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TITLE: Artificial Intelligence for Explosive Ordnance Disposal System (AI-EOD)

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ARTIFICIAL INTELLIGENCE FOR EXPLOSIVE ORDNANCE DISPOSAL SYSTEM (AI-EOD)

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ABSTRACT

Based on a dynamically configurable neural net that learns in a single pass of the training data, this paper describes a system used by the military in the identification of explosive ordnance. Allowing the technician to input incomplete, contradictory, and wrong information, this system combines expert systems and neural nets to provide a state-of-the-art search, retrieval, and image and text management system.

PROJECT OVERVIEW

The Artificial Intelligence Explosive Ordnance Disposal System (AI-EOD), developed in support of the Naval Explosive Ordnance Disposal Technology Center, is a neural net AI-based multiple-incident identification, recording, and tracking system featuring state-of-the-art search, retrieval, and image and text management.

Artificial Intelligence

The foundation of the system, the *neural net*, is a dynamic data driven configuration with single pass learning and represents an innovative implementation of artificial intelligence.

The result is a search and retrieval capability that uses any combination of available information, including incomplete, inaccurate, contradictory, or negative data, to access Series 60 publications.

Recording Tracking

For incident recording and tracking purposes, the system prompts the Explosive Ordnance Disposal (EOD) technician for pertinent information. It also tracks the status of the incident.

Identifying Objects

The AI-EOD system's unique search and retrieval capabilities assist the technician in identifying objects. For example, one can search by characteristics such as physical attributes, by common name or alias, by nomenclature, or by publication number.

Audit Trail

During a session, each characteristic, or lack of a characteristic, is recorded as the EOD technician enters it. This record serves as a type of audit trail to document the effort.

Publication Listing

Based on information provided by the technician, the system displays and updates a list of relevant publications in real time. The system also evaluates and rates the publications and places the publications with the *best* fit to the input characteristics at the top of the list.

Viewing

At any time, the technician can select one or more publications, consisting of text and images, for viewing to assist in confirming the identity of an object. Viewing features include multiple windows, zoom-in and zoom-out, rotation, and scrolling.

Reporting

For times when a hard copy of the publications would be useful, one or more publications can be selected and output on a laser printer. The audit notes can also be printed.

PROJECT BACKGROUND

Under the general management of the U. S. Army Research Institute (ARI) for the Behavioral & Social Sciences (PERIMB), designated by the Joint Services Manpower and Training Technology Development (JSC/MTTD), a management and information system incorporating Artificial Intelligence for Explosive Ordnance Disposal (AI-EOD) was to be developed. The objective of the AI-EOD project was to provide EOD technicians of each branch of the military services with an efficient, easy-to-use information system for identifying ordnance and retrieving the appropriate render-safe procedures. The entire AI-EOD development program was directly managed by a task leader from the Navy Personal Research and Development Center (NPRDC).

As the size and complexity of the EOD mission continue to increase, the accuracy and efficiency of the technicians are dependent on an improved information support system. The EOD community is composed of approximately 3,000 joint-service military personnel. The material is also used by EOD personnel from the Federal Bureau of Investigation (FBI); Department of the Treasury, Bureau of Alcohol, Tobacco, and Firearms (ATF); Secret Service; and other governmental agencies.

The military EOD community is called on to respond to approximately 20,500 operational tasks per year. Each year the increasing sophistication and complexity of munitions and their incorporated countermeasures further tax the skill and training of the EOD technicians. At the same time, acquisition of munitions by third world nations and terrorist groups is becoming easier—as is the ability to fabricate and assemble munitions.

There are approximately 117,000 pages contained in the Series 60 publications. These pages comprise about 2,800 separate documents with about 25,000 diagrams and photos. The munitions are separated into 13 categories; each category has different identification features with which the EOD technician must be familiar. The supply of candidates for the EOD career field who possess the aptitude to master this material is decreasing, while the requirement for numbers of EOD technicians in each of the services is increasing. Currently, the joint service EOD community is at 80 percent strength and continues to lose experienced veterans because of retirement. The EOD school has a 25 percent attrition rate and a 52 percent setback rate in training to graduate 300 EOD technicians per year.

The two-drawer safe microfiche/paper-based information system used both in the field and as part of EOD training is difficult and confusing to use. EOD readiness is adversely affected by the slow process of technical information retrieval in the field. The microfiche/paper system is frequently cited as a cause of difficulty leading to attrition and setbacks in school, as well as reduced performance levels in the field. The Naval Explosive Ordnance Disposal Technology Center in Indian Head, MD issues about 200 revisions per year to each of the Series 60 publication holders. Keeping the bookshelf up to date is both error prone and a major administrative task in each of the units.

It has been recognized that the technology currently exists to automate the storage, retrieval, updating, and reproduction of the technical information. Less experienced EOD team members could take advantage of an automated, field-portable system to increase their performance to the level of more experienced technicians. The EOD school could take advantage of the information system in its curriculum to enable candidates with a wider range in aptitude scores to successfully enter the EOD career path.

With this as a background, a team was assembled at Los Alamos National Laboratory to design, build, and demonstrate the effectiveness of an information system incorporating artificial intelligence to increase the efficiency of EOD teams.

PROGRAM DESIGN

The categorization of explosive ordnance into 13 groups should not be understood to mean that the boundaries between groups are clean and distinct. While there are distinct and obvious differences between a 500-pound bomb and a hand-thrown grenade, the same can not be said for a large number of the ordnance. The increasing sophistication and deadliness of modern devices has shown the gradual incorporation and sharing of features and appearances of diverse munitions. The variations from one category to another can be blurred and indistinct.

The analysis for the AI-EOD system has found at least 73 major characteristics or features that can be used to identify an ordnance. These identifying features can range from the simply ***yes it does*** or ***no it does not*** have the feature to: ***if there are fins, how many are there, their position, shape, composition, markings, and color.***

Collecting this information is done by the traditional attribute value pairing:

Number of Fins (the attribute) = 8 (the value).

Casual observers may say that, given this information, an ordinary database system will store and retrieve the correct documents. Given the ability to view the ordnance undamaged—from many view points—and having plenty of time, they would be correct. If the information available is correct and unambiguous, there would be no reason for an artificially intelligent system.

Outside the classroom, the ordnance can be partially obscured, rusted, corroded, bent, broken, or modified. The microfiche/paper method of identification relies on obtaining the diameter and length. If the device is buried, bent, broken, obscured, or too dangerous to approach, the information available to the traditional database is not obtainable or suspect. A normal database will provide no answers if even one input parameter does not exactly match the specifications of the known ordnance.

Previous prototypes using expert system data retrieval have been able to extract the expertise for a small number of identifications. However, the complexity level of the program was high and growing quickly. Worse yet, the expertise had to be incorporated directly into the software code. Any missing, incorrect, or ambiguous information would invalidate the expert system. The effort of creating and then maintaining an expert system that must be modified to handle the continuous data revisions would be unsustainable. A method also had to be found that would deal with the problems of incorrect, incomplete, or ambiguous information.

The EOD technicians contend with these problems with varying degrees of intelligent reasoning coupled with experience. Reasoning gives the ability to realize that if a device looks like a mortar but has a bullet trap, the device must not be a mortar but a type of rifle grenade. Experience is the recall of information connected with a given situation or data characteristic.

The role of the AI-EOD software is not to think for or replace the EOD technician, but rather to provide the technician with a useful tool. To be useful, the software must be able to augment the lack of seasoned reasoning and experience of the new EOD technician while not forcing the experienced EOD technician to a slow pace.

A network, hierarchy, or relational database, by default, assumes that a list of criteria given to it for document selection will be used by logically ANDing the criteria. Suppose the EOD technician wants to find a document that describes a device that has six fins, a nose fuze well, and a light metal body casing. If all of the information is correct, the database system will find any matching documents by looking for a document that describes a device that has fins

- AND there are six of them
- AND a nose fuze
- AND a light metai body casing.

If there are no documents with these exact features, the database system will make no response. The EOD technician could reformulate the request to look for a device that has fins

- AND there are six of them
- OR a nose fuze
- OR a light metal body casing.

Now the system would respond with far too much data. After all, there are bombs, grenades, mortars, torpedoes, and missiles that have six fins. And, there are landmines that have light metal body casings but don't have fins that would be presented. This list would be of no help to the EOD technician.

One alternative would be for the EOD technician to refo. mulate the request to look for a device that has fins

- AND six of them
- OR a nose fuze
- AND light metal body casing.

While this would narrow the response, the object was to aid the EOD technician, not require the technician to master logic and database processing.

The situation becomes even more complicated if the device does not, in fact, have a light metal body casing, but instead has a plastic body casing. A knowledgeable EOD veteran, upon hearing the description characteristics, could discount the light metal body casing as not matching a known device; or respond that there is a device with light metal body casing, but it has eight fins not six.

It was the goal of the AI-EOD system to provide this ability to present information while not knowing which input characteristics were correct, incomplete, or slightly wrong. The veteran EOD technician uses the knowledge and experience stored in his brain. The AI-EOD system uses the building block of the brain, the neuron, to base its artificial intelligence.

Neural Net Design

Basic Components. The neural software is constructed in the C++ language. The object-oriented nature of the language meets the needs of the logical design. The artificial neuron is based on the basic biological model. The central cell body, the soma, is where the nerve impulses are received, processed, and sent out. The nerve inputs can be excitatory or inhibitive as are the outputs. Input signals are not simply received then sent out, but are processed by the soma. If the soma does not receive enough stimulation to exceed its excitation threshold, no output is generated. In addition to the varying degree of excitatory and inhibitive signal strengths received, time will decay the stimulation level of the soma.

The basic transmission nerve, the ganglia, is the electrical wire through which the signals are sent. As in its copper counterpart, there is resistance that modifies the signal. The ganglia can send the signal in only one direction. The ganglia used to send a signal out from a soma are called axons. Ganglia that bring a signal into a soma are called dendrites. In effect, one cell's axon is another cell's dendrite. At the receiving end of the axon is a signal filter called a synapse. The synapse further modifies the signal that the receiving soma finally receives.

This aggregate of soma and ganglia comprise a neuron. Individually, a neuron is relatively simple. Its true power comes from the diversity and complexity of the interconnection of neurons and the summation of the parallel processing of each neuron being greater than the sum of the parts.

Interactive Activation, Competition, and Associative Memory. One capability that neural net software has shown is called associative memory. Given a portion of a pattern, be it a picture of a dog or a description of a bomb, the neural net could reproduce the full pattern. This is the same as seeing only the side of someone's face but still knowing who that person is. If that person had on sunglasses, it may be harder or take longer but recognition still comes. It is the same with the neural net. The major obstacle is that, like some humans, it takes hours and sometimes days of training before the neural net can learn a new pattern. This is not acceptable for a combat EOD unit receiving revisions and new data.

Like recognizing a person at a costume party because of height, weight, body shape, mannerisms, and patterns of speech while discounting the facial paint and body costume, the neural net needs to reinforce the pattern of items that fit together (interactive activation) while repressing (competition) the items that don't fit into that pattern. This interactive activation and competition of the neurons, coupled with associative memory, is the basis for the AI-EOD neural net.

The interactive activation results when the relevant neurons send excitatory signals to associated neurons to complete known patterns. Exciting the neurons for propellers will cause them to send signals to other features of torpedoes but not send signals to features of landmines. The competitive nature comes when the propeller is also described as being six bladed. The neural net will further reinforce those features of torpedoes that have six bladed propellers, while sending inhibitory signals to other torpedo patterns without six-bladed propellers.

Expert System Knowledge Acquisition. Since there is no decision logic within the neuron to decide where the signal will be sent, how does it know where to send positive and negative signals? The answer is that individual neurons don't know. An expert system first had to be developed to collect the necessary information about each ordnance.

Each publication contains what is known as Figure 1. This figure is a drawing of the device. Within the text of the document there is usually a description of the device detailing those features not revealed in the drawing. Since the important descriptive information is only visually available in the drawing, a system was developed to extract this information.

After identifying the name and category type of the ordnance, the expert system will ask for information based on previous answers. While gathering information for a landmine, no question will be asked about fins. Whereas, for other ordnance, not only will the question of the presence of fins be asked but also the number, placement, composition, coloring, and shape of the fins. Now, in addition to a Figure 1, there is an identification table within each publication. This table has the list of attributes (length, width, number of fins, body casing material, etc.) that can be used to identify this ordnance. Only those attribute value pairings pertinent to an ordnance are included in that ordnance's identification table.

Whether or not a question is asked depends on the ordnance being described and the answers to previous questions. This expert system embodies the knowledge of experienced EOD technicians as to what can be useful in the identification of an ordnance.

Knowing which questions to ask represents the reasoning power of a veteran EOD technician. The data produced from this program is the knowledge base of what distinguishes one ordnance from another; in other words, an EOD technician's experience. The expert knowledge is also the user interface to the neural net.

With the reasoning and identification information available, the artificial neurons can now be configured to reproduce the abilities of an expert EOD technician in the identification of explosive ordnance. As part of the development of the expert system, 73 categories of identification attributes were identified. Each category may have many different attributes or have a list of acceptable values for that attribute. For example, within the Dimensions category, there are more than 40 ways of measuring the various ordnance. Obviously, only some are appropriate for a particular device. Other categories such as Body Color list the 50+ known body colors recognized as a valid identification feature. This basic information about the different categories, their names, materials, and acceptable value range is collected into one file. The data collected by the expert system about each individual ordnance, identifying attribute, and value is aggregated into a second file. These two files are used to configure the neural net.

Neural Net Creation. The first file is used to create the basic foundations of this artificial brain. It creates neurons to represent each of the individual values, except for numerical values. There is a neuron for *yes there are fins* and one for *plastic body casing.* These neurons are clustered logically via axons and dendrites, within attribute clusters. Neurons representing light metal, heavy metal, plastic, cast HE, and other materials would be clustered together to represent the body material attribute. Each neuron is connected to the others within the cluster with an inhibitive axon. From each neuron, a positive axon would be connected to other neurons that share in the identification of a particular ordnance. The plastic body material neuron would be connected to the rubber pressure plate neuron and the ribbed body texture neuron in describing a particular landmine. The set of neurons describing an ordnance would be connected to a neuron representing the publication number of the ordnance.

The neural net software has no preconceived notions about the attribute categories, the values, or the interconnections of the neurons. This is totally controlled by the data contained within the two files produced by the expert system. Instead of hours or days to train the neural net, the program builds and establishes the trained neural net in seconds. Whenever an updated CD-ROM is sent to the EOD unit with these two files a[illegible] the Series 60 publications, the neural net is also fully updated and ready to go whenever the system is started.

Neural Net Operation. The expert reasoning power used to collect the data from the publication is now used to allow the EOD technician to enter information that is known or estimated about an unknown ordnance in the field. Depending on the answer to particular questions, the program may ask for additional information. When an answer is given, a neuron will be stimulated. This external stimulation of the neuron will exceed its threshold value and cause it to send a signal through each of its axons. The axons connected to the neurons in the same cluster will be sent inhibitory signals. This will dampen the excitation of the other neurons within the same cluster since, if it is one thing, it cannot be the others at the same time.

The connection to the other neurons that describe an ordnance that shares this neuron's attribute will receive a positive signal; that is, this signal will be sent to all ordnance patterns that share this neuron. Each of those neurons in turn, if their threshold limit has been exceeded, will send forth a wave of signals. Each of those signals contri' ute to the excitation or inhibition of other neurons. Eventually, the propagation of the signals through the interconnection of neurons will return to the originating neuron. These incoming signals may further excite the neuron causing stronger output signals or dampen the neuron all the way to a quiescent state.

Because of their interconnection, when more than one neuron of a particular ordnance pattern is stimulated, their signals to each other start to reinforce and resonate—building their excitation level. This harmonic resonance will continue to gain strength, pulling in other neurons that fit within patterns that share the characteristics input by the EOD technician. Each neuron of these patterns will also be sending inhibitory signals to other members of its own cluster, thereby dampening them. These dampened neurons may be members of other resonating patterns, thereby dampening the other patterns as well. Each ordnance pattern will then have its own relative strength depending on the closeness of the match of its characteristics to those characteristics input by the EOD technician.

Since the neuron makes no decision as to who receives a negative signal, the converse is also true—each neuron will be sending positive signals to neurons not shared by the other neurons. This ensures that other ordnance that share some, but not all, of the features being described are also included in the consideration of possible devices. After all, the EOD technician may have input an incorrect attribute value. If the object is thought to be a mortar with four fins but all other descriptive features describe a rocket-propelled grenade, the inexperienced EOD technician could be in serious trouble with a misidentification.

If the EOD technician changes an input selection or value, just as in the biological neuron, the artificial neurons excitation level will decay over time. The decay will be faster in isolated neurons or neurons with weak interaction with other neurons. Those neurons that are in stronger resonant patterns will continue to be stimulated by the other members of the pattern. The loss of the outside stimulation will, however, over time, have an effect and lessen the pattern resonance strength.

Within the artificial neural net, time is created by computational cycles through the net. The net can be cycled whenever an attribute is input or can wait until a set of attributes has been selected and then initiate the neural net cycle. Each neuron is visited, at which time the analysis of its inputs takes place. During the first cycle, few neurons will have any interneuron signals since the other neurons have not yet been visited for processing. However, the presence of outside stimulus (the EOD technician selecting this attribute) will determine if any signal is sent from this neuron. On the second pass, many neurons will have interneuron signals. These will be processed and the resulting neuron stimulation level will determine if a signal is propagated. Depending on the quantity and quality (correctness) of the attributes input, only a minority of the total neurons will be stimulated and require some sort of processing. This selective processing, coupled with the independent (parallel) processing of each neuron, makes the *searching* of the data very quick. The search time is not directly proportional to the size of the database.

At least three cycles are needed to estabiish any harmonic resonance. Five cycles will most likely result in the final precedence list of most likely publications, with ten cycles providing finer detail of their relative strengths.

Analog Data. The input of numeric data is handled differently than that for a set list of possible values. While there is a neuron to represent a specific value, such as plastic, it would not be possible, or wise, to have separate neurons for each possible numeric value.

Each axon modifies the value of the signal sent out by the soma; this weighted value is what the receiving neuron uses as input. The modification provides a means of weighting the relative importance of a signal. As an example, the diameter of a device is more important than the color of paint that may or may not still be on the ordnance. At the end of each axon is the synapse filter. For most axons, this synapse is wide open and does not alter the signal strength. For those axons transmitting measurement values, the synapse filter is individually configured to alter the strength of the signal. The closer the signal is to the design specifications, the stronger the signal that passes through to the receiving neuron—thereby influencing the strength of the resonance. The further the signal is from the specified measurement, the weaker the transmitted signal is until it finally becomes negative—thereby dampening the resonance for a pattern. These synapse filters can be dynamically adjusted to give the ability to alter the range of closeness. When measuring the length of a guided missile, it is probably all right to be off by a foot or two, while measuring a fuze will require a tolerance of a few millimeters.

Fuzzy Word Searching. The same ability to ask the system to give information about an ordnance when its measurements are imprecise is the foundation used to find relevant words. The AI-EOD system uses the neural net to allow an EOD technician to use any word from the title or a commonly used nickname to find a publication.

Word information is gathered by the expert system when it collects the technical specification about the ordnance. Since the neural net will retrieve the publications relevant to something with a diameter of three inches and those that are *about* three inches, it will also find those publications that have a particular word or close to that word. Looking for a publication with the word missile in the title, the EOD technician may enter *missle* or *missel*. This approach also finds many acronyms or abbreviations, such as *mssl* for missile. Now, when looking for missile, the system will return entries for missile, *missle*, *mssl*, *missel*, and variations of *missiles*.

SUMMARY

The AI-EOD has proven itself by meeting the goals established for it. Using the system augments the abilities of both the less experienced and seasoned technician. The AI-EOD does not require new training of veteran units and can be used in the training of new recruits. The maintenance ease and portability of the CD-ROM overcomes the problems with microfiche and paper.

Testing and evaluation have shown that using the microfiche/paper-based identification system requires approximately 9.6 minutes to make a correct identification, while the AI–EOD system takes an average of only 5 minutes. The AI-EOD system has overcome the inconsistencies, contradictions, and errors during the search for a particular publication. This is shown in the most important statistic: using the microfiche/paper system, experienced EOD technicians have a 98% correct ordnance identification; using the AI–EOD system, the correct identification rate is 100%. Considering the 20,000+ yearly calls, that 2% difference can mean saved lives.