In search of IEDs
(Improvised Explosive Devices)
Using
KEEL® Technology

A Compsim Whitepaper

In today's asymmetric warfare, the Improvised Explosive Device (IED) has proven to be a formidable weapon used by our adversaries.

"The first IEDs were triggered by wires and batteries; insurgents waited on the roadside and detonated the primitive devices when Americans drove past. After a while, U.S. troops got good at spotting and killing the triggermen when bombs went off. That led the insurgents to replace their wires with radio signals. The Pentagon, at frantic speed and high cost, equipped its forces with jammers to block those signals, accomplishing the task this spring. The insurgents adapted swiftly by sending a continuous radio signal to the IED; when the signal stops or is jammed, the bomb explodes. The solution? Track the signal and make sure it continues. Problem: the signal is encrypted. Now the Americans are grappling with the task of cracking the encryption on the fly and mimicking it—so far, without success. Still, IED casualties have dropped, since U.S. troops can break the signal and trigger the device before a convoy passes. That's the good news. The bad news is what the new triggering system says about the insurgents' technical abilities."[1]

A high priority has been assigned to the development of solutions that can respond to the IED problem. This paper decomposes the IED problem into several "phase domains" and addresses each of them individually as subjective issues. The phase domains are a series of states that a person (soldier) or an autonomous (or semi-autonomous) device might transition through - relative to IEDs.

We would suggest that the IED problem can be treated much like any other data fusion problem associated with dynamic systems. These problems are characterized by the need to interpret complex data patterns within these dynamic systems and to take controlled actions based on what is observed. The broad information domain encapsulates all data items that can be used as inputs and outputs to the domain as well as intermediate accumulations of data items. Another characteristic of these information domains is that any significant piece of information can be used one or more times in interpreting the information within the domain. It is also a characteristic of these information domains that each time a piece of information is used, it has the potential of impacting other parts of the information domain with different levels of significance. One is left with a complex web of inter-related data items that must be evaluated together in order to select from competing controllable actions.

We would suggest that the response to the IED problem needs to be handled with judgment and care. This paper describes how KEEL Technology can participate in the solution to the problems associated with IEDs.

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[1] Johnson, Scott and Liu, Melinda; Newsweek; "The Enemy Spies" June 27, 2005; http://www.msnbc.msn.com/id/8272786/site/newsweek/

This document is work-in-progress and is intended to provide some structure for further investigation and decomposition.

KEEL Technology (Knowledge Enhanced Electronic Logic) [2]

KEEL is:

- A development environment suitable for addressing complex, dynamic, non-linear, inter-related, multi-dimensional problem sets
- A model for accumulating supporting and objecting arguments in order to make a decision or take an action
- A small footprint engine that processes sensors or other inputs according to the design of a system created in the development environment
- A method for implementing the cognitive model as an analog circuit

Using the KEEL toolkit, a human (i.e., a "Domain Expert") can document how to analyze problems and take actions. The resulting code can be embedded into a device, a software application, or demonstrated on the web.

Special characteristics include:

- Decisions or actions are explainable
- Graphical development tools focus on subjective "right brain" reasoning
- Generating a small memory footprint makes it possible to add human like reasoning to very small devices
- Interactive development environment allows the designer to get immediate feedback in the reasoning process
- A single design can be deployed in a variety of environments
- Architecture independent (simple stand-alone applications, client-server, distributed)
- Easy to integrate into existing systems (simple API)

KEEL technology attempts to mimic the way that humans balance input information to make subjective decisions. In this manner, a KEEL engine operates like an analog computer. It accumulates supporting information and balances this with objecting or blocking information. Individual considerations interact with other decisions or actions in a web of relationships that are balanced to achieve the best overall set of actions for the system. In a KEEL system, the importance of information is likely to be constantly changing. The importance of information can be controlled from external events or can be controlled as part of an internal process.

Within the context of this document, KEEL is suggested as a technology that has the potential to interpret IED related information the way that a human expert might choose

[2] Compsim document; "KEEL Technology for Embedded Intelligence"; http://www.compsim.com/papers/About_KEEL.pdf

to do so. The decisions and actions modeled with KEEL are completely explainable and auditable. We would consider this a mandatory service, because the scope of the problem is so broad. It is likely that the IED data fusion problem will not be completely satisfied on the first pass. We would expect that the judgmental model will have to evolve over time. To support this controlled evolution, it will be necessary that any decision or action be exposed for auditing purposes as well as for extension to incorporate new sensors and new data sources.

Phase Domains:

In the context of this document, the concept of "phase domains" is used to describe the states that pieces of information might pass through in order to address a particular problem or inter-related sets of problems. The entire problem domain will include the need to address a hierarchy of component problems; most of which will require the integration of information items.

- Detection Phase
- Identification Phase
- Evaluation Phase
- Investigation Phase
- Reaction Phase

Detection Phase:

The Detection Phase is the "situation awareness" phase. This phase is triggered when new or changing inputs in the information domain are detected. The Detection Phase is not focused only on detecting IEDs. It is triggered by fused data sets of sensor and intelligence data points. When a human is involved, the human "sees" his/her environment, "hears" new sounds, and "feels / smells" the surroundings. The human also possesses historical information that tunes his/her expectations. The human's Detection Phase may fuse multiple data items to determine that the "event" is abnormal; and justify further consideration.

The reaction time of humans and their limited ability to react to constantly changing environments, demand that the detection of IEDs be assigned to a variety of autonomous or semi-autonomous devices.

In some cases, the system may detect a potential IED. In other cases, the system may detect other "features" that may be important (or may not). Some features may be important for navigation (for example a bump in the road) or for action selection (collateral damage)…

The Detection Phase might be considered a lower level or continuously running phase. This doesn't mean it is less important; only that "human expertise" is not being deployed. In animals, this may be outer level sensory processes that trigger more conscious interpretation.

It is not the responsibility of the Detection Phase to make any judgmental interpretations of the data. It is only responsible for collecting information sets into packets that justify further evaluation

The Detection Phase can receive information from higher level processing when specific situations might be expected or are of specific concern. This information can then be used to amplify or de-amplify certain observations (if appropriate). The "(if appropriate)" statement is added to enable or disable a human trait. For example, a human builds biases into observations as a means of reducing the demands on the brain. This allows humans to be "tricked" into believing they have seen something that did not occur. This is a common technique used in magic tricks. Computers can, by design, treat every observation as completely unique and not take any short cuts. We say "(if appropriate)" to suggest that there will be cases when we want history to bias the interpretation.

KEEL Technology addresses the Detection Phase by fusing elementary data items into actionable data items or packets. These actionable data items are then prioritized and sorted for further analysis. KEEL can provide this subjective prioritization.

Identification Phase (IED):

The Identification Phase is initiated when an IED (or potential IED) is detected. Identification is accomplished by interpreting multiple data packets from multiple intelligent sensors. So, where the Detection Phase is fusing of multiple raw data items into preprocessed data packets, these packets may still not be sufficient for identification. In this case more integration is necessary. The Identification Phase provides this service.

In many cases, more than one data packet will be used in the identification process. There may be observations that directly focus on the IED. Other information packets may focus on the surroundings. These peripheral packets can be used to validate the IED packets or to recognize why the IED observations might be impossible.

Electrical signatures will provide one type of information. Vision sensors will provide other pieces of information. When vision sensors are used, each "feature" will come with some level of confidence. Other sensors will contribute other pieces of the puzzle. To make an "educated" decision, the combined set of data items will need to be interpreted.

This is where KEEL Technology is applicable. In each observation, a variety of data items will be collected. Some will include quality information, defining the confidence level attributed to that respective item. These “non-linear data sets” must be “fused” or “integrated” as part of the detection process. Because we are dealing with complex data sets, this can result in demands for very complex models, the design of which offer opportunities for error in the design, or in the implementation, using conventional techniques.

The output of the Identification Phase is an itemized list of items that have been identified with a confidence factor.

Evaluation Phase (IED):

The Evaluation Phase takes the identified objects and makes the determination of what to do at a high level. If the confidence factor is low, then it may be passed off to the Investigation Phase. If the identified object is not an IED, then it may be discarded or placed in an observation repository. If it is determined that the identified object has no value, it could be discarded. (Discarding might mean that the observation is placed on some queue of useless information for later disposal. This might be analogous to short term memory in humans.)

If there is high confidence that the device is an IED, then it could be passed to the Reaction Phase.

The selection of the appropriate options is the domain of KEEL Technology. Here options are balanced according to risks and rewards. External intelligence can dynamically tune the decision making by adjusting the sensitivity or controlling the importance of different options.

Investigation Phase:

If an information packet is passed to the Investigation Phase, it will participate in the development of a strategy for the device. In a semi-autonomous situation, the human component of the system may be asked to participate in the investigation by deciding how to address the “soft” value judgments. In an autonomous solution, the device will have to exercise its own judgment to determine a course of action in order to gather additional information. The autonomous device will balance tactics necessary to gather the additional information about the potential IED with alternative tactics. The situation may dictate what is done. This type of subjective justification is the domain of KEEL Technology. The potential for success of alternative investigation techniques will be balanced against potential risks. These will all be compared with alternative reactions such as diversion, destruction (by various means), transfer of responsibility, or ignoring the data.

Reaction Phase:

The Reaction Phase is the culmination of all of the information acquisition and interpretation. The Reaction Phase is where the determination is made as to how to respond to the situation. The basis of this reasoning will be the "rules of engagement" or "policies" that are in existence at the time. To determine the most appropriate course of action, a number of pieces of information will need to be considered, such as:

- Detailed "observed" IED information
- Background data on the type of IED that was "observed"
- An evaluation of collateral damage
- The environmental conditions that might impact the different courses of action
- The present operational situation
- The resources available
- Self assessment

Each response profile will include the integration of information items, such as those identified above. The result will be the selection of the "best" alternative. The cognitive work does not stop at the selection of the best alternative, however. The response will most likely be qualified with the relative application of resources. In other words, a reaction will likely include soft values of speed or timeliness, a controlled amount of force, a positioning of response (how close, from what direction, etc.)…

This integration of subjective values and the distribution of relative levels of response (outputs) is the domain of KEEL Technology.

Self Preservation:

In human systems, or in systems composed partially or completely with autonomous devices, self preservation must be considered as part of the overall solution. Two aspects are considered in this document.

First, self preservation can be considered as a component of the Reaction Phase where the best option is being selected and qualified. In the prior "phase domain discussion", self-preservation can be used in risk assessment evaluations that contribute to reaction decisions. This concept would be just a normal part of the decision-making process when there is sufficient time available to make a reasonable decision.

Second, self preservation can be considered a service of a general architecture. This contributes to system architecture considerations when one needs to accelerate the response to real-time events. The concept of interrupts was introduced to computer systems to allow some events to interrupt the serial processing of computer instructions and enable the processing of higher priority activities.

In the IED context, there may be cases where there is a need to accelerate the system response to detected events. The most obvious of these events would be the detonation of the IED itself. The desired response would be to exercise whatever defense mechanisms are available, whether to protect human operators, or to protect the autonomous device itself.

If it was possible to have a single simple sensor detect the explosion and trigger the defense mechanism, then this would be the approach selected. On the other hand, if the detection process involved the integration of multiple sensors that could benefit from cognitive (reasoning) functionality, then the single sensor approach may not be acceptable. The single sensor approach may also be susceptible to false triggers. This is certainly not desired either as it may compromise the objective of the entire system.

KEEL Technology can participate in this solution by creating the KEEL Engine as an analog circuit. The potential advantage of KEEL Technology over a custom design is that the KEEL Engine could be constructed and emulated as a computer based model and tested in simulation before taking the KEEL design and implementing it as an analog circuit where higher performance could be expected.

Summary:

Humans are "taught" rules of engagement or policies that describe how they are to respond to situations that they are expected to encounter. In the United States, the English language (written and verbal) is used in this training. Humans are also placed in simulated environments where they are tested to see how they respond. When they make errors in judgment, they are reprimanded in an attempt to tune their response. Unfortunately humans are still "human". One cannot guarantee how each human will interpret their situation. Humans also suffer from fatigue (mental and physical), that can cause them to misread their situation. They can also suffer from information overload. They can still make bad judgments, even when they have been exposed to extensive training.

As future combat systems move to include more autonomous and semi-autonomous devices, those devices will be challenged to take on more of the roles where judgment and reasoning are required. Judgment and reasoning are data fusion related capabilities. When delegated to autonomous devices, the English language does not provide an acceptable method for defining the rules of engagement or policies that will be interpreted by these devices. Even with humans, the rules of engagement defined in the English language are subject to the interpretation of individual humans.

When integrating the rules of engagement into autonomous and semi-autonomous devices, we are dealing with the integration of data items at a much lower level than commonly described for humans. These might be sensor values that must be interpreted in light of the present situation. Should these rules be described in the English language, they would be much too burdensome for any human. On the other hand, for a device to exhibit the same kind of reasoning expected from a human, it must be completely explainable and auditable. This is especially true of a device that is operating in a safety critical environment.

KEEL Technology fits in these data fusion domains, because it can address these complex situations with solutions that are completely explainable and auditable. The explicit representation of the KEEL dynamic graphical language makes this possible. The ability to take a cognitive model created for deployment in a computer (microprocessor)-based design, and to produce it as an analog circuit when very high performance is required, is an added advantage.

This paper suggests the decomposition of the IED problem into both a series of cognitive phases and also into a hierarchy of data fusion activities. It does not suggest any specific architecture for coupling the phases or any specific packets of fused data that will be necessary. It does not identify any specific sensors or data sources. It attempts to highlight a common need that can be deployed at multiple levels: the need for an auditable data fusion model that can handle dynamic, non-linear systems. This paper is intended to highlight areas where KEEL Technology can contribute to a solution.

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