropriate personnel. Each member of the list receives a page and e-mail with a live URL which links to the FIDO interface. Figure l illustrates the FIDO process flow.

FIDO requires the population of two configuration files: l) the watcher configuration file should contain a list of the events that require action and the personnel required for each action, 2) the dictionary file should contain all the pre-defined events and a list of terms related to each event.

The EUVE implementation was particularly difficult since the network which FIDO is monitoring is an isolated operations network. This network is isolated from all networking devices to ensure security. A Redundant Array of Inexpensive Disks(RAID) box was used to bridge the network to the outside word in a "read only" fashion without compromising network security. Figure 2 illustrates the EUVE implementation of FIDO bridging the two networks.

6.1 Functional Components

The FIDO approach, as mentioned above, leverages the capabilities of several Public Domain (PD) and Commercial-Off-The-Shelf (COTS) products.

The basic functional components of FIDO are: 1) a log watching facility; 2) an anti-aliasing script; 3) a HTML browser; 4) a bookmaking script; 5)HTML frame set; 6) ready-made casebase entry templates, and an indexing/searching engine. In addition, a simple paging facility called SEPAGE is available at http: //cea.berkeley.edu to automate the notification process.

6.1.1 SWATCH

Simple watcher facility (SWATCH) is a free utility for watching BSD UNIX system log files. The FIDO system has SWATCH configured to watch all critical machines on the operations network. In the case that an event arrives in a system log that either matches the list of events which need action or is not defined, the SWATCH daemon starts the FIDO searchexpdr process (see 6. [.2) passing it all event names which are previously designated as events which need action or are unidentified (SWATCH is available from Stanford University at http://ciac.llnl.gov/ciac/ToolsUnixSysMon.html.)

6.1.2 Searchexpdr

Searchexpdr takes the event names passed above and compares them to a dictionary list looking for a match. If a match is found, terms matching the original event names are passed to a searching function. (If matches are not found, searchexpdr waits for additional event names. If none are found after a specified number of tries or a specified time, a request is sent to the paging and mailing facility to warn the FIDO administrator that the dictionary might need adjustment.) Searchexpdr also begins the mailing and paging functions to warn operators of the event. (searchexpdr is a CEA product that is currently not available for distribution, but when available it will be located at http: //cea.berkeley. edu.)

6.1.3 Excite WS (for Web Sites)

Excite WS is used to index the entire search space. The indices are not processed in real-time, hence there is not a latency issue associated with indexing. The indexing is automatically processed daily to keep the index corpus current.

Excite takes the arguments passed by searchexpdr and retrieves the documents relevant to the query. These documents are displayed in the main frame of the FIDO interface frame set. (Excite WS is available at http://www.excite.com/navigate/home.html.)

6.1.4 HTML Frame Set

The HTML frame set designates the layout of the user interface. A FIDO instance populates 5 frames with event information. The header contains status of the system N (N is set in a configuration file) minutes prior to the event, the current system status after the event and the event terms that started the FIDO process. The frame below the header contains the output of the searchexdpr query; links to all documentation in the search space relevant to the event, The left most frame contains the main control box. The right most frame is the display area for documents. The footer contains the bookmark links relevant to the particular case or document in the display window.

6.1.5 Statuschecker

The statuschecker maintains the status buffer. The system status buffer contains records for the last N minutes prior to being turned off by SWATCH. The contents of the buffer are displayed as parameters in the top frame of the frame set. (Statuschecker is a CEA product that is currently not available for distribution, but when available it will be located at http: //cea.berkeley. edu.)

6.1.6 Netscape Communicator

A live Universal Resource Locator (URL) is passed m each person on the paging list for the particular type of event through e-mail. The person has the convenient option of retrieving their mail with a browser supporting live URLS. If a browser supporting live URLS is not used, then the URL will have to be cut and pasted from the mail tool into the browser. (Netscape communicator is available at http: //www.netscape. corn.)

6.1.5 **Bookmark**

The interface provides the list of events that triggered the FIDO process, a snap shot of the relevant system functions before and after, as well as the documentation in the casebase and search space related to the event. This collection of information provides the operator with the knowledge necessary knowledge for resolution of the event and publishing of a casebase entry. The bookmark function is the first step in that process.

The bookmark function allows the operator to append the document path to the event casebase entry. Each subsequent instance of a bookmarked event case will also populate the bookmark window with links to information that has been previously bookmarked.

The next step in the knowledge publishing process is to use a template to add entries to the casebase. (book-***mark is*** a CEA product that is currently not available for distribution, but when available it will be located at http://cea.berkeley.edu.)

6.1.6 **Templates**

Templates are used with the browser's text editing features to create new entries for the casebase. Standardized templates force the consistency of the casebase and provide an easy capture mechanism at the time of the event resolution.

7.0 RESULTS

Individual functions of FIDO have been tested. Each function performs its function to specification. A full in series test has not been performed. A full release of R l is pending, but early demonstrations indicate a high interest and a need for the functionality provided by FIDO from EUVE operations personnel.

FIDO remains a human-mediated system. It's design dictates the involvement of humans to provide the knowledge as well as refine the knowledge over time. The quality of the casebase overtime will indicate if the FIDO system alone will produce the quality of casebase needed for expert systems rule development. Early indication of the quality of output from the functional pieces is strong.

8.0 FUTURE RESEARCH

After FIDO has acquired an operations record, during a "burn-in" period, we have interests in incorporating a stochastic and rule-development module with FIDO. A high quality casebase verified through the use of FIDO should produce knowledge units which are trivial to translate to expert system rules.

Another area we would like to explore is strong relevance feedback and how the shape of the casebase might change over time if a strong automatic relevance feedback system like that used in the INQUIRY system were incorporated [13].

Discussions of additional implementations of FIDO for other satellite missions are in process.

9.0 ACKNOWLEDDGEMENTS

We thank R. Doyle (JPL), F. Girouard (CEA), M. Gunter (CEA), K. Kaier (CEA) and F. Kronberg (CEA) for their support and patience in reviewing this text. We acknowledge programmatic support from M. Montermerlo, G. Riegler and S. Venneri at NASA Headquarters.

REFERENCES

[1] R.F. Malina., "Low-Cost Operations Approaches and Innovative Technology Testbedding at the EUVE Science Operations Center," Proc. of 45th International Astronautical Congress, IAA Symposium on Small Satellite Missions, October 1987

[2] D.C. Lin, J.R. Klein, R.D. Pendley, S.L. Hoge, "Use of Xrunner for Automation," Proc. 32nd International Telemetering Conference, October 1996

[3] R. Doyle, R., J. Carraway, R. Bruce Crow, J. Wyatt, "Mission Operations Concept for Pluto Fast Fly By," I 994

[4] A. Wiener, D. Thurman, C. Mitchell, "Applying case-based reasoning to aid fault management in supervisory control," Proc. IEEE International Conference for Systems, Man, and Cybernetics, 1995

[5] S. Bowyer, R.F. Malina, "The EUVE Mission," Extreme Ultraviolet Astronomy, Pergamon Press, New York, XXXI, 1995,286

[6] T. Morgan, R.F. Malina, "Advances in Autonomous Operations for the EUVE Science Payload and Spacecraft," Proc. American Astronomical Society of the Pacific, 1995

[7] T. B. Sheridan, Telerobotics, Automation, and Human Supervisory Control, MIT Press, Cambridge, 1992

[8] D. A. Thurman, C.M. Mitchell, "Multi-system management: The next step after supervisory control?", Proc. IEEE International Conference for Systems, Man, and Cybernetics, 1995

[9] E. Hutchins, Cognition in the Wild, MIT Press, Cambridge, 1995

[10] E. A. Feigenbaum, Tiger in a Cage, University Video, Stanford, 1993

[11] F. Kronberg, A. Wiener, T. Morgan, B. Stroozas, F. Girouard, A. Hopkins, L. Wong, M. James, J. Kneubuhl, R.F. Malina, "Document Retrieval Triggered by Spacecraft Anomaly: Using the Kolodner Casebased Reasoning(CBR) Paradigm to Design a Fault Induced Response System.," Proc. 32nd International Telemetering Conference, October 1996

[12] J. L. Kolodner, Case Based Reasoning, Morgan Kaufmann, San Mateo, 1993

[13] W. B. Croft, J. Broglio, J. CalIan, "INQUIRY System Overview", Computer Science Department, University of Massachusetts, Amherst, 1994

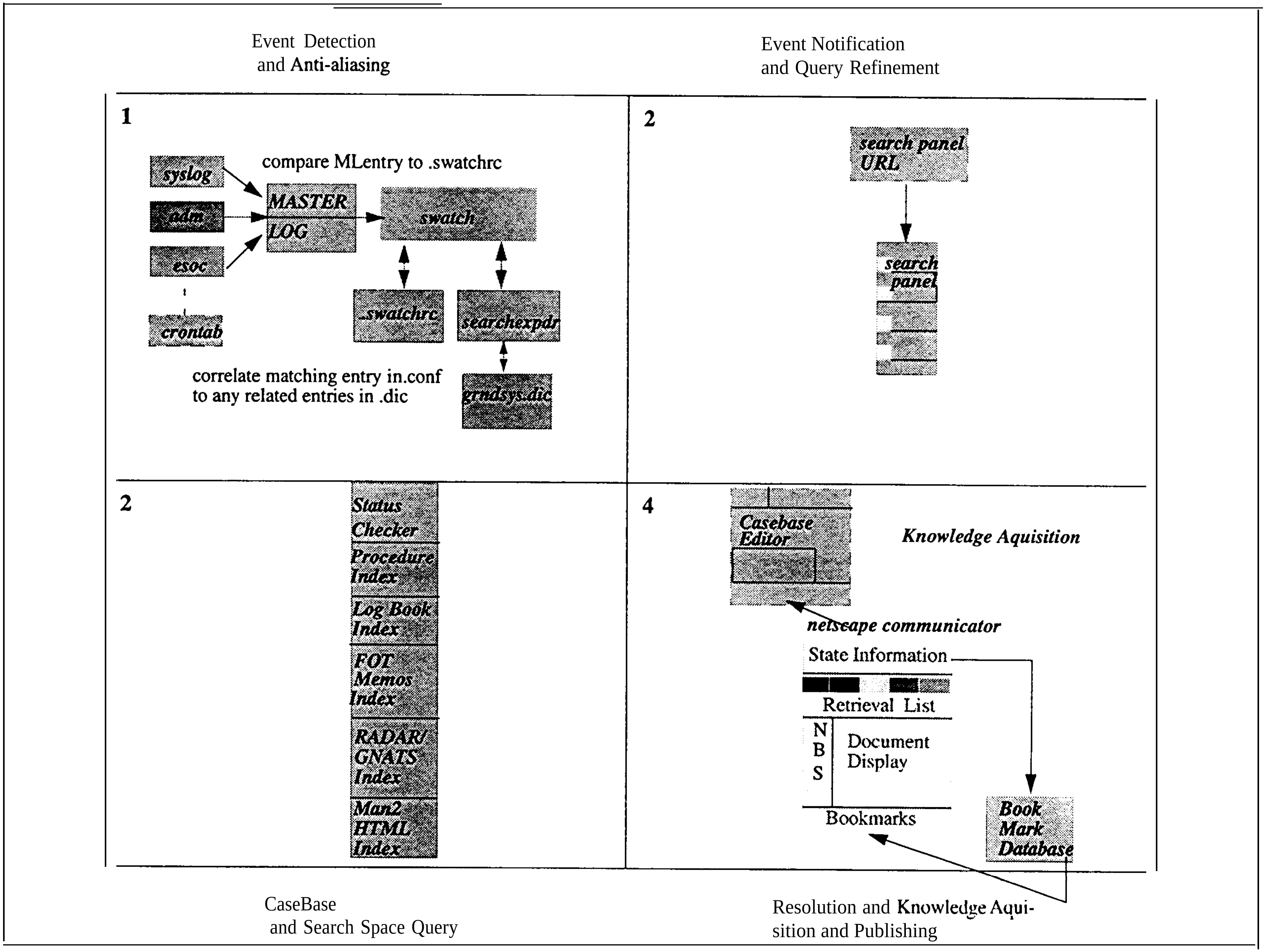

Fig. 1 FIDO Functional Flow

CEA EUVE/ESOC Network with FIDO Incorporated

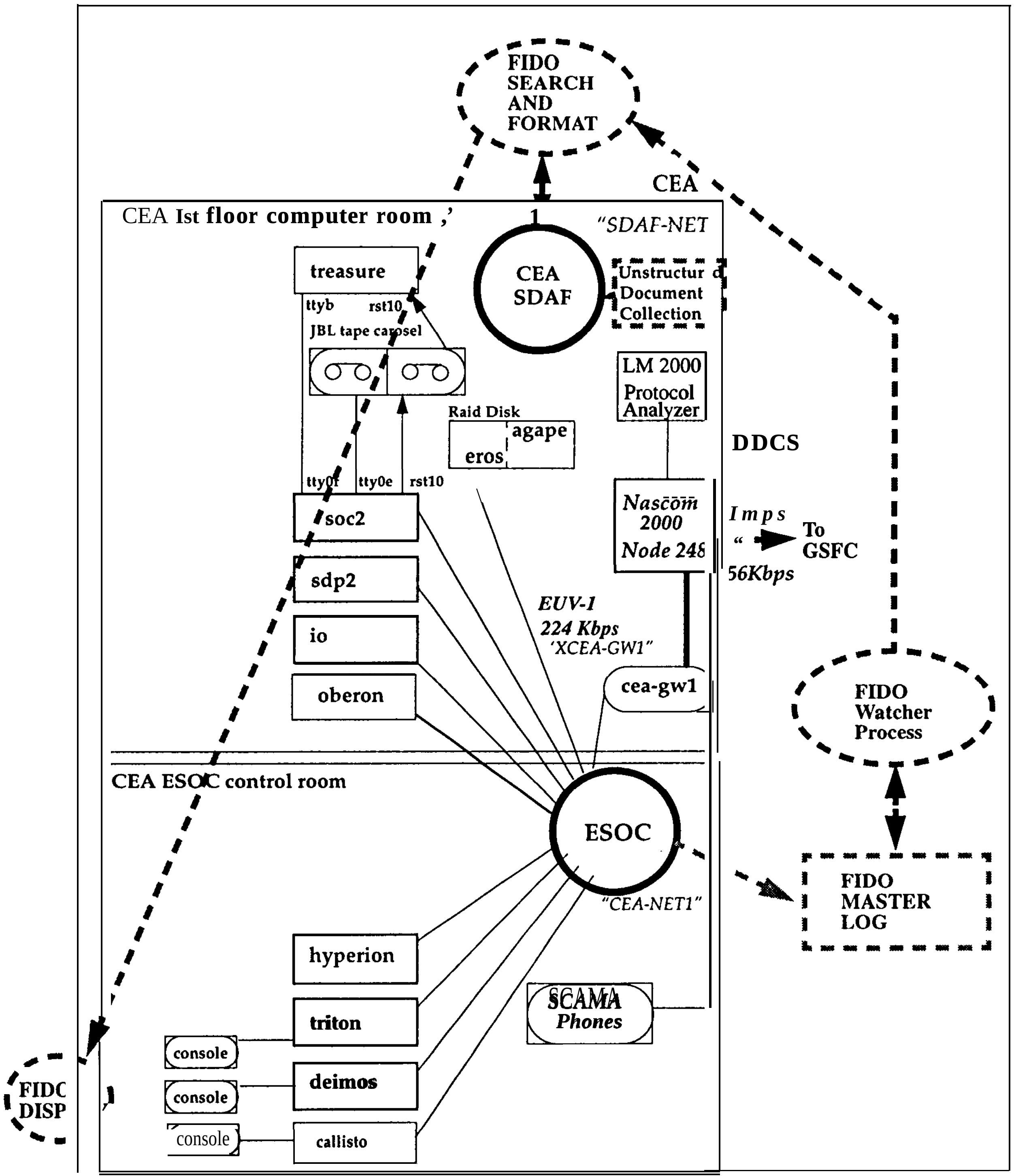

Fig. 2 FIDO incorporated into ESOC network