A Situation-Driven Adaptive Pilot/Vehicle Interface

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Abstract

This paper describes an effort under way to develop pilot/vehicle interface (PVI) concepts that use computational situation assessment models and pilot workload metrics to drive the content, format, and modality of cockpit displays. The goal of this research is to develop PVI concepts that support a tactical pilot's situation awareness and decision-making. The envisioned system is driven by two key information streams: 1) a ***content path****, driven by a tactical situation assessment module that uses avionics system outputs to determine the aircraft's current tactical situation and the pilot's information needs based on the situation; and 2) a* ***format path****, which uses an estimate of the pilot's state (workload level, attentional focus, etc.) to determine the most appropriate modality for conveying the required information to the pilot. The system will be integrated into the SIRE simulator at the Armstrong Laboratory.*

Introduction

Advances in aircraft performance and weapons capabilities have led to a dramatic increase in the tempo of tactical situations facing the combat pilot, reducing the pilot's available processing and decision time. Technological advances in cockpit displays and electronics have resulted in an explosion in the complexity and sheer quantity of information that is available to the pilot. The pilot has more things to deal with in the cockpit (each of which is becoming more complex to understand), and less time with which to deal with them [1]. This motivates the development of advanced pilot/vehicle interface (PVI) concepts that will make optimal use of the pilot's abilities, while recognizing his limitations. The PVI should enhance the flow of information between pilot and cockpit in such a way as to improve the pilot's situation awareness and decision-making, while alleviating workload, and thus improve the pilot/vehicle system's survivability, lethality, and ultimately, its mission effectiveness.

To meet these objectives, a clear understanding of the pilot's capabilities and limitations should drive the development of the interface concept. The objective of this work is to investigate the feasibility of developing interface concepts that adapt PVI content, format, and modality to meet the pilot's information needs as a function of the tactical situation and the pilot's workload level. The goal is to develop a PVI that knows what the pilot needs to know, when he needs to know it, and how to convey that information (i.e., via visual, auditory, or haptic interfaces).

A number of requirements must be met to develop an adaptive PVI for improving mission effectiveness. The air-combat task is a process in which the pilot must make dynamic decisions under high uncertainty and time pressure, and rapid change. It has been well-demonstrated that high pilot *situation awareness* (SA) is a key predictor of engagement success in complex time-stressed scenarios [2-7]. As a result, improving pilot SA in air combat has become a key goal of the Human Systems Technology Recommendations made by USAF's Development Planning Directorate. Many new technologies and subsystems are being considered to enhance pilot SA, including advanced sensors, on-board datalinks to theater C^3I systems, helmet mounted virtual reality displays, and decision aids. Given the importance of situation assessment in the cockpit, any PVI should maximize the pilot's SA, without overloading him with superfluous information.

A multi-modal PVI should take advantage of a human's capacity for parallel processing across sensory modalities. At the same time, it should reflect the human's perceptual, cognitive, and performance limitations within these modalities. The use of multivariate measures of pilot workload offers considerable potential to adapt the display to pilot state. For example, if a workload assessor determines that the pilot's visual channel is saturated (or if his line-of-sight is directed out the window), a high-urgency display element that would nominally be presented on a visual display (e.g., approach of a *g*-limit) could be presented auditorally or via force feedback in the control stick. Furthermore, the PVI could prioritize and filter visual displays to present only the highest priority information for the current tactical situation, to alleviate the pilot's visual search workload and make the crucial information readily available. Another possibility is to have the PVI control the allocation of tasks between human (manual) and system (automated) as a function of the pilot's level of engagement in the task [8] or his mental workload [9]. In all cases, the PVI adaptation strategy should be founded on a coherent model of human capabilities, to maximize effectiveness of the pilot/vehicle system. If the adaptation is performed in an *ad hoc* manner that does not take into consideration human limitations and the pilot's needs for accurate situation assessment, the effect may be counterproductive, and serve to degrade pilot performance and mission effectiveness.

Background

Pilot Situation Awareness and Decision-Making

Situation awareness is the starting point for pilot decision-making and procedure execution. The pilot obtains information to maintain awareness of the flight situation visually (through aircraft windows and from instruments), aurally (from other crew members and over radio communications), and through vestibular senses. The information thus obtained forms the basis of the pilot's decisions. Since all of the pilot's information-gathering skills are subject to error, failures in maintaining adequate SA can severely impact flight safety and mission effectiveness.

The relationships between SA, decision-making, and task performance have been studied extensively by psychologists and human factors researchers, primarily through empirical studies in the field but increasingly so with computational modeling tools. Early decision-making models viewed the decision-maker as "faced with alternatives, and considering the consequences of each alternative in terms of analysis of future states (odds/probabilities) weighed against alternative goals (preferences/utilities)" [6]. However, subsequent research found that *expert* decision-makers did not generate or evaluate options, but focused almost exclusively on situation assessment, the process by which effective decision-makers achieve situation awareness. Experiments were performed on the decision-making of expert fire ground commanders and tank platoon leaders under high time pressure, and it was found that once they had assessed the situation, the reaction strategy was almost automatic. In contrast, only *novice* decision-makers generated and evaluated options.

McDonnell Aircraft Company conducted a study of air-combat decision-making, in which Tactical Air Command (TAC) line fighter pilots flew in realistic man-in-the-loop simulations. In this study, SA was identified as the "single most important factor" in mission success. The study concluded that "success is tied to good situation assessment, and generally speaking the better the situation

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assessment the better the outcome" [10]. This point of view on human decision-making is now formalized as the *Recognition-Primed Decision* (RPD) model to distinguish it from the classical *option-selection* model [6].

Given the importance of SA, the PVI should take into account the pilot's needs for accurate, timely situation assessment. Endsley [1] lists a number of caveats to be considered in the development of intelligent interfaces that use filtering strategies to manage the information flow and support the situation assessment function:

1) The pilot's temporal transition from goal to goal must be considered. Each goal will have certain SA requirements, dictating which information is most important to that goal. Switching between goals may occur rapidly, requiring an almost immediate response. However, pilots do not instantly achieve SA by looking at instantaneously presented information. Rather, it is developed over a period of time by observing system dynamics. If a filtering strategy changes displays under the expectation that the pilot will achieve full SA immediately, problems may occur. The pilot will be unable to build up his awareness over time, and may have difficulty in orienting himself to a new situation. If the interface changes on its own, it may inadvertently require that the pilot direct more attention to *attaining* SA, just to keep up with display changes.
2) The pilot must be able to respond to immediate crises, and look ahead to possible future situations. This will enable the pilot to plan ahead to avoid unwanted situations, or plan future actions ahead of time. Accordingly, the information filtering strategy should ensure that the pilot is not denied access to information that will support looking ahead.
3) Individual differences should be considered with respect to the formulation of interface adaptation strategies. Pilots may differ from one another in the types of information they use to assess a situation. These differences may exist between individual pilots, and also across different tasks for the same pilot (or even change as a function of experience).

To cope with these potential problems, Endsley suggests the following principles be considered when formulating adaptive interface design schemes:

1) The pilot should be kept informed of the "big picture." The PVI should enable him to maintain a global understanding of the developing situation. The big picture need not depict tremendous detail, but rather provide high-level information about a broad range of elements. The pilot should be able to focus in on any particular element on demand. The big picture will provide a good backdrop for rapid switches between various parts of the picture. This will help to minimize orientation time as the system prioritizes specific pressing elements to deal with.
2) The pilot should be incorporated into the control loop in an effective manner. The system should do things for the pilot, not to him. If the pilot is incorporated into system decisions (when to switch between displays, filter out certain elements, or incorporate others), the pilot's "system awareness" (a subset of overall SA) will improve and the workload involved in tracking autonomous display changes will be minimized.
3) When information is filtered, the cues that are critical to the pilot or triggering long-term memory stores should not be filtered out. Situation assessment depends in part on relating perceived cues in the environment to past experience. As such, it would not be appropriate to block any information that makes it difficult for the pilot to relate a current situation to something he has experienced in the past.
4) Individual pilot differences should be considered; it may be that experienced pilots require one filtering scheme and less experienced pilots require another in certain categories of situations. At other times, global filtering schemes may be appropriate for pilots of all experience levels.

These guidelines will serve as a framework during our effort to develop a rule-based logic for PVI adaptation, to ensure that the proposed PVI supports pilot situation awareness and mission effectiveness, while trying to alleviate workload.

Human Performance Limitations

Any PVI adaptation strategy should be founded on a coherent model of human capabilities and limitations. Wickens [11] discusses a number of issues that pertain the human's ability to share mental resources across multiple tasks, in the context of a multiple-resource theory of human information processing. These are discussed in terms of the compatibility between *stimulus modality* (visual or auditory), *central processing* (spatial or verbal), and *response* (manual or speech) (S-C-R compatibility). With regards to stimulus, often it is the case that humans can divide attention between the eye and the ear better than between two visual channels or two auditory channels; i.e., *cross-modal* time sharing can be better than *intramodal* time sharing. Earlier, Wickens *et al* [12] found that cross-modal displays possessed advantages over intramodal displays in a laboratory experiment and a complex flight simulation task. Reaction time studies indicate that auditory/speech and visual/manual S-R assignments are most compatible.

Consideration should also be given to the cognitive resources that a task demands. Any task requiring a judgment or integration concerning the three axes of translation or orientation is said to require *spatial central processing codes*, while any that requires the use of language or some arbitrary symbolic coding for completion is a *verbal* task. In the airplane, spatial tasks are those that involve tracking and orientation of one's own aircraft and other aircraft. Verbal tasks use language (e.g., communication), or discrete logical operations (e.g., interaction with hierarchical data systems). The benefits of auditory/speech assignments are best realized when associated with verbal tasks, while visual/manual assignments should be associated with spatial tasks.

In many circumstances, operators perform only one task at a time, and the principle of S-C-R compatibility can provide guidelines for design. In an environment such as the airplane cockpit, the pilot must time-share his attention across multiple tasks. As such, the competition for processing resources between concurrent tasks must be considered. Two tasks that share common resource demands will be time-shared less efficiently than two tasks having non-overlapping demands. Accordingly, the PVI should be designed in such a manner as to make the most efficient use of the pilot's time-sharing ability. When the PVI modifies display modalities, it should have minimal adverse impact on the competition for the pilot's resources.

Situation Assessment Modeling

A variety of situation awareness models have been hypothesized and developed by psychologists and human factors researchers, primarily through empirical studies in the field, but increasingly so with computational modeling tools. The U.S. Air Force has taken the lead in studying the measurement and trainability of SA [13]. Numerous studies have been conducted to develop SA models and metrics for air combat [1-7, 10, 14].

Belief Networks for Situation Assessment Modeling

A computational model of SA requires a technology that has: 1) a capability to quantitatively represent the key SA concepts such as situations, events, and the pilot's mental model; 2) a mechanism to reflect both diagnostic and inferential reasoning; and 3) an ability to deal with various levels and types of uncertainties, since imprecise information prevails at each step of the SA process. Through numerous projects, we have found that belief network (BN) technology is an ideal tool for meeting these requirements and modeling SA behavior. Belief networks (also called Bayesian networks, inference nets, or causal nets) are directed acyclic graphs of nodes and directed links, where each node represents a probabilistic variable whose probability distribution is denoted as a belief value, and each directed link represents an associative or inferential dependency between nodes, quantified by a conditional probability matrix associated with the link.

The origins of BNs can be traced back to the inference networks of PROSPECTOR [15]. They were developed in their present form by Pearl [16], Heckerman [17], and others, and were recently embraced by Microsoft as a cornerstone technology in developing its intelligent operating systems, user interfaces, computer languages, and speech recognition paradigms [18].

The unique strength of BN technology comes from its combination of two powerful artificial intelligence (AI) tools: neural networks and Bayesian reasoning. Like conventional neural networks, BNs represent domain knowledge using nodes and links that can carry and modify information propagated among nodes. The knowledge stored in the network (nodes, links) can be specified *a priori*, or learned from examples. The network outputs can be an intricate nonlinear mapping from the inputs. However, unlike conventional neural networks whose knowledge representation and information propagation usually have no semantics and is totally incomprehensible, BNs represent knowledge in nodes and links using Bayesian reasoning that has semantics (beliefs and conditional if-then rules) naturally communicable to network developers. Furthermore, BNs use Bayesian reasoning logic as the basis for the information propagation and inferencing, reflecting a *rational* reasoning process.

Figure 1 shows a computational model of the situation assessor using BN technology. Its development consists of two steps: 1) developing a BN structure to represent the SA mental model; and 2) developing a belief update (propagation and projection) algorithm to reflect SA event propagation and projection.

The SA mental model representation uses a hierarchical BN of two types (or layers) of discrete nodes: situation (round) and event (square) nodes. As shown in figure 1, at the top of the BN are the situation nodes, each representing a particular situation. Below the situation nodes are event nodes, each taking on values from a set of mutually exclusive and collectively exhaustive states. An event state represents a specific event occurrence (e.g., a target range event might be represented via three states: long, medium, and short). The events can be observable or unobservable, and are represented by shadowed and non-shadowed square nodes, respectively. An observable event is one in which evidence is available by observation for inferencing the likelihood of event occurrence (e.g., the target range event is an observable event whose event likelihood vector can be determined using radar output), while an unobservable event node is one in which no direct evidence is available for inferencing its likelihood vector (e.g., the event targeted_by_a_missile is unobservable).

Through several previous projects, we have used BN technology to develop a computational model of the SA process. Our approach has the following four important advantages over other modeling approaches including rule-based, neural network (NN), and empirical approaches:

1) It provides the capability and flexibility to represent a pilot's mental model in its full richness via a graphic representation structure as powerful as NNs but at same time directly comprehensible to the model developer. This first feature facilitates the development of domain-specific SA mental models, via conventional knowledge engineering paradigms.

2) Each of the important SA concepts and processes such as situations, events, event cues, event propagation, event projection, situation assessment, and situation awareness is quantified. This enables a quantitative rather than just a qualitative description, to support comprehension and measurement of the SA process.

3) The event *propagation* algorithm reflects the continuity of situation assessment—an evidence accumulation process where the impact of new event cues is combined with the old ones to assess the situation based on all available evidence. Similarly, the event *projection* algorithm reflects the continuity of situation awareness—the projection of future events based on the currently assessed situation. This temporal continuity feature is not present in other memoryless approaches, such as rule-based or conventional NN-based approaches.

4) Bayesian logic is mathematically sound and provides a consistent and coherent automatic reasoning process. It is a normative reasoning process that prescribes what the ideal reasoning agent or operator associate should do, given the information-event-situation relationships and the information itself. This feature can thus be used for the design and development of on-line SA aids for the enhancement of pilot SA.

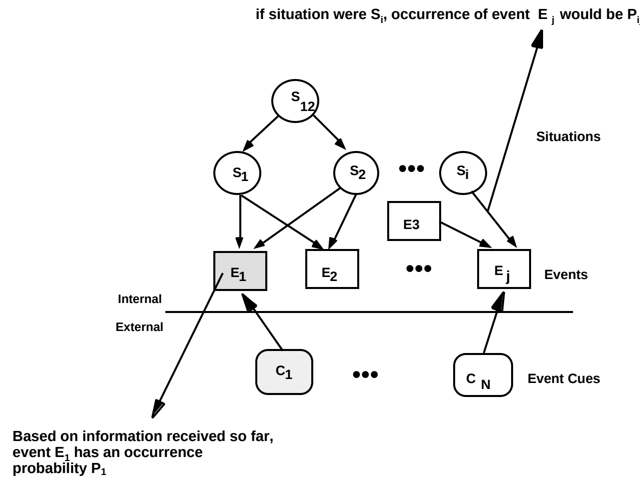

Figure 1. Situation Assessment Modeling Using Belief Networks

Workload Estimation

A key driver of the proposed adaptive PVI design will be a measure of pilot mental state. By pilot state we mean a set of metrics that serve to define the pilot's workload level and his level of engagement in a set of tasks. There exist three broad categories of workload measurement techniques: 1) subjective procedures, which use operator judgments of task workload; 2) performance-based techniques, which assess workload based on the operator's ability to perform tasks; and 3) physiological techniques, which interpret the operator's physiological response to a task to measure workload. During this effort we plan to explore the feasibility of integrating these methods to construct an overall measure of pilot state. Wierwille and Eggemeier [19] suggest that it is often desirable to use multiple workload measures, since a single technique may not always provide an accurate indication of operator loading. We briefly discuss how we can use the three methods for on-line workload assessment.

Subjective Workload Estimation

Subjective workload measures can first be computed off-line during the system design and evaluation process using any one of a number of established subjective assessment techniques (e.g., the modified Cooper Harper (MCH) Scale [20], the Subjective Workload Assessment Technique (SWAT) [21], or the NASA Task Load Index (TLX) [22]. The subjective measures can then be used in a *projective mode*, to estimate the workload that would be experienced under stipulated conditions or mission scenarios [19].

Performance-Based Workload Estimation

Performance-based workload assessment techniques are applied with the expectation that as an operator's workload increases beyond a certain threshold, the speed and accuracy of performance decline. Performance-based measures include two sub-categories of techniques: primary task and secondary task measurement. Primary task measures judge the operator's performance at the specific task of interest (e.g., following flight path guidance commands). A caveat associated with their use is that at low-to-moderate loading levels, humans can maintain a certain level of performance through increased effort. As such, the method may not be sensitive to variations in workload. Secondary tasks are laboratory procedures that assess workload by judging the performance at a second task that must be conducted concurrently with the primary task. When secondary tasks are used, the possibility of *intrusion* must be considered: the presence of the secondary task may result in a reallocation of the operator's resources during moderate or high workload levels; i.e., the attempt to measure workload affects the workload.

Carefully chosen and ecologically relevant performance-based methods can be applied in two ways here: 1) primary measures such as response time to system alerts and degree of flight path stability can be used to construct piloting proficiency measures; and

2) secondary tasks can be used in an off-line design phase to assess the relative benefits of different PVI configurations.

Physiological Indicators of Workload

In recent years there has been considerable interest in correlating human physiological response with implied workload. Wierwille and Eggemeier [19] review numerous recent efforts. Wilson [23] has developed methods to process physiological signals, and these have been incorporated into the Workload Assessment Monitor. Pope [8] has developed candidate EEG indices for characterizing an operator's level of engagement in a task. Such measures can optimally drive the allocation of functions between human and machine. Vidulich *et al* [24] explored the relationship between physiological measures and operator SA.

The incorporation of accurate physiological pilot state indicators offers tremendous potential for improving the link between human and machine. In particular, pilot loading measures on visual and auditory sensory channels can be used to dynamically vary the modality of specific PVI elements. For example, if we can determine that a pilot is heavily loaded on his visual channel at the instant that something must be brought to his attention, the auditory channel can be used to convey the information (using localized or non-localized audio, as appropriate). Also, if we can determine that the pilot is heavily engaged in some activity (evading an enemy, etc.) and does not have the resources to attend to another task (e.g., activate the ECM), the PVI could automatically perform the task and inform the pilot of its completion.

Multi-Modal Adaptive Displays

There have been a number of efforts addressing the potential of multi-modal interfaces in the cockpit, and we briefly review some recent results that are directly applicable to the current effort. Selcon, Taylor, and Shadrake [25] explored the potential of multi-modal warnings. They conducted an experiment in which warning/caution visual icons and verbal warning messages were used singly and in combination to alert subjects to danger situations. The results showed a significant decrease in response latencies when correlated bi-modal information was provided, as compared to either uni-modal alert. Furthermore, subjective SA rating scores indicated a potential benefit in workload and depth of understanding. Within the context of the RPD model, the increased information provided by two sources can increase the "recognizability" of the stimuli (through greater associational links), thus improving SA and decision-making. They suggest that the presentation of correlated, bi-modal information can be a desirable design goal for functions where attentional priority is not an issue. In another study, McKinley *et al* [26] examined the effect of 3-D auditory cueing on visual target detection. The results indicated a substantial benefit in terms of objective performance measures and subjective workload measures. The effects were most pronounced in restricted field of view conditions.

Some recent efforts have explored the potential of haptic interfaces, which use the pilot's sense of touch to convey information. Brickman *et al* [27] conducted a simulation experiment in which a force-reflecting control stick was fed with information concerning lateral deviation from a runway centerline during landing. Results indicated a consistent advantage in performance and perceived workload for the force feedback system, particularly in heavy turbulence.

Stall warning systems such as stick-shakers or stick-pushers have been available for years to warn pilots of impending stall conditions. In the rotorcraft community, Massey [28] explored the development of "carefree" handling systems for helicopters, with the goal of improving the pilot's ability to use full vehicle performance while minimizing workload associated with monitoring limits. In a survey of 70 pilots flying seven helicopter types in a variety of missions, it was found that approximately 40% of the pilot's workload during a typical mission was associated with respecting limits. He explored HUD, audible, and tactile cueing of limits in a piloted simulation study. He found that warnings (*both* visual and auditory) often went unnoticed in high workload situations, and more significant performance benefits were afforded from *direct intervention* methods, which actively prevented the pilot from pushing past a limit. Similar results were found by Howitt [29]. Notably, most of the pilots who participated in the study rejected the notion of an active control intervention scheme, preferring instead a head-up or helmet-mounted display study. As in Massey's study, it was found that such warnings often were unnoticed in high-workload situations, and the active control intervention yielded significant benefits in terms of limit protection, workload reduction, and increased agility. We believe that these results are directly relevant to the proposed effort. For example, if the workload assessor determines the pilot to be heavily loaded in the visual channel and an auditory alert goes unnoticed, the PVI control module could get the pilot's attention by altering the control stick's force gradient.

System Architecture

Overview

Figure 2 shows a block diagram of the system that we plan to develop, shown within the context of an overall pilot/vehicle system. The dotted lines indicate the scope of the proposed system. The initial effort will focus on the development of PVI adaptation strategies, but we first describe the system's overall operation as envisioned. The system design will be structured in such a manner as to facilitate its implementation within the Synthesized Immersion Research Environment (SIRE) flight simulator [30] at the Armstrong Laboratory.

The pilot interacts with the aircraft using a number of modalities. Graphical displays may be in the form of head-down, head-up, or helmet-mounted displays. The PVI provides auditory alerts in the form of tones or synthesized speech, using localized 3-D or non-localized audio as appropriate. Speech recognition technology may make it possible for the pilot to command system modes and content verbally. The pilot operates the aircraft via manual control inputs, and he may receive tactile feedback from the controls via (for example) a control loading system.

The content, format, and modality of the PVI's output is controlled by the **PVI control module**, which is driven by two key information streams: 1) a **content path**, driven by a tactical situation assessment module that uses avionics system outputs to determine the aircraft's current tactical situation and the pilot's information requirements based on that assessed situation; and 2) a **format path**, which uses an estimate of the pilot's state (workload level, attentional focus, etc.) to determine the most appropriate modality for conveying the required information.

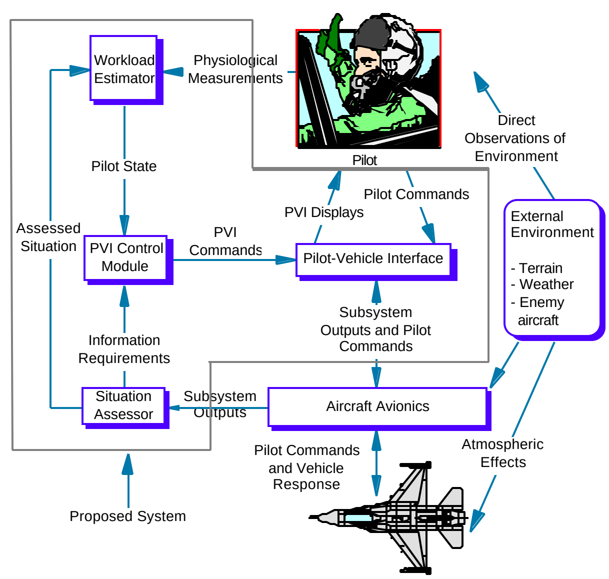

Figure 2. Functional Block Diagram of Proposed Adaptive Pilot/Vehicle Interface.

Figure 3 presents an expanded view of the PVI control module, along with the situation assessor and workload estimator. The structure of the content path is loosely based on the Crew/System Integration Model, which is an integrated model of aircrew SA and decision-making that has been used for analyzing the fighter attack mission [31] and air superiority modeling [7]. The first step in the content path is the **information processor** module, shown in the diagram's lower right portion. This entity consists of a continuous state estimator and a discrete event detector. The continuous state estimator uses avionics system outputs to generate estimates of the vehicle's linear and angular velocities, position, and attitude, as well as significant subsystem states, and states of any targets or threats that might influence overall situation assessment. The event detector generates occurrence probabilities of mission-relevant events, such as system failures, requests for action, mission-related milestones, or other enunciated conditions (e.g., radar lock-on).

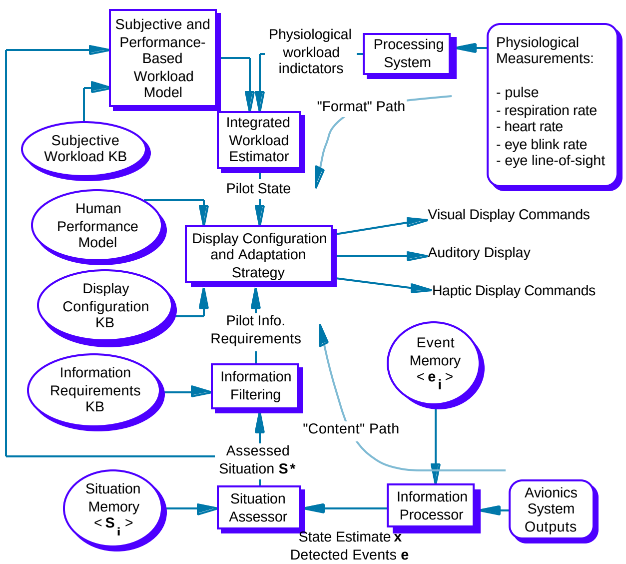

Figure 3. Detailed System Architecture.

The **situation assessor** block takes in the estimated states and the detected events, and generates an assessed situation **S***, which is a multi-dimensional vector defining the occurrence probabilities of the possible tactical situations that face the pilot. For model tractability, a fixed and pre-defined set of candidate situations is assumed, determined solely by their mission relevance. That is, a situation defines an aggregated set of states, events, and possibly other situation that call for a given course of action or procedure selection on the pilot's part. The situation assessor relies on *Bayesian Networks*, as described earlier.

Given the assessed situation **S***, the **information filtering module** prioritizes the information stream to determine what information must be presented to the pilot to support his SA and procedure execution. Filtering strategies rely on a hierarchy of events, goals, and situations and a prioritization of information in relation to these to remove superfluous data [1]. Information filtering seeks to ensure that at any given time, the information presented to the pilot directly supports his current goals, without distracting or overloading him. The output of the module is the specification of the information that will be presented to the pilot.

The other side of the system is the format path, which uses an estimate of pilot mental state (workload, task engagement level, etc.) to determine the appropriate modality and format for configuring the PVI. The first element of the format path is the physiological processing system, which can use measurements such as (but not restricted to) the pilot's pulse, respiration rate, eye blink rate, eye line-of-sight (which could be determined from an HMD-mounted eye tracker), and EEG measurements to compute physiological correlates of pilot workload. The intent of this effort is not to design new systems for computing such correlates, but to leverage existing systems (e.g., the Workload Assessment Monitor [23]) to drive the creation of adaptive interfaces.

The physiological workload estimator works in parallel with a **subjective and performance-based workload model**, which provides additional workload measures derived from off-line subjective evaluations (implemented in a *projective mode*) and/or performance-based assessment techniques. The individual measures fuse together to construct an aggregate indicator of pilot state (workload level, eye line-of-sight, etc.) as shown.

The **display configuration and adaptation strategy** (DCAS) takes this pilot state indicator and the pilot information requirements, and determines how to configure the PVI displays. The DCAS will likely be implemented in the form of an *expert system*, and it will make use of two principal *knowledge bases* (KBs) to configure PVI content, format, and modality. The **display configuration** knowledge base contains a specification of all normal display modes, formats, and contents. This KB will define the baseline, non-adaptive PVI, which may be manipulated by the pilot via cockpit switches. The key function of the DCAS is to determine how to modify the PVI in response to inferred tactical situations and measured pilot states. It is important that this adaptation not be performed arbitrarily, but rather, on the basis of firmly grounded principles of human perceptual, cognitive, and response capabilities [12]. The **human performance model** knowledge base will contain such a model, and provide rule-based guidance on how to adapt the PVI to a given situation.

The DCAS uses its two knowledge bases and input sources (information requirements and pilot state) to drive PVI content, format, and modality. Visual display elements would appear on programmable head-down displays, head-up displays, or helmet-mounted displays. Auditory cueing could take the form of synthesized speech alerts, warning tones, or 3-D localized sounds.

Envisioned PVI Adaptation

Figure 4 illustrates in simplified form how the elements of human performance modeling, integrated workload assessment, and tactical situation assessment will converge to support PVI adaptation. The integrated workload estimator produces an overall quantitative measure of pilot loading, ideally broken down across categories of visual, auditory, mental, and psychomotor demands (shown here in bar graph displays). As discussed earlier, these quantities are computed using subjective, performance-based, and physiological workload models. The information filtering strategy determines the pilot's information requirements, using the assessed situation fed to it by the situation assessment module (not shown here). Assume that there exist *k* pieces of situationally-relevant information to be displayed on the PVI. These information items may be the event cues that support the diagnosis of the current situation. As shown, each piece of information has associated with it the imposed mental demand that will be placed on the pilot for interpreting the information, as well as the sensory demands that will result by presenting the information by *either* visual or auditory modes (the loading effects of haptic displays are neglected for the purposes of this illustration). The DCAS then uses the measured demands on the pilot (and the implied *reserves*) and the loads that will be imposed on the pilot by the required information set to optimize the content, format, and modality of the PVI. In essence, this is an exercise in *resourceallocation*. The DCAS must determine how to optimize the PVI configuration based on resource availability and requirements, while ensuring that the interface properly supports pilot SA. To the extent possible, the expert system should observe the guidelines of S-C-R compatibility.

Summary

An effort is under way to develop PVI concepts that use computational situation assessment models and pilot workload metrics to drive the content, format, and modality of cockpit displays. The envisioned system is driven by two key information streams: 1) a **content path**, driven by a tactical situation assessment module that uses avionics system outputs to determine the aircraft's current tactical situation and the pilot's information needs based on the situation; and 2) a **format path**, which uses an estimate of the pilot's state (workload level, attentional focus, etc.) to determine the most appropriate modality for conveying the required information to the pilot. The system will be integrated into the SIRE simulator at the Armstrong Laboratory.

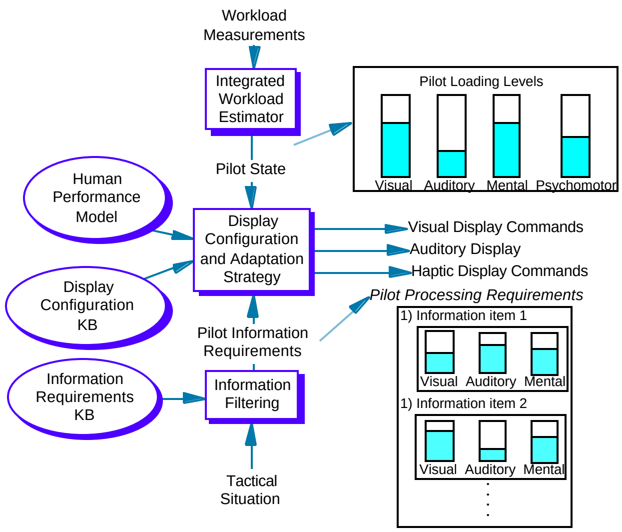

Figure 4. Integration of Workload Metrics with Information Requirements for PVI Adaptation.

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