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DEVELOPMENT AND EXPERIMENTATION OF AN EYE/BRAIN/TASK TESTBED

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An SBIR (Small Business Innovative Research) Phase I was awarded to Analytics to investigate the feasibility of an innovative concept that uses an operator's brain waves as a control mechanism for computer systems. The Phase I reported that the present brain wave recording technology is incapable of using these signals for direct data transmission. But the development of such technologies as super conductive materials at near room temperature and biomagnetism is advancing rapidly. A direct application from conventional MEG or EEG sensing systems could determine an operator's state of awareness.

The principal objective of Phase II is to develop a laboratory testbed that will provide a unique capability to elicit, control, record, and analyze the relationship of operator task loading, operator eye movement, and operator brain wave data in a computer system environment. The ramifications of an integrated eye/brain monitor to the man and machine interface are staggering. The success of such a system would benefit users of space and defense, paraplegics, and the monitoring of boring screens (FAA, nuclear plants, Air Defense, etc.)

INTRODUCTION

A variety of man-machine interface concepts have been developed in recent years in an attempt to: (1) increase the flow of relevant information between the system and the operator, and (2) alleviate the need for complex programmer-oriented input protocols. These concepts have concentrated on the presentation, selection, or display aspects of the interface. Another component of innovative interface design is control mechanisms for computer systems. Development of advanced hardware and software systems for mission planning and control is desirable to enhance the human operator's job performance, especially during periods of high workload.

METHODOLOGY

The Phase I research was an investigation of the feasibility of using brain waves as a control input to a computer system. Currently, there are a number of devices, such as the mouse and the touch screen, that allow for more direct and intuitive control than do conventional keyboards. Use of these devices requires only simple software for managing hardware communication protocols, but the approach to controlling a system via brain waves requires more sophisticated software for the interpretation of encephalographic data. Although, in the absence of pilot studies, it is premature to assume that brain wave sensing is capable of conveying complex instructions to a computer, it seems plausible that brain waves are capable of conveying coarse information.

In order to establish the feasibility of the concept of using brain wave sensing for computer control several research questions were addresses. A review of several technologies was undertaken in order to evaluate the relative merits of each technology to the application.

Another issue considered in the Phase I research was the current status of hardware necessary for measuring brain waves. The field of neuromagnetometry is advancing rapidly, but is still in its early stages of development. It was clear that if conclusions were based on existing instrumentation and methods of data analysis the results of the Phase I feasibility study would have been that the control of systems through brain wave signals was not very practical. Therefore, the scope of the Phase I research was expanded to include an evaluation of anticipated future developments in instrumentation.

The approach to the Phase I feasibility study involved several research techniques. Initially, an extensive literature search was conducted to determine the state-of-the-art in the application of MEG technology. The literature review revealed that MEG had advantages over the conventional EEG, however the scope of the MEG was limited.

Electroencephalography (EEG)

In the domain of the spontaneous EEG only a very limited band of EEG activity could be of possible use. Alpha activity is of large amplitude and it is strongly associated with activity of the visual cortex in the relaxed, wakeful but visually inattentive individual. In principle, the modulation of alpha by changes in the level of visual attention could be used for control of computers. However, this would be a very primitive level of control, as the changes in level of alpha activity are quite slow as compared to the speed with which a person can type instructions at a computer keyboard. To date, studies of the effects of changes in level of attention have been based on very simple experimental paradigms. The results of these studies do not provide conclusive evidence regarding the variables that affect the alpha wave form. Therefore, alpha and its modulation should be studied further using procedures that provide a much greater degree of experimental control over the amount and type of mental work being done by the subject.

Magnetoencephalography (MEG)

Magnetic recording techniques offer several advantages for monitoring specific neural activity in the brain with regard to computer control. However, some of the problems associated with the EEG are also present in MEG. Specifically, alpha activity is indeed the strongest MEG spontaneous signal, it is not certain precisely how it is affected by states of attention, as well as intentions, even when these states are under very good experimental control. Clearly the problem resides in the cognitive processes of the human operator, and not within the recording techniques. For example, subjects given a vigilance task in which they simply monitor an oscilloscopic display are required to make decisions based upon changes in the visual information. The relative frequencies with which such decisions must be made, the difficulty in making the "correct" decision, the properties of the display itself (e.g., spatial frequency content, flicker or temporal frequency, moving or static targets), and the duration of an experimental session are all factors that could affect MEG output.

Eye/Brain/Task Monitor Concept

A system for monitoring operator task activity can now be built around the manual control operations necessary to perform various task procedures. This is possible because a computer can easily be made aware of these events. A certain degree of task-level ambiguity is inherent in such operations but most of these could be resolved with a fair degree of certainty by reference to fixed task-domain knowledge. However, a more severe criticism can be leveled against such a system on the grounds that its results are of too coarse a grain. Decisive action is usually taken after a considerable period of "silent" mental activity -- analytical tasks performed by an operator are not likely to be identifiable in the sequence of manual control operations. Unfortunately it is just such tasks which are of critical importance to decision aiding and intelligent problem solving systems. Analytics believes that a system which records and correlates human ocular and brain wave activity can bridge the gap between isolated manual control operations.

The examination of ocular activity can clarify what is going on during discrete control events. Eye data is ambiguous when used to identify an ongoing task: scanning out a straight line could as easily mean that the operator was tracking a moving object, estimating a path, or even briefly glancing from one point to another. Since the effect of visual attention and vigilance on brain wave activity is extremely robust, it is expected that components within specific wave bands can be used to disambiguate ocular behavior vis-a-vis operator performance of analytical tasks. This is not to say that brain wave data will not itself prove ambiguous, for it will undoubtedly do so. The entire task identification problem is characterized by the need to resolve potential ambiguities and conflicts in and between all the various levels and types of available information -- eye position, brain wave readings, manual events and fixed domain knowledge.

In order to handle mutual disambiguation, an actual system must be capable of passing information both upwards and downwards between levels to achieve a "best fit" between the low-level information and the high-level task hypotheses. This type of processing has been applied successfully in the domain of speech recognition (for example, in the HEARSAY system), where low-level phoneme and word recognition is permitted to interact with higher-level notions of syntax and semantics. Errors and ambiguities in word recognition can be corrected by determining what "makes sense" in the context. This kind of approach is generally termed "hypothesize-and-test", since there are several independent knowledge sources and the interpretation of each can be evaluated against the interpretation of the other. Also termed "iterative guess-building", the reinterpretation ceases when some predetermined level of confidence has been attained for the interpretation system as a whole. For the eye/brain/task monitor it is expected that eye data, brain wave data, manual control data, and knowledge of the mission task domain (a task syntax) can be fused to build a continually updated task history which can be extended as needed for purposes of prediction. In the context of this application, the feasibility of using brain wave information to contribute to computer system control appears highly plausible.

The successful application of brain wave data to intelligent systems revolves around a thorough understanding of the complex linkage of task structure, operator eye-movement, brain wave response, and task syntax. The definition of that linkage at a level sufficiently specific to provide the basis for distributed intelligence system algorithms requires that a testbed be developed that focuses specifically on the issue of eye/brain/task linkage (Figure 1).

Analytics, under contract to NASA, has pioneered development of the application of eye-sensing technology to computer control and has successfully integrated an eye/voice controlled interface into a complex task/scenario generator. This unique system, called OASIS, has been refined and demonstrated as a working prototype. OASIS will provide a baseline system that will be further refined with the addition of brain sensing capability into a functional prototype testbed that will focus directly on the issue of eye/brain/task linkage.

TECHNICAL FEASIBILITY OF COMPUTER CONTROL

In almost every field where computer hardware is employed, operator work stations are characterized by growing complexity and continuously increasing data flow. In general, two major issues are of prime concern: 1) the increased operator workload and 2) the reduced habitability which typically results when older control technologies are extended to support increased functionality.

Workload problems are believed to be responsible for operator errors in critical tasks and more generally for reductions in operator effectiveness or productivity. A competent workstation design attempts to reduce workload by efficiently organizing the entire suite of operator tasks. More recently, system developers have begun to focus on the possibility of creating additional channels for operator/machine communication and of redistributing workload across the resulting range of control options. This is of special interest when a continuous control task such as steering must be integrated with a variety of other operations. Offloading to new control channels os also of interest in the context of special environmental conditions such as high G forces where normal operator functioning may be highly restricted. The development of commercially available voice systems is the most obvious result of this approach to the issue of operator workload, although other technologies such as control by head position are already in use. Voice interaction has been of particular interest to developers in the aerospace industry where hands-busy and eyes-busy operation are common and where workload redistribution is an attractive solution.

Humans and machines are rapidly becoming components in distributed intelligence systems where tasks are performed cooperatively. When tasks are complex, the passive role of "ready servant" requires that operator needs be anticipated, much as the nurse attending a surgeon must know what is likely to be requested before the request is made. As the computer begins to take on a more active role, the need for machine knowledge of operator activity and intentions becomes essential. Now the machine may need to query the operator regarding his actions or plans, as well as spontaneously criticize or offer alternative solutions. Ideally, a smart system would know when intervention was appropriate. By analogy to the situation of human cooperation, it is obvious that in all but the most critical situations the appropriateness of intervention is dependent on an understanding of what the operator is doing or is about to do.

In order to cooperatively solve a problem, humans depend on shared knowledge regarding the problem domain and available courses of action. Techniques are already available for providing machines with this type of intelligence. However, humans also depend on observation of their partners, frequently utilizing subtle cues to assess the significance of more easily recognized actions. For example, facial expressions and posture are usually taken as indicators of a person's relative satisfaction with the results attained by specific goal directed activity. Efficient human cooperation requires just this kind of inference in order to continuously adjust individual strategies as a problem develops over time. Unfortunately, the cues used by humans themselves are by no means completely understood and many, such as facial expressions, would require major research efforts before the sensing equipment itself could be developed. In order to provide a machine with the inference capabilities required for efficient cooperation, all available resources will have to be focused on machine understanding of operator behavior. This will require a dedicated, focused laboratory facility such as the EBT testbed.

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NEXT STEPS

The Phase II effort will concern itself with the development of a prototype Eye/Brain/Task (EBT) testbed, and through applied research and development, the refinement and optimization of the system. The principal objective of the proposed Phase II effort is to develop a laboratory testbed that will provide a unique capability to elicit, control, record, and analyze the relationship of operator task loading, operator eye movement, and operator brain wave data in a computer system environment. Additionally, the testbed will have the capability to serve as the vehicle for demonstrating computer control using brain waves at a future time.

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