N92-22338

THE APPLICATION OF INTEGRATED KNOWLEDGE-BASED SYSTEMS FOR THE BIOMEDICAL RISK ASSESSMENT INTELLIGENT NETWORK (BRAIN)

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ABSTRACT

One of NASA's goals for long duration space flight is to maintain acceptable levels of crew health, safety and performance. One way of meeting this goal is through BRAIN, an integrated network of both human and computer elements. BRAIN will function as an advisor to mission managers by assessing the risk of inflight biomedical problems and recommending appropriate countermeasures. This paper describes the joint effort among various NASA elements to develop BRAIN and the Infectious Disease Risk Assessment (IDRA) prototype. The implementation of this effort addresses the technological aspects of: (1) knowledge acquisition, (2) integration of IDRA components, (3) use of expert systems to automate the biomedical prediction process, (4) development of a user friendly interface, and (5) integration of the IDRA and ExerCISys systems. Because C Language, CLIPS, (the C Language Integrated Production System), and the X-Window System are portable and easily integrated, they have been chosen as the tools for the initial IDRA prototype.

INTRODUCTION

One of NASA'S goals for long duration space flight is to maintain acceptable levels of crew health, safety and performance. To do this, NASA will monitor crew physiological, psychological and task performance. It also must administer appropriate countermeasures (17,29,37). It is our philosophy that determining the risk of inflight performance problems is the first step of preventing them.

Biomedical risk assessment estimates the probability of a specified human response to a challenge (10,19). The probability estimate is based on epidemiological studies of populations at risk after exposure to extreme conditions. And, certain physiological, psychological and environmental indicators change the estimation of risks for the individual. The specificity of the indicator to predict a human response is the limiting factor in the risk assessment. The acceptable limits of risk have to be understood to manage them.

As the duration of space flight lengthens, the risk and number of biomedical problems will increase. It is crucial to make an assessment and initiate countermeasures. It also is important to predict the impact of the selected countermeasures on crew health, safety and performance. If more than one change in crew status is observed, it is critical to evaluate each countermeasure relative to the others.

A partial solution to the decision-making process required for long duration flights is the application of automated technology. It reduces the volume of data, facilitates data interpretation and resolves incompatible data. For example, expert or knowledge-based systems can automate the diagnostic process that relies on large quantities of related physiological or anatomical data (20,25,40). Each specific discipline has its specific expert system (5,6,7).

Expert systems are commonly rule-based production systems (13). The Software Technology Branch at NASA/JSC has developed a rule-based production system called CLIPS, the C Language Integrated Production Systems (9,12,35). CLIPS and its functions serve as an example of the principles and programming of expert systems (13). CLIPS is being used to automate the prediction process of the Infectious Disease Risk Assessment (IDRA) prototype (see below) and BRAIN (Biomedical Risk Assessment Intelligent Network).

NASA is presently supporting the development of three life sciences expert systems for use on long duration space flight:

1. The IDRA prototype, which assesses the risk of infectious diseases and recommends countermeasures to reduce the risks. The implementation approach and the results of this development are presented in this paper.

2. The Exercise Countermeasures Intelligent System (ExerCISys), which prescribes an exercise protocol to maintain muscle strength and cardiovascular aerobic capacity inflight.

3. The Performance Prediction Model (PPM), which assesses and predicts the level of work performance of astronauts. PPM assesses the cognitive sensory motor performance of the individual as it relates to the individual job tasks, or the individual's job as a whole.

These expert systems are independent from each other. They are designed for a single user and the data are not automatically shared. The greatest concern to us is the length of time required for a mission manager to resolve recommendations from these systems and then make real-time decisions.

A solution to this concern is the (BRAIN). The application of knowledge-based systems or artificial intelligence is a vital component of BRAIN. BRAIN is an integrated network for biomedical risk assessment and management. It provides the consensus of multiple experts. We hypothesize that BRAIN will reduce the time required for one to arrive at real-time decisions about biomedical risk analysis and management.

Others outside NASA will benefit from the development of BRAIN. Institutions such as hospitals, medical clinics, boarding schools, military services, and nursing homes for the mentally and physically handicapped are potential users.

IMPLEMENTATION APPROACH

1. Documentation Of Requirements

The preliminary software requirements of BRAIN will be documented according to the IEEE Standards Board and the American National Standards Institute (20).

The BRAIN concept is illustrated as a triangle (Figure 1) with users on the left side of the triangle and expert systems on the right side. The network still permits each user and system to work independently and interact independently with the mission manager. Through BRAIN, each system may access pertinent data from other systems. BRAIN cooperates with the independent expert systems by use of a knowledge base that relates all of them.

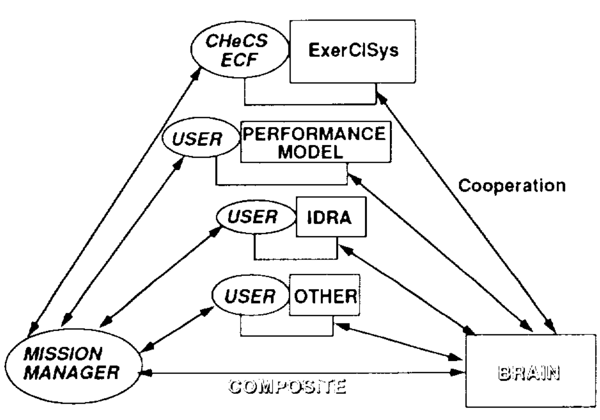

Figure 1. The BRAIN Concept

The functions of BRAIN are to:

- access IDRA, ExerCISys, PPM and other undefined systems for pertinent information.

- assess the biomedical risks and recommend countermeasures.

- function as a clearing house of information to be shared between systems.

- resolve incompatible information given by other expert systems and derive a consensus for a mission manager.

2. System Design

Knowledge Definition

A major activity of this project is to develop the knowledge-based system design. This includes the identification of data sources, knowledge definition, knowledge design and the architecture of the hardware/software environment for BRAIN. The knowledge definition task defines the knowledge requirements of the network and identifies and selects the knowledge sources. The knowledge is acquired, analyzed and extracted. The knowledge design comprises the knowledge representation, i.e., rules, internal fact structure, detailed control structure and preliminary user interface (13).

BRAIN receives input from PPM, IDRA, and ExerCISys, or the user, as illustrated in Figure 1. Other data that BRAIN requires are derived from textbooks, journal articles and reports. Inaccessible data may be simulated as necessary during initial development. The data are stored in a local or working database.

The data structure and network configuration of BRAIN must be compatible with IDRA, ExerCISys and PPM. These expert systems share related data through BRAIN by accessing the working database. We will test the feasibility of IDRA, ExerCISys and PPM to regularly post data that are required by other systems. A standard protocol will be established for each system to access BRAIN and vice versa.

The knowledge base for BRAIN utilizes and interprets the data, predicts the risk of biomedical problems and recommends the appropriate countermeasures. It is retrieved from the sources listed below.

- *Spaceflight Historical Information*
- *Expert Medical and Science Personnel*
- *Texts, Journal Article and Reviews*
- *Epidemiological Studies of Normal Populations*

The resources available in the medical sciences arena and NASA life sciences groups are explored for the knowledge definition of BRAIN. The relationships among IDRA, ExerCISys and PPM are defined by means of workshops, personal consultation and collaboration of existing study results. Experts will be identified so we can model their expertise and to evaluate the demonstration of BRAIN during the developmental stages.

Knowledge Acquisition

Once the knowledge base has been defined for BRAIN, methods will be developed to acquire the specific knowledge. Since a great deal of knowledge has to be acquired for BRAIN, an automated method may be required for that purpose. That method must be consistent and reproducible while extracting information from human experts and written sources.

Knowledge Design

A conceptual design of BRAIN is illustrated in Figure 2. Further definition of the knowledge representation and design is delayed until the Knowledge Acquisition is completed. At that time, more will be known about the structure of the knowledge and how it can best be represented.

It is anticipated that the knowledge may be subjected to a software tool called RuleMaster that uses the ID3 algorithm. The ID3 algorithm analyses empirical data and derives rules for the knowledge base of BRAIN. Advanced techniques, e.g., CLIPS, will be tested to automate the biomedical prediction process. Other existing and newly developed tools will be evaluated for their best knowledge representation and design capability.

BRAIN will be designed with a learning capability. It will incorporate, by a feed-back mechanism, the experience of an expert . The decisions and interpretations of data obtained from actual test cases are acquired automatically in the knowledge base and new rules are induced. This function is entirely under the control of the appropriate user. But once initiated, it is automatically included in the knowledge base. Tools such as the Automated Reasoning Tool (ART) and the Automated Structured Rule Acquisition (ASTRA) are being used to capture the expertise of exercise physiologists for ExerCISys. ART and ASTRA are being evaluated for application to BRAIN.

Knowledge Verification/Validation

Verification and validation of BRAIN is a vital step throughout the life cycle of its development (9,18). Verification of BRAIN determines that the software is developed according to specifications. Validation determines that BRAIN performs the functions as specified by the requirements and is usable for field testing (11).

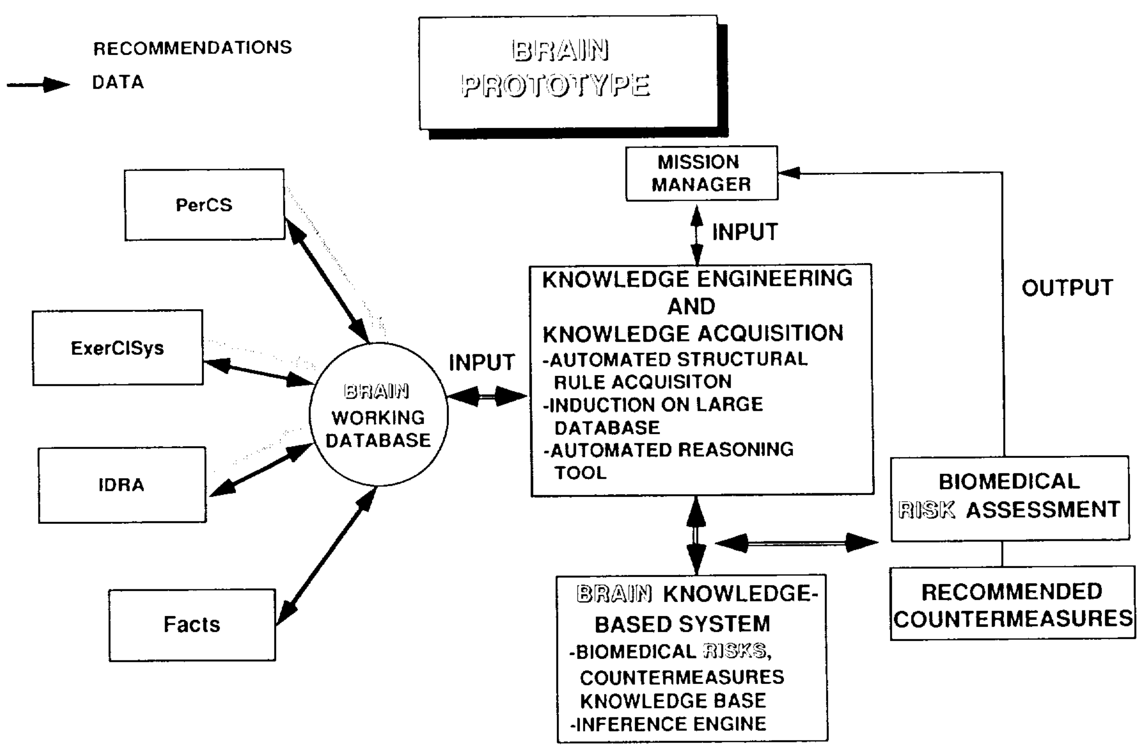

Figure 2. Conceptual Design Of Brain

During the knowledge design, verification determines that the design adheres to the requirements. The knowledge base is verified by checking specific details to the level of each rule.

Validation of BRAIN encompasses aspects of:

- determining the validation criteria. (25)
- specifying the sets of input data.
- developing a library of test cases and detailed space flight scenarios.
- validating BRAIN by an independent panel of experts.
- using BRAIN in parallel with the independent operation of PPM, IDRA and ExerCISys and then comparing the results. (11)

After the Preliminary Design Review of the project, the detailed design description will be documented. It will specify the logic and content of the knowledge base, the implementation of the system, hardware requirements, the detailed user interface and the detailed demonstration plan.

The hardware/software environment of BRAIN will be compatible with PPM, IDRA, ExerCISys and Space Station Freedom standards. The development environment that is used to create the software may not run on the identical platform as the demonstration version.

3. User Interface

It is essential for the flight components of BRAIN to have user friendly interfaces. Ease of use is important to whether or not a system is fully utilized. The X-Window System will be used to develop the preliminary user interface. The user interfaces to BRAIN will be designed in accordance with human factors principles and the Space Station Volume of the Man Systems Integration Standards (NASA Std 3000) document. Some of the factors that will be addressed are controls, visual displays and auditory demonstration displays (41). Prior to completion of the final BRAIN design, all interfaces will be empirically evaluated using subjects similar to the typical user. Based upon findings of this study, the design of the interfaces will be refined.

After BRAIN is developed, it will be field-tested during future space flights, bed rest studies, military activities and Antarctic expeditions. New versions of BRAIN will be developed (based on field-test results) to accommodate each test environment. The scientific potential for advancing telescience communications between BRAIN and remote study locations also exists and will be explored. Advanced computer technology promises to assist humans in the 21st century to better cope with the uncertainties of health, safety and performance at home and in the work place.

Table I. Expected results. At the end of the project period the products will function as indicated.

PRODUCTS	FUNCTION
BRAIN SOFTWARE (Interference Machine)	Automates the biomedical risk assessment and prediction process by appropriately executing the rules
	Accesses IDRA, ExerCISys, and PPM
WORKING DATABASE	Contains the facts required for rules
BRAIN KNOWLEDGE BASE	Evaluates and interprets the related outputs of IDRA, ExerCISys, and PPM in a set of rules.
BRAIN OUTPUT	Generates a composite risk analysis and recommendations to assist the user in making real-time decisions
STANDARDIZED PROTOCOL FOR INTEGRATION	A standard procedure to integrate expert systems in BRAIN
COMPUTER HARDWARE CONNECTIONS	Communicate with IDRA, ExerCISys, and PPM
USER-FRIENDLY COMPUTER HARDWARE/SOFTWARE	Increase efficiency, productivity, and quality of the BRAIN output

4. The IDRA Prototype

Because the prevention of infections in space is important, an IDRA prototype was developed (3,28,33). The goal of the functional IDRA prototype is to test the feasibility of using knowledge-based systems for infectious disease risk assessment.

The IDRA prototype focused on respiratory infections, especially influenza. The epidemiology and procedures for preventing, diagnosing and treating influenza are well defined (1,4,38).

Epidemiological studies have evaluated the risk factors and their predictive value for influenza in the general population (8,24,35) and the efficacy of chemotherapeutic prophylaxis (14). Earlier studies investigated the outbreak of influenza in isolated populations, e.g., on aircraft (27), ships at sea (32) and college campuses (23,34). From these sources, we concluded that sufficient information was available to construct a knowledge base about influenza.

Studies show that exercise has a profound effect on the immune system (22,30,31) and sometimes induces changes similar to those arising from the stress of space flight (16). The exercise regimen and related physiological data are factors that must be taken into consideration for the risk assessment of infectious diseases and for prescribing an exercise program. This was exemplified on the MIR when Cosmonaut Gennady Strekalov caught a cold following exercise (reported by the Associated Press, October 18, 1990). The IDRA prototype will be compatible with the ExerCISys prototype. We will integrate IDRA with the ExerCISys as a model for BRAIN.

IDRA Results

The knowledge for the IDRA knowledge base was extracted and analyzed from textbooks and journal articles. We identified the critical indicators that predict the probability of respiratory infections. These indicators were best understood for influenza.

The risk of influenza for an individual is described by general population statistics. It is dependent on an individual's location, age group and level of immunity. This information is encoded in a set of 23 rules using CLIPS. The integrated knowledge-base of IDRA and ExerCISys will contain information about the relationship between exercise, the immune system and infections.

Figure 3 illustrates the major components of the IDRA prototype. A C-based data management tool interacts with all the components of the system. It processes information from the database and from the user interface. The expert system using CLIPS assesses the probability of influenza. It retrieves the information from the data management tool and outputs it to the user interface. A screen displays the probability of infection and illness in the form of a text and a graph.

For the preliminary user interface, we used the X-Window System. All of the tools are portable and compatible with Space Station Freedom requirements.

CONCLUSIONS

- BRAIN can help solve the problems of assessing biomedical risks and performance decrements of humans working in microgravity.

- BRAIN can provide a consensus to the mission manager by surveying independent expert systems.

- The functional IDRA prototype demonstrates that risk analysis for influenza can be automated using C Language, CLIPS, and the X-Window System. The IDRA prototype will be integrated with ExerCISys and used to develop BRAIN.

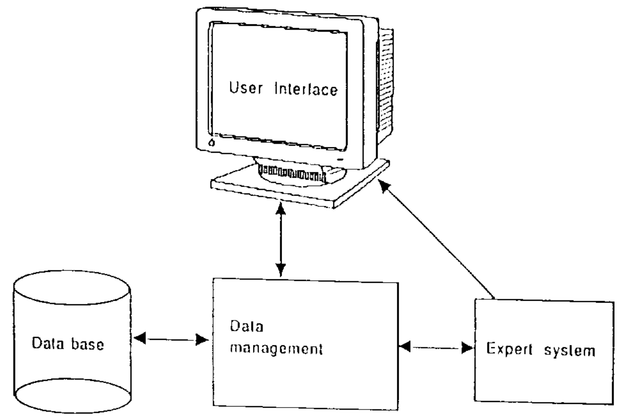

Figure 3. The Major Components Of The IDRA Prototype

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