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REAL-TIME KNOWLEDGE-BASED SYSTEMS FOR THE NAVAL SITUATION ASSESSMENT PROCESS

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ABSTRACT

Initially, an important command and control function of an anti–air warfare (AAW) frigate was the threat evaluation and weapon assignment (TEWA) function since it ranked the tracks detected by the ship's radars according to certain criteria and assigned hardkill or softkill weapons to the air threats in order to destroy or decoy them. Recently, the command and control functions in an AAW frigate have been grouped into three principal processes called: sensor data fusion, situation assessment and resource allocation. Sensor data fusion is the process of obtaining the best tactical picture from the sensors on board the ship and from those deployed at other locations exterior to the ship, situation assessment concerns the interpretation of this tactical picture and resource allocation is the assignment of hardkill weapons and softkill weapons to air threats in order to destroy or decoy them.

This paper describes a real–time model for naval situation assessment in terms of knowledge–based systems and case–based reasoning systems. The paper also describes the subfunctions of naval situation assessment which will be simulated using these technologies. In order to make the knowledge–based system function in real time, design–to–time and anytime approaches have been studied and some indication of the former is given on rule sets of the knowledge bases. This paper describes the real–time inputs and outputs of the situation assessment process. A uniprocessor architecture has been chosen for the implementation since the scheduling and mapping problems will be less complicated than in the multiprocessor case. An analysis is given of the bounded response times that a uniprocessor system executing these implementations will have to satisfy in order to produce response times within the rapid constraints of anti–air warfare.

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INTRODUCTION

Work in naval command and control started with a study of the threat evaluation and weapon assignment (TEWA) function. A knowledge-based system was built in SMALLTALK 80/HUMBLE to do threat evaluation and weapon assignment for a single stationary AAW destroyer. The knowledge-based system comprised four knowledge bases for a total of 110 rules. The initial system was integrated into a SMALLTALK anti-air warfare simulator which was designed to simulate air attacks on multiple ships. Each ship in the anti-air warfare simulator was equipped with SMALLTALK objects representing the ship's sensors, weapons, communication systems and command and control systems.

Recently, the theory of command and control for air defence has been revised so that it now comprises three major denominations : sensor data fusion, situation assessment and resource allocation. Sensor data fusion is defined to be the correlation of information coming from different sources in order to obtain the best tactical picture of the air situation around the ship; situation assessment is defined to be the interpretation of the air tactical picture generated by the data fusion process, while resource allocation is defined to be the assignment of hardkill/softkill weapons to the air threats attacking the ship or ships.

This paper presents some real-time models for the naval situation assessment process which are based on knowledge-based systems and in some cases use hypothesize and test techniques in the knowledge-based system. The aim of the latter is to provide a situation prediction facility to the above water warfare officer. The situation assessment model is based on a four function development : threat assessment, defence assessment, kill assessment and plan monitoring. The threat assessment function is a very important function of situation assessment, since it decides what is a threat or is not a threat in the tactical situation and produces a short term prediction of the tactical situation, while the defence assessment function is concerned with the positioning of air defence ships in the face of an air attack. The kill assessment function takes in data from various sensors in order to determine the outcome of a surface-to-air missile engagement of the threat or that of a softkill weapon deployed against the threat. The plan monitoring function diagnoses whether unexpected events have occurred in the tactical situation and, if so, whether resource allocation functions need to be called again to revise the current plan under execution because the tactical situation has changed.

In order to implement these functions in real time, design-to-time and anytime algorithms are being studied and applied to knowledge bases. This paper presents a list of real-time inputs and outputs of the situation assessment process and an analysis of the real-time constraints for situation assessment assuming both a uniprocessor architecture and an implementation of the situation assessment functions in the MUSE shell. The mean and standard deviation of the response times of a 60 rule MUSE knowledge source to radar and electronic support measure (ESM) data are presented. The response times were obtained for a Sun Sparc 1 workstation and the data was submitted to the knowledge source at only one time stamp.

SITUATION ASSESSMENT IN REAL TIME

Situation assessment is concerned with the interpretation of the tactical picture generated by the sensor data fusion process. As such, situation assessment concerns building a real-time model of the tactical situation, monitoring the various processes in the tactical picture and diagnosing major tactical problems that could result in the destruction of the warship or threaten the existence of assets protected by it. In the present formulation of situation assessment, a model has been built depending on four real-time air defence functions : threat assessment, defence assessment, kill assessment and plan monitoring. A nine function model for situation assessment has been devised in the United Kingdom (see reference [1]) which includes the four functions mentioned above and additional functions which are not considered to be time critical such as mission monitoring.

Much work has been done to develop non real-time methods and algorithms for situation assessment (see references [2], [3], [4] and [5]). These methods depend on knowledge elicitation procedures using case-based reasoning (see reference [2]) or on knowledge acquisition techniques based on long term memory, procedural memory and short term memory (see reference [3]). In order to make these approaches function in real time, an external mechanism such as a meta-level controller can be imposed on the knowledge structure to handle asynchronous inputs and interrupts, organize and schedule tasks using priorities and control the various reasoning mechanisms in order to satisfy hard task deadlines. This kind of approach is called a *design-to-time* approach to real-time artificial intelligence and it is described in reference [6]. The approach to be used in future research will be to build the artificial intelligence application so that it will satisfy the real-time requirements of naval situation assessment. This kind of approach will use the *anytime* approach to artificial intelligence. The basic characteristics of anytime algorithms are : the algorithm can be suspended and resumed with negligible overhead, the algorithm can be terminated at any time and will return some answer, and the answers returned improve over time. The concept of anytime algorithms is well described in reference [7].

Threat Assessment

This function performs threat classification, threat evaluation and threat prioritization. A possible implementation of the threat classification function is that of a knowledge base in which there are rules defining a track to be hostile, friendly, neutral, unknown and its platform type (e.g. aircraft, anti-ship missile, helicopter, etc.). Each time the identity of a track becomes known the appropriate rule in the knowledge base can be fired and the identity can be placed on a blackboard. Obviously, there is a difference between a proof of concept system and an operational system. In the latter case, it may be necessary to refer to a database in which are stored radar modes, emitter data, radar frequency, etc. in order to lead to a correct identification. A cluster analysis of the platform types may also be performed, i.e., the rules of the knowledge base will decide based on proximity criteria whether certain platforms correspond to a group or not.

The threat evaluation concerns determining whether a track from the threat classification rule base constitutes a threat to the force (single ship or multiple ships) and the extent to which it is a threat. In order to do this, the threat evaluation function will undertake two important operations, i.e., it will interpret the tactical situation and attempt a short term prediction of the situation. The interpretation consists of a guess of the mission which the air platform or cluster is currently undertaking, and the situation prediction is forecasting what the platform or cluster will be doing in the near term based on knowledge of enemy tactics and doctrine. Obviously, situation prediction is an operation which could easily lead to erroneous predictions. Hence, it must be validated by a hypothesize and test technique. The interpretation of the tactical picture will be made in terms of confidence factors or variables involving fuzzy logic. A comparison is made between the predicted tactical situation of the previous time step and the actual interpreted tactical picture of the present time step. In the current anytime implementation of situation assessment, the time step over which the comparison is made is chosen by a meta-level controller (see figure 1 for a possible architecture of a real-time situation assessment and resource allocation process).

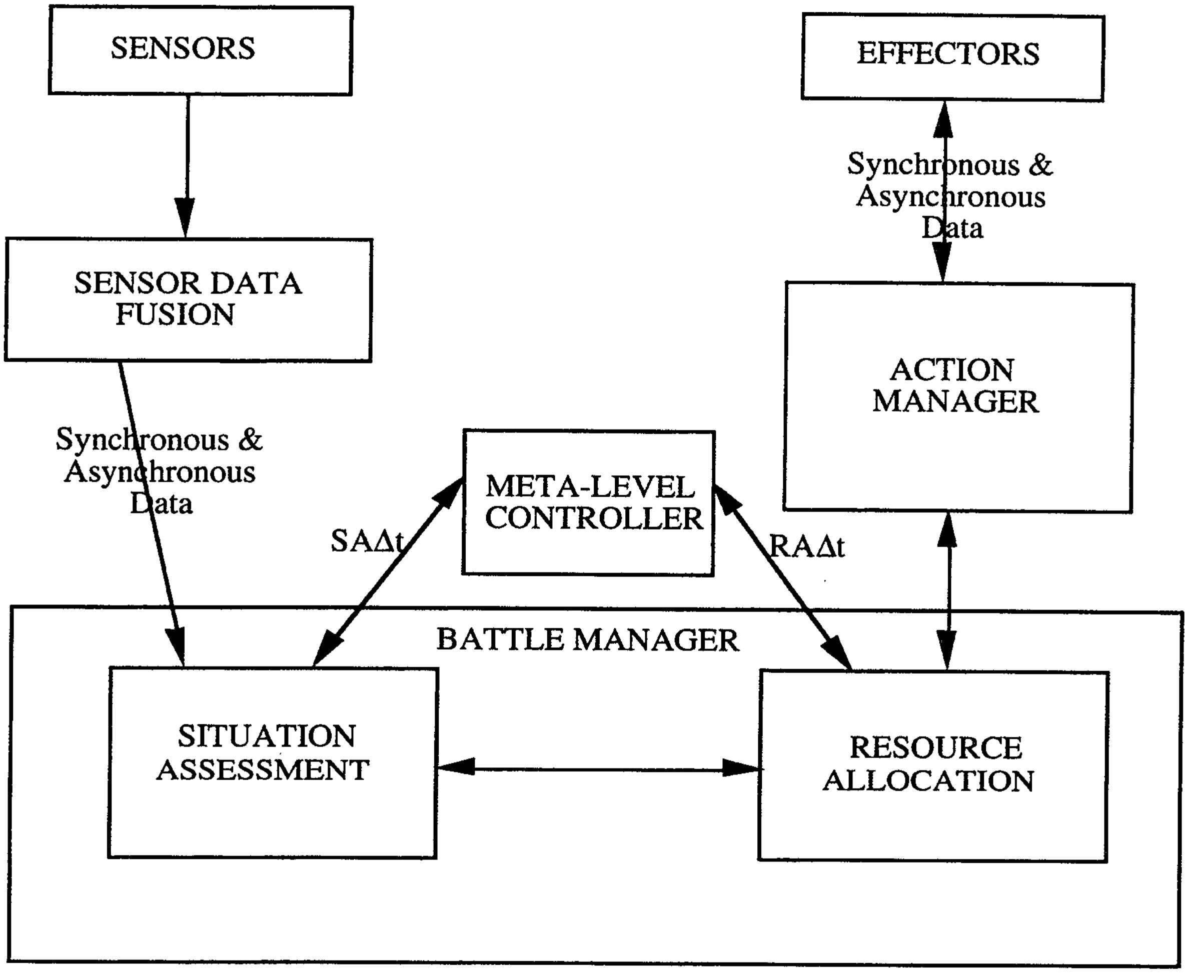

Figure 1 : A Real-Time Architecture for the Situation Assessment and Resource Allocation Process

The meta-level controller contains algorithms which independently allocate time intervals during which the situation assessment and resource allocation processes will operate on synchronous or asynchronous data received from a suitable process. In addition to situation prediction, threat evaluation is concerned with extracting information from mission doctrine, target dynamics (position, velocity, acceleration, and manoeuvre), target lethality, identity, track history, electronic emissions, tactical activities such as jamming, engagement actions, target emitter status (on/off) and target radar mode (acquisition, tracking). A proper combination of these elements should determine if a target track constitutes a threat to the force and to what extent.

The final function performed by threat assessment is threat prioritization. The threat prioritization subfunction computes a ranking value for each threat identified as being harmful to the force. Threat values are assigned according to a rule base depending upon static or dynamic properties attached to the mission doctrine of the force. Threat values rely on threat type and intelligence (indication of the ability of the threat to do damage), threat status (engaged, assigned, not allocated), threat behaviour (track history), kinematic parameters (threat position, range, velocity, closest point of approach (CPA), time to reach CPA (a prediction measure based on track extrapolation)) and other parameters such as the radar mode of the threat seeker head.

Defence Assessment

The objective of defence assessment is to interpret the strength of the force's assets in the face of an enemy attack. The inputs to this function are the states of all force resources, the state of all ongoing engagements and the threat priority lists obtained from the threat assessment function. The defence assessment function considers the situation prediction obtained from the threat assessment function and tests the air defence capability of the force assets to see whether there are weaknesses. If there are any weaknesses, the AAW commander should be informed and corrective measures will be taken to improve the air defence effectiveness of the convoy. In the event of an air attack on the convoy, the defence assessment function must evaluate the force's capacity to perform area defence, self defence or some other mission and list the factors which will prevent the force carrying out its mission. The output from the defence assessment function is a list of the weaknesses of the force to perform a certain mission (area defence, self defence) characterised by certain measures of effectiveness given an air attack as described by the threat assessment function.

Kill Assessment

The objective of kill assessment is to determine whether the force's weapons are having an effect on the air threats attacking the ship or ship(s) of the force and, conversely, whether the air threats are sinking the ships of the force. Kill assessment of softkill weapons is difficult. Kill assessment of medium range SAM systems with radar guidance is done by monitoring the Doppler signal or range gate of the fire-control radar during the SAM intercept. If the Doppler shift goes to zero or the air target disappears from the fire-control radar range gate, the target is destroyed. If the Doppler shift remains nonzero or the target remains in the range gate, the air threat is not killed. Kill assessment of gun systems is done visually since the intercept typically occurs at 2-3 km. The information from kill assessment must be sent to the threat assessment and defence assessment functions so that the tactical situation can be updated in real time.

Plan monitoring

The purpose of the plan monitoring function is to monitor and decide whether the resource (weapon or sensor) allocation plans produced by the anytime planner are being followed and if not, to alert the planner of any discrepancies or inconsistencies occurring in the execution of the plan. If a planned situation is one resulting from linear interpolation then any discrepancies between the observed situation and the planned one caused by the appearance of new threats, kill assessment, track loss or unexpected threat behaviour may suggest a desirable revision and trigger a new planning cycle. In order to do this, the plan monitoring function will go through two operations : plan validation and plan refinement. Plan validation is carried out in order to determine if commitments made so far are likely to lead to a complete plan given the changing tactical situation. The process of making choices in the course of extending an existing or partial plan in order to make suitable modifications to initial plans is called plan refinement.

REAL-TIME ANALYSIS OF THE SITUATION ASSESSMENT PROCESS

A real-time analysis of the situation assessment process was conducted and the inputs, outputs and temporal constraints of the situation assessment process were listed below in the following sections.

Inputs

The following inputs are considered to be essential to the real-time situation assessment module :

(a) fused tracks from a sensor data fusion process. The sensors contributing to this process will be the long ranged radar, the medium ranged radar, the IFF, the ESM, the IRST and phased array radars such as the APAR.

(b) identity inputs from an ESM system.

(c) air traffic information. This information is non real time and can be loaded into the situation assessment knowledge sources before the air engagement.

(d)real-time information from datalink. Improved versions of datalink for AAW communications are Link 16 and NILE.

(e) doctrine information. This information is usually stored in a database. Retrieval of the information may be slow but the slowness has nothing to do with the artificial intelligence systems used in the situation assessment module. It concerns searching a large database given the right identity for aircraft, helicopters or anti-ship missiles and then sending the appropriate encyclopedic information about these air platforms to the correct knowledge base in the situation assessment module.

(f) real-time data coming from the ship's own navigation radar. This data may be combined with datalink information and be sent to the defence assessment knowledge base for use in calculating the position of air defence screens from an air attack.

(g) real-time interrupts. In an air engagement, there will real-time interrupts coming from the action manager, the resource planner and the meta-level controller. In an air engagement, there will be information coming from the missile launch controller, weapon direction system or electronic warfare control processor (EWCP) giving kill assessment information about SAM encounters with air threats or the use of EW weapons against air threats. This information will update the kill assessment knowledge base and the force resources knowledge base. Finally, the meta-level controller may decide that the time interval specified to the situation assessment module for building a tactical picture needs to be changed because of the current tactical situation. Accordingly, an interrupt will be sent to the situation assessment module from the meta-level controller to modify the time interval.

Outputs

After analysing the situation assessment process, the outputs from the situation assessment module to the resource allocation module were listed to be :

(a) fused tracks and for each track its classification (i.e., type of platform),

(b) its identity (e.g., Skyhawk, Exocet AM 39, etc),

(c) its allegiance (Argentinian, British, neutral, etc),

(d) its group status (alone, in a fighter squadron with two other aircraft),

(e) the threat levels for each track,

(f) the status of all weapons on the ship,

(g) the results of kill assessment,

(h) engageability information for each weapon on the ship applied to each track in the air track database,

(i) diagnosis of unexpected events which may or may not require a plan refinement of the resource allocation module in the future,

(j) plan validation verdict of plan monitoring,

(k) the current prediction of the tactical situation with associated certainties (which may be invalidated later),

(l) a defence assessment recommendation concerning the repositioning of own force assets in the face of an attack.

Temporal Constraints and Bounded Response Times for the Situation Assessment Process

A preliminary analysis shows that the temporal constraints for situation assessment are dependent on computer architecture. Those for a multiprocessing system will differ from those for a uniprocessor system such as the single Sun Sparc 1.0 processor on which the real-time knowledge-based system shell MUSE runs. The author has carried out an analysis of the real-time constraints of a situation assessment process implemented on a uniprocessor workstation using the MUSE shell. The analysis does not include the time taken by the processor to reset the internal data structures of MUSE or initialise all the knowledge source databases or place entries on the agenda or execute events in the agenda. The author has concentrated on those knowledge-based operations (backward chaining, forward chaining, rule-firing) which are known to be slow operations. The current design is based on the analysis described in the previous sections of this paper and is shown in Table I. If the knowledge sources of Table I are executed for a two ship scenario neither of which is equipped with a phased array radar only the first seventeen knowledge sources will be used. In this case, the worst case response times of the situation assessment module to incoming data or for handling interrupts coming from the action manager, the resource planner or the meta-level controller correspond to a serial execution of all seventeen knowledge sources. This situation will arise in an anti-ship missile attack of the two ships by fighter aircraft, in particular, after the anti-ship missiles have been launched at the ship. This analysis does not consider cases where large queues of tasks may be awaiting to be put on the MUSE agenda. It supposes that all the tasks up to the present moment have been successfully executed by the processor and calculates the worst case response time when newly arrived data or interrupts are sent to the situation assessment module. If T_i denotes the execution time of a knowledge

TABLE I

Knowledge Sources of a MUSE Implementation of the Real-Time Situation Assessment Process

KNOWLEDGE SOURCE	FUNCTION
1. classify_ks	Reads in real-time data from C programs to the subsequent knowledge sources
2. radar_track_ks	Real-time store of ownship radar tracks coming from surveillance radar or phased array radars
3. ESM_ks	Real-time store of ownship ESM tracks
4. datalink_radar_ks	Real-time store of a second ship's or AEW radar tracks communicated to ownship via datalink
5. datalink_ESM_ks	Real-time store of a second ship's or AEW ESM tracks communicated to ownship via datalink
6. IFF_ks	Real-time store of ownship IFF contacts
7. fire_control_radar_ks	Rules to decide whether a target is manoeuvering when illuminated
8. air_traffic_ks	Rules for identifying passenger aircraft from ESM information
9. threat_classification_ks	Rules for classifying air tracks according to type, identity and allegiance
10. threat_group_status_ks	Rules for doing cluster analysis and determining the mission of groups of air tracks
11. situation_prediction_ks	Rules for building the present and short term future tactical situation
12. threat_level_ks	Rules for determining the threat levels of air tracks
13. force_resources_ks	Rules for updating the status of the ship's weapons
14. kill_assessment_ks	Rules for updating the air track database after deployment of hardkill and softkill weapons
15. engageability_effectiveness_ks	Rules for two dimensional engageability calculations of hardkill and softkill weapons
16. defence_assessment_ks	Rules for calculating the position of air defence screens
17. plan_monitoring_ks	Rules for diagnosing unexpected events in the tactical situation
18. sensor_management_ks	For applications using a phased array radar rules are required for selecting the tracking beams in situation assessment

source i in response to a data entry or interrupt (in the situation assessment model, it is assumed that each knowledge source will receive only one type of data entry or interrupt) then this time T_i will be the time for a knowledge source execution corresponding to a maximal number of air tracks N, where N = N1 + N2 + N3 and N1 is the number of aircraft, N2 is the number of anti-ship missiles and N3 is the number of helicopters. The situation assessment module receives synchronous and asynchronous inputs from the DATA FUSION module at an input rate which will be denoted by R_1 Hz and asynchronous interrupts from the ACTION MANAGER at an input rate denoted by R_2 Hz and asynchronous interrupts from the RESOURCE PLANNER at an input rate denoted by R_3 Hz and asynchronous interrupts from the META-LEVEL CONTROLLER at an input rate denoted by R_4 Hz. The interrupt rates cited above will be assumed to be maximum rates. When a fire-control radar is performing an ECM effectiveness assessment for the Electronic Warfare Control Processor, the moment at which the fire-control radar is assigned to the ASM track is an asynchronous event as are the EWCP jog detections. The rate at which these asynchronous interrupts arrive at the situation assessment module will probably be different over each one second time interval. However, it suffices to do an analysis over a fixed one second time interval and in this time interval the number of asynchronous interrupts coming from the action manager will be denoted by R_2. Therefore, in a time slot of one second, the situation assessment module will receive R_1 data inputs and $R_2 + R_3 + R_4$ interrupts. In the implementation of situation assessment that is under study, the meta-level controller will supply intervals Δt based on certain criteria during which the situation assessment module will build up a tactical picture. The candidates for Δt in a testing scenario would be (1/4)s, (1/2)s, (3/4)s, 1s, (5/4)s, (6/4)s, (7/4)s, 2s. In the case that $\Delta t > 1$, the Δt time interval should be divided into two subintervals Δt_1 and Δt_2 where $\Delta t = \Delta t_1 + \Delta t_2$ and $\Delta t_1 = 1s$ and Δt_2 is the remaining time in Δt. If R_{21} denotes the number of asynchronous interrupts that arrive from the action manager in the interval Δt_1 and R_{22} denotes the number of these interrupts that arrive in the interval Δt_2, then the analysis which is described in the subsequent paragraphs and which is applied to R_2 and Δt to produce the inequality (1) can be applied to R_{21}, Δt_1 and R_{22}, Δt_2 to yield two sets of conditions similar to (1). Now assume that $\Delta t \leq 1s$, then in a time Δt, there are $\lfloor R_1 \Delta t \rfloor$ data inputs and $\lfloor (R_2 + R_3 + R_4)\Delta t \rfloor$ interrupts. With our current design, the first twelve knowledge sources require sensor data inputs to calculate a result. Each of the results calculated may either be sent to another knowledge source in the collection of seventeen or they may be considered an end result that will be sent to the resource allocation module. If T_i is the processing time for the ith knowledge source, T is the maximum of these processing times and it is assumed that the scheduling of the knowledge source tasks takes place at the highest priority on the MUSE agenda (i.e., all tasks have fixed priority equal to 1) then the following upper bound can be calculated for the knowledge-based processing time:

$$T \le \frac{\Delta t}{a\Delta t + b} \qquad (1)$$

where

$$a = 14R_1 + 2R_2 + R_3,$$
$$b = 14(R_1 - 1) + 2(R_2 - 1) + R_3 - 1$$

The details of this derivation can be found in the reference [8]. For interrupt rates compatible with the AAW problem, e.g.,

$$R_1 = 10\text{ Hz},\ R_2 = 6\text{ Hz},\ R_3 = 1\text{ Hz}, \qquad (2)$$

a is equal to 153 and b is equal to 136 in (1). In the seventeen knowledge source system described in Table I and for the data and interrupt rates given by (2), it was noted that Δt scaled almost linearly, i.e., the requirement for the bounded response time from the knowledge sources with Δt = 1s is approximately 3 ms while for Δt = (1/4)s it is approximately 1 ms.

In the case of asynchronous inputs to the situation assessment module where the number of interrupts varies over each second, the above analysis can be applied to time intervals $\Delta t \le 2$s as follows. First, it is necessary to divide Δt into two parts Δt_1, Δt_2 such that $\Delta t = \Delta t_1 + \Delta t_2$. The interrupt rates R_2, R_3 and R_4 are then divided into two values, the first of which is the number of interrupts over the first second and the second is the number of interrupts over the remaining time. Two inequalities are then derived similar to (1) one being for Δt_1 and the other for Δt_2. The bounded response time T for the knowledge sources KS must satisfy the Δt_1 inequality and the Δt_2 inequality, i.e., T must be the smaller of the two values.

DESIGN-TO-TIME ALGORITHMS FOR SITUATION ASSESSMENT

A knowledge base can be implemented in real time on a uniprocessor system using a design-to-time algorithm. A tree node diagram is drawn for each search pattern in the knowledge base. Each search pattern in the knowledge base is ranked by a utility factor. In general, the utility factor will depend on the certainty that choosing the search pattern will lead to a correct answer in the forward/backward chaining scheme and it will also depend on the search time. After a utility factor is chosen, all possible search patterns are ranked giving a sequence of values U_1, U_2, U_3,... If the real-time requirement for the forward/backward chaining is T ms, this will induce an upper bound U on the largest possible value of the utility factor corresponding to a time satisfying the real-time requirement. The only plans satisfying the real-time requirement will be those for which $U_i < U$ (see reference [6] for more details).

RESPONSE TIMES FROM A SIXTY RULE KNOWLEDGE SOURCE

The threat level knowledge source of Table I has been implemented as a 60 rule forward production rule (FPR) knowledge source. At the present moment, the knowledge source is divided into five rule sets consisting respectively of 4 threat identity rules, 13 threat kinematic rules, 2 engagement status rules, 3 radar mode rules and 40 threat level rules. At the present moment, there are radar and ESM schemas which supply radar and ESM data to the track schema. From one to eight tracks have been submitted to the knowledge source at any given instant. The MUSE rule set implementation works in such a way that the radar and ESM data for track 1 are submitted to rule set 1, then those for track 2 are submitted to rule set 1, then those for track 3 are submitted to rule set 1 etc and finally those for track 8 are submitted to rule set 1. This cyclic process is then repeated for rule set 2, rule set 3, rule set 4 and rule set 5. By using demons, the total cumulative time for rule sets 2, 3, 4 and 5 to process any number of air tracks can be measured from the workstation real-time clock. Statistical testing of the knowledge source response time to 4, 5, 6, 7 and 8 tracks were made on samples of radar and ESM data of size 20 submitted at one time stamp only. The response times as measured in milliseconds appear in Table II below.

TABLE II

Response Times from a 60 Rule Knowledge Source

	average response time (ms)	standard deviation (ms)
4 tracks	40.65	3.45
5 tracks	51.25	6.80

6 tracks	66.6	24.51
7 tracks	71.8	23.57
8 tracks	72.85	5.48

The average response time in Table II appears to increase linearly with the number of tracks. It is also to be noted that as the number of tracks increases from 4 to 7 and hence the number of data slot values also increases, the variance of the response time increases. Since for 7 tracks, the mean response time is 71.8 ms and its standard deviation is 23.57 ms, this means that occasionally the response time could be as high as 118.94 ms. Therefore, it is a good idea to write 120 ms as an upper bound for the response time of the knowledge source in any MUSE design-to-time algorithm for situation assessment (see reference [6]).

In theory, if the naval situation assessment process consists of only this knowledge source then it should be able to accommodate a 8 Hz radar and an ESM system that fuses its events with this radar. Although the radar and ESM track data is sent down into the MUSE knowledge source 8 times a second, there will be a need to make sure that all 8 packets of radar data are processed within the second, i.e., all sensor processing deadlines are satisfied.

In theory, if the naval situation assessment process consists of four knowledge bases and there are functional dependencies in the inputs and outputs of each knowledge base (this is always the case with the situation assessment knowledge bases) then they must be executed in a prescribed order and if it is assumed that the worst case execution time for 4-8 tracks is 120 milliseconds and if the four knowledge-based tasks are scheduled by assigning each the fixed highest priority of 1 then the four knowledge-based situation assessment system can accommodate a 2 Hz radar fused with ESM data. When the radar and ESM track data is sent down into the MUSE knowledge sources twice a second, there will be a need to make sure that the data is processed twice a second by the four knowledge bases, i.e., the sensor deadlines are satisfied. If periodic data is submitted to a knowledge-based process, the knowledge-based tasks can be scheduled by a rate monotonic scheme. Reference [9] gives an application of rate monotonic scheduling to the TEWA problem. More research and programming are required in order to decide whether preemptible fixed priority scheduling is better suited to handle the situation assessment problem compared with a generalised[2] rate monotonic scheduling scheme. One of the assumptions of rate monotonic scheduling is that the execution times of the processor tasks are constant. In the case of situation assessment, some knowledge-based tasks have large variance. Therefore, it is a challenge to find a reasonable worst case execution time for the knowledge-based tasks in order to apply generalised rate monotonic scheduling efficiently and accurately. In fact, once a generalised rate monotonic analysis has been performed the number of deadlines satisfied should be compared with the number satisfied of the preemptible fixed priority scheduling scheme.

The answers returned by the threat level knowledge source were verified for accuracy. The threat levels obtained were comparable with those calculated by the knowledge-based system of reference [10] and found to be identical. Thus in the current MUSE implementation of the threat level knowledge base, the accuracy of the calculated results have not been sacrificed for speed. In other words, if it takes an average time of 72.85 milliseconds to calculate the threat levels of 8 tracks, the same values are returned by the MUSE knowledge source as by the SMALLTALK/HUMBLE program of reference [10] for the same input data.

CONCLUSIONS

In this paper, the naval situation assessment process has been defined, a functional decomposition of the process into elementary defence functions has been made and some real-time models in terms of design-to-time algorithms for knowledge-based systems have been described for this functional breakdown of the situation assessment process. A real-time knowledge-based implementation of the naval situation assessment process in terms of the MUSE shell has been described which has been followed by a real-time analysis of the MUSE implementation. Finally, one of the knowledge sources of the MUSE implementation has been coded as a forward production rule system and the response time of this coding on a Sun Sparc 1 workstation has been presented.

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