

A FUZZY LOGIC ASSISTANT FOR VIRTUAL ENVIRONMENT OPERATORS IMMERSED IN A BATTLESPACE

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ABSTRACT

We present the motivation for and preliminary design of a decision aid that assists the operator of a synthetic environment that emulates a large, complex battlespace. The purpose for the decision aid is to increase the situational awareness of the operator concerning the activity within the battlespace. The decision aid, called the fuzzy logic assistant, uses the fuzzy logic control paradigm within designated watchspaces in the battlespace to assess the interest level of the activity and provide feedback concerning the level of interest to the operator. The paper discusses the fuzzy logic operators and rule set used to make assessments and describes the forms of feedback provided to operators of the synthetic environment.

INTRODUCTION AND BACKGROUND

Virtual environment technology is the ability to create, view and interact with computer generated objects. This concept of human-computer interaction and cooperation to accomplish a task can be traced to Sutherland's work in the mid-1960's ([Sut65]). We hypothesized that a simulation and training environment that provides a capability for participants to interact in real-time when performing group and individual tasks can provide an effective mission visualization aid, mission planning tool, and training device for commanders, pilots and planners. To evaluate this hypothesis, the Air Force Institute of Technology is building a virtual environment system, called the Synthetic Battlebridge (SBB), that immerses a user within a large-scale, complex, rapidly changing virtual battlespace and augments the immersion with information visualization techniques and automatic operator assistance.

The SBB's purpose is to allow users to evaluate and interact with large-scale (several

hundred thousand cubic miles) war games and mission plans. The SBB is designed to provide a visualization and force-level training environment that is useful to commanders at all levels, from that of a flight commander or platoon leader to the theater commander. The system has demonstrated its ability to incorporate terrain, threat, and enemy and friendly forces information into the virtual battlespace environment. The system uses local- and wide-area network technology and general-purpose workstations with Polhemus sensors, voice control, audio cueing, and color helmet-mounted displays to provide a multi-user synthetic battlespace environment.

The work at the University of North Carolina at Chapel Hill (UNC), ([Air90], [Bro86], [Bro88], [Chu89]), is relevant to our project because of its aim of improving the understanding of complex, spatial data using virtual environment technology. While their application areas of architectural design, molecular modeling, and radiation treatment planning differ from the mission planning and battlespace visualization work we have undertaken, they also have similarities. Both sets of research projects involve large-scale, complex synthetic environments and provide appropriate feedback to the user. Both sets of projects assume that the complexity and interplay between elements of large-scale realistic environments are beyond the ability of most people to assimilate, let alone analyze in depth for potential conflicts. Additionally, both projects attempt to reduce the cognitive workload required to comprehend a complex spatial environment by allowing a user to move about and interact with an environment that realistically depicts spatial relationships.

Others have also built virtual environments to allow operators to visualize battlespaces as well as interact and orient themselves within battlespaces (see [Bes92], [Bla92], [Fal93],

[Pra92], [Tho88], and [Zyd92]). The work reported by Falby, Pratt, and Zyda ([Fal93], [Pra92], [Zyd92]) on NPSNET is closest to our own, especially in regard to their work in implementing large-scale virtual environment battlespaces on commercial workstations. They have implemented a distributed system that allows users to view the activities of multiple actors within a medium-scale virtual battlespace as well as place actors into the environment. They provide a 2D plan view to allow users to orient themselves within an environment and auditory cues to enhance the sense of realism provided by the visualization of the environment. They do not provide other assistance to help the operator determine where to direct his/her attention.

One of the primary challenges faced by an operator in the SBB (and possibly any large-scale virtual environment) is determining where to look because the operator cannot comprehend the entire battlespace at once. This occurs for four reasons. First, the important portions of the environment differ from moment to moment. At one instant it might be a reconnaissance event, which could be followed by the beginning of an aerial operation, a ground engagement, a dogfight, or the arrival of a resupply mission. Second, the "interest" value of these and other potentially important events is not assessed in isolation by the user. Instead, their value is judged in relation to other events happening at the same time in the same location as well as events happening at the same time at other locations. Third, current synthetic environment user interface technology relies upon the operator to move the viewpoint to potentially interesting areas of the battlespace. Fourth, because the operator is limited in the amount of information perceived and processed at any time, the operator can miss or forget important information about the battlespace. As a result, synthetic environment operators usually lack situational awareness of events outside their field of view.

Plan-view displays and high-altitude observation posts have been used as one means of improving the operator's situational awareness. However, they are of limited help because they obscure detailed information in their attempt to portray the whole battlespace. Because of these circumstances, we concluded that operators need help in assessing the

importance of information they are not looking at but should be aware of and need help making decisions concerning where to focus their attention. To provide the assistance needed to improve the user's situational awareness, one of the goals for our project is to allow the operator to monitor, in real-time, interesting activities within the battlespace without exceeding the operator's capability to process the data. Our progress toward this goal is the subject of the paper.

We are investigating the usefulness of the fuzzy logic control paradigm to assist a virtual environment user in assessing interesting activity and automatically moving the operator to an interesting portion of the battlespace at the appropriate time (see [Kin77], [Kos92], [Lee90], [Mam74], [Zad73]). We decided to use fuzzy logic because it can recognize a pattern of activity and mimic human judgments concerning the importance of the patterns. Because fuzzy logic allows us to assess the relative importance of an input in relation to other inputs, the system can adaptively react to changes in an environment. This characteristic effectively mimics a human's behavior to environmental changes. We have adapted this controls paradigm to the problem of assisting and automatically positioning a user in a virtual environment by developing a fuzzy logic assistant, called a sentinel, to monitor and assess activity within the battlespace.

The sentinel currently makes its assessments of "interest" within user-designated subsets of the battlespace. The level of interest is a numerical representation of the information that would be sent to the commander by a tactical operations center based upon observations by scouts. Multiple sentinels can be quite valuable in a complex battlespace because the operator can move to other portions of the battlespace and leave these designated areas to be assessed by the sentinel. To further enhance the sentinel's usefulness, the operator can interactively designate subspaces that will automatically be monitored.

Each sentinel checks on the status of its subspace during each assessment cycle. At the beginning of each cycle, the sentinel determines the numbers and types of vehicles, troops, and other important information within its watchspace. These inputs are converted into fuzzy variables, after which decision rules are

evaluated to give an overall assessment of the level of interest of each subspace. The operation of the sentinel is described in the implementation section. The result of each assessment is communicated to the operator using a visual display. The display allows the operator to remotely monitor the overall activity within selected subspaces without moving to an observation point.

The current system operates upon a 22 enemy object subset of the 616 object Distributed Interactive Simulation (DIS) 2.0 will support. The selection of enemy objects to be recognized and processed is based upon the US Army publications ([USA84a], [USA84b], [USA84c]) dealing with Soviet doctrine and tactics.

IMPLEMENTATION

The fuzzy logic assistant was implemented using a simplified model of the battlespace and was used to test our hypothesis concerning the potential usefulness of fuzzy logic as a decision aid. The initial implementation was based upon the process model outlined in Figure 1. The fuzzy logic assistant was decomposed into a set of sentinels, one for each watchspace. The decomposition simplified the design and implementation of the fuzzy logic assistant. Since each sentinel operates identically, the following discussion describes the operation of a single sentinel.

The procedure used by the sentinel determines the appropriate level of interest, κ , for the sentinel's portion of the battlespace, ϕ . The model we used employed general categories for types of threats within each sentinel's area of the battlespace. These categories for both friendly and enemy formations are infantry threat, armour threat, combat aircraft threat, AAA/SAM threat, artillery threat, jammers threat, smart bombs threat, and helicopters threat. Let i represent each category. Then $T(i)$ is the term set of i , with each value being a fuzzy number defined on the universe of discourse. Let O be an object in the battlespace. The sentinel begins by observing the state of the fuzzy system and finds the number of objects belonging to each threat category X_i within its volume, V_s .

$$X_i = (\sum O_i | (O_i \text{ within } V_s)) \quad \forall i \quad (1)$$

The total number of objects for each category is then assigned a membership function value for each of the term sets (Big, Medium, Small, and Low). The membership functions, $\mu_i(x_i)$, within each $T(i)$ are based on subjective evaluations and each fuzzy set is convex and normal (as in Figure 2).

The next step in processing is to determine the linguistic variable of i with the highest membership function value, ω_{x_i} . Let A, B, C, D be the four fuzzy sets associated with i . Equation (2), the union operation, is applied across all four fuzzy sets to determine the value of ω_{x_i} .

$$\omega_{x_i} = \mu_{(A \cup (B \cup (C \cup D)))}(x_i) \quad \text{where}$$

$$\mu_{A \cup B}(x_i) = \max\{\mu_A(x_i), \mu_B(x_i)\} \quad (2)$$

The output from this step is then used to compute a numerical estimate for military presence for enemy and friendly forces, θ_e and θ_f , within the sentinel's volume. Military presence is computed by taking a weighted sum of all the ω_{x_i} for a side, and falls in $[0, 1]$.

$$\theta = \sum_{i=1}^n (\omega_{x_i} \cdot p_i) \quad (3)$$

The total military presence, $\theta_t = \theta_e + \theta_f$, is then assigned a membership function value for each linguistic variable within $T(\theta_t)$ and application of the approach in (2) results in the γ value for presence. The membership functions for θ_t are based on subjective evaluations and each fuzzy set is convex and normal.

Two other variables are used to evaluate the level of interest in the sentinel's area; the size of each area chosen by the commander, ϕ , and whether the enemy forces outnumber the friendly forces, τ . The first step in determining ϕ is computing the projected area, A , of the volume that the user wants the sentinel to monitor. The projected area, A , has a term set, $T(A)$, and the linguistic variable of A with the

highest membership function value is found by applying the approach described in (2).

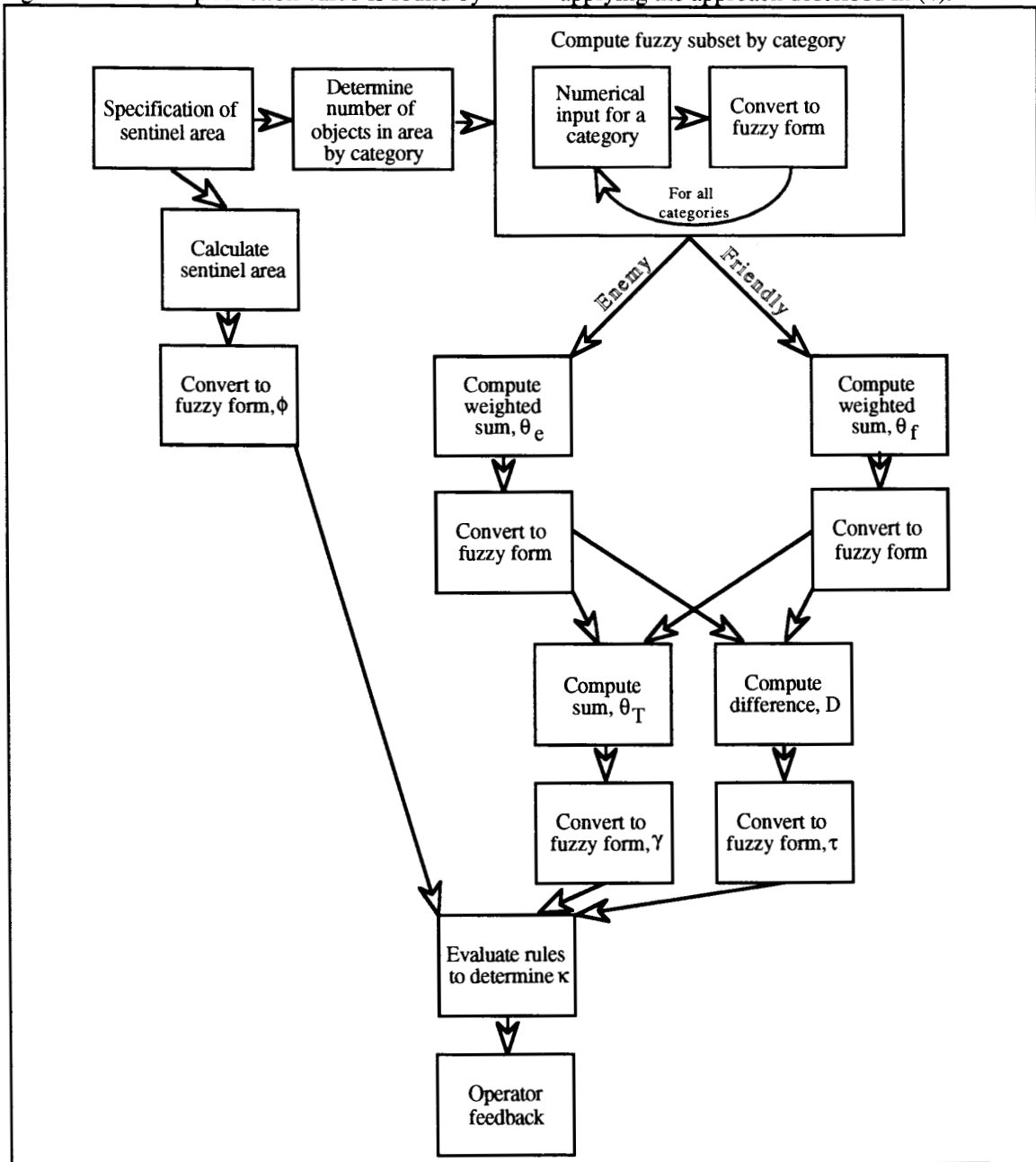


Figure 1: Process Model for Computing Level of Interest for a Sentinel's Area.

We determine the outnumbered variable, τ , by looking at the difference, D , between enemy and friendly forces within the sentinel's watchspace. That difference is the input to the

membership function evaluation of $T(D)$, (Yes, No, Equal), with the value of τ determined by applying the approach we presented in (2).

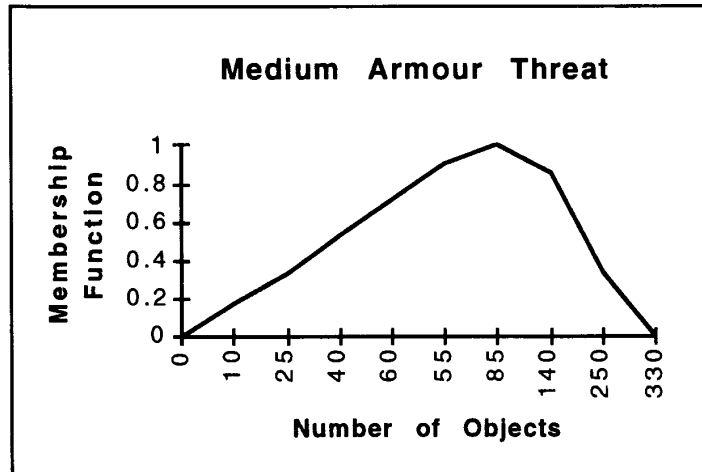


Figure 2: Fuzzy Set Defining a Medium Threat by Armour.

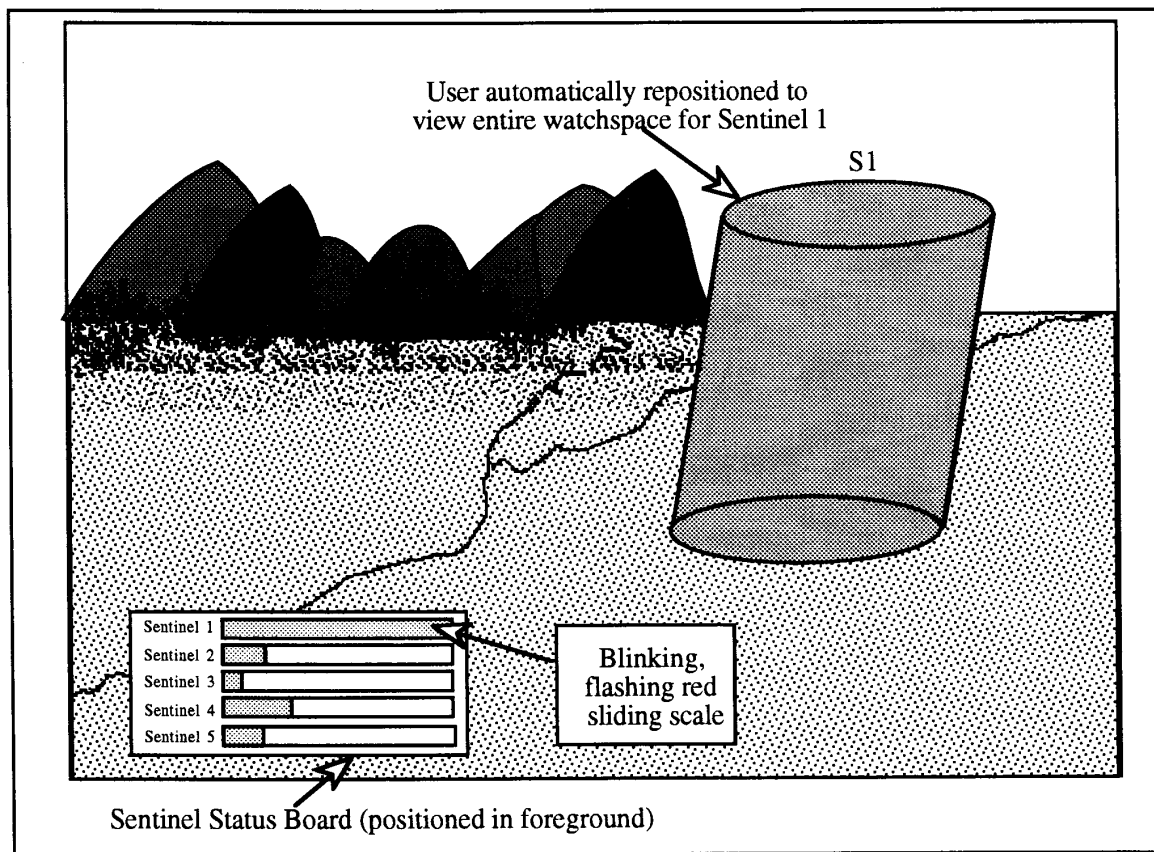


Figure 3: Example Display Showing a DANGER Level of Interrupt for Sentinel 1 After Rule 1 (above) Fires and the Sliding Scale for a Complete Set of Sentinels.

The values for τ , ϕ , and γ are used as input to the rule set to determine the appropriate control action. The processing up to this point serves to summarize the information within a watchspace into larger, conceptually related chunks of information. We exploited this chunking process when we designed the rule set to minimize the computational time required to evaluate the control actions. The rule set design produced 48 rules that are capable of responding to all input conditions. A few examples rules are presented in Table 1.

TABLE 1	
Example Fuzzy Logic Assistant Rules	
Rule 1	If γ is BIG and ϕ is SMALL and τ is YES then level of interrupt is DANGER and color is RED.
Rule 2	If γ is MEDIUM and ϕ is SMALL and τ is EQUAL then level of interrupt is CAUTION and color is BLUE.
Rule 3	If γ is LOW and ϕ is LARGE and τ is NO then level of interrupt is NIL and color is GREEN.

The control actions that result from the rule set evaluation provide the operator with notification concerning the level of interest required for a sentinel's watchspace. Feedback is provided using two general cueing mechanisms, a sliding scale and a level of interrupt.

The sliding scale gives visual feedback by changing color and length according to the value of κ . In addition, four interrupt levels coincide with the color sliding scale, and only engage under specific circumstances. The interrupt level of danger indicates the highest level of interest. This level causes the slider to blink for 3 seconds, followed by an automatic repositioning of the user to a vantage point outside the sentinel's watchspace. The interrupt level of warn is the second highest level of interest, and causes the slider to blink and beep, but does not automatically reposition the user. The interrupt level of caution acts as the third highest level of interest, and causes the slider to blink. The fourth level of interrupt gives no further cues to the operator.

FUTURE WORK

Based on our results to date, we have concluded that the fuzzy logic paradigm has the potential to provide the type of decision and monitoring aid needed in a virtual battlespace environment. However, several aspects of the implementation need improvement. Because the virtual battlespace environment is growing in complexity from the current 100 objects to 8000 total objects, we will have to implement a capability to resolve operator feedback conflicts between sentinels. This may be accomplished through the use of fuzzy modifiers to give us additional levels of operator notification.

Another change is being forced upon us by the growth in complexity of the simulated battlespace. Currently, the sentinels only analyze volumes that have a battalion front. Since the battlespace's volume is growing and becoming more complex, the fuzzy logic assistant's capabilities must be expanded to support evaluations on fronts for larger combat formations.

In our initial user studies, we discovered that the technique we used to compute ω_{x_i} sometimes conflicts with commander's intuition about the situation in a sentinel's watchspace. The fuzzy logic assistant we have under development will compute ω_{x_i} in a manner that more closely resembles that of a tactical operations center. Analysis has also indicated that we should separate the computation of level of interest for ground forces from that for air forces. Further work must also be done in determining the most effective components of the rules as they relate to current military doctrine. For example, the types of objects and their relative firepower ratings must be as accurate as possible so that they reflect the military training philosophy inherent in the training of commanders, and so that the user studies can be effectively performed. Follow-on work will involve the recognition of troop/vehicle formations and the speed of these formations, the incorporation of elapsed time, orientation of weapons systems, and obstacles.

One further area of future interest is the human factors of the display, particularly regarding the range and types of colors to be used, the design of the sliding scale, and the effects on the user of both the sliding scale and the level of interrupt.

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