N96- 12957

PREDICTION OF SHIPBOARD ELECTROMAGNETIC INTERFERENCE (EMI) PROBLEMS USING ARTIFICIAL INTELLIGENCE (AI) TECHNOLOGY

S44-32
64169
p. 10

Written By:

DAVID J. SWANSON
Systems Exploration, Inc.
4241 Jutland Drive
San Diego, CA 92117

ABSTRACT

The electromagnetic interference prediction problem is characteristically ill-defined and complicated. Severe EMI problems are prevalent throughout the U.S. Navy, causing both expected and unexpected impacts on the operational performance of electronic combat systems onboard ships. This paper focuses on applying artificial intelligence (AI) technology to the prediction of ship related electromagnetic interference (EMI) problems.

INTRODUCTION

Electromagnetic interference, radio noise, and radio frequency interference all refer to the same condition. Most commonly referred to by the Navy as EMI, this condition inhibits, prevents, or distorts clear reception of an electromagnetic (EM) signal and degrades the overall performance of an electromagnetic system. The largest single consumer of the electromagnetic spectrum is the military. Modern military operations require that a large number of electromagnetic pieces of equipment be compatibly operated within a relatively small geographical area. The complexity of shipboard antennas, military radio frequency communications, and military combat EM systems is increasing far more rapidly than the improvements in EM design technology[1].

DEFINING THE PROBLEM

With the increased use and dependence on electromagnetic equipment, the accurate prediction of EMI has become a major tactical concern as well as a system design issue. More EM equipment is on U.S. Naval vessels today than ever before and most of it is considered critical to the vessel's success and survival in combat and routine day-to-day operations. While the U.S. Navy has received substantial benefit from the technological advancements, shipboard EM systems have become increasingly complex and vulnerable to EMI effects. Although shipboard EMI is not a new issue, the U.S. Navy is currently undergoing what the President of the U.S. Navy Board of Inspection and Survey called an "Electromagnetic Interference Pandemic"[2]. This means that every U.S. warship suffers from mild to severe electromagnetic interference that could threaten safety and decrease the ability of a ship to successfully complete its mission. The Navy has already witnessed several EMI induced disasters.

Three examples include:

* HMS SHEFFIELD. To avoid EMI to satellite communications, missile defenses were turned off resulting in the loss of this ship in 1984. Losses included over $200 million in damage and the death of many crew members.

* USS FORRESTAL. EMI triggered an aircraft rocket detonation on this aircraft carrier in the late 1960s. Losses included 134 crew members, 32 aircraft, and $172 million in damage to the carrier.

* NAVY CRUISER. A missile hit a friendly cruiser in the late 1960s due to electromagnetic interference. Losses included over $100 million in damage, the destruction of the topside of the ship, and the injury of many crew members[3].

In an effort to mitigate interference problems, the Navy has sponsored research and development to investigate various methods of solving the shipboard EMI prediction problem.

MATHEMATICAL MODELING

One standard approach to EMI prediction uses computationally intensive mathematical models. These mathematical models will produce reliable forecasts if the number of possible EMI sources and victims is small. Unfortunately, in U.S. warship communications and radar systems, the number of EMI sources is vast, varied, and constantly changing, making this mathematical approach cumbersome and impractical. An example that demonstrates the inefficiency of the mathematical model approach involves hull-generated intermodulation interference (IMI) signals. IMI signals are multiple transmissions that combine in a nonlinear fashion in and around the topside of a ship and reradiate as unwanted signals. A mathematical model is used to determine the interference frequency. The means for predicting when and which signals cause interference involves analyzing an overwhelming number of transmitter frequency combinations[4]. Due to the large number of frequencies that have to be considered, the testing process is labor-intensive, costly, and can take up to 24 hours to complete, although automated testing systems are being explored that are expected to reduce the overall testing time to about 6 hours[5].

It is frequently too costly, time-consuming and impractical to use these mathematical models in a rapidly changing tactical situation. In an effort to resolve EMI obstacles two alternatives are often employed.

CURRENT EMI SOLUTIONS

Two approaches have been relatively successful in containing and eliminating EMI. These approaches attempt to ensure EM equipment will function as designed without adversely affecting surrounding EM systems. The first approach relies on maintenance. Wait until an EMI problem occurs and then attempt to correct it. The second approach stresses prevention. Impose rigid design specifications on the system during the planning stages in an attempt to "over-engineer" or design-out all possible interference problems. Both of these approaches have been reasonably successful in reducing EMI in the past, but as additional EM equipment is installed aboard U.S. warships, these methods are not able to cope with the complexity and complications resulting from the presence of the large number of electromagnetic devices[6].

Once again, forecasting is possible, but only in an environment containing a small number of possible sources and victims of EMI. To meet the challenge of electromagnetic compatibility in an increasingly dense electromagnetic environment, the Navy is directing its attention to the application of AI technology to this problem.

AI AS AN ALTERNATIVE SOLUTION

Artificial intelligence technology has been widely successful in bringing ill-defined or combinatorially explosive problems into a tractable state[7,8]. AI technology differs from conventional programming technology in several ways.

One of the fundamental differences is AI techniques solve problems by manipulating symbols and symbolic relationships instead of performing standard mathematical computations. Another important distinction between AI techniques and conventional programming techniques is the use of heuristics instead of algorithms. Heuristics are useful principles or guidelines applicable in an area that may not be strictly defined.

Heuristics are typically used in areas that are resistant to mathematical approaches or algorithmic solutions[9]. The algorithmic approach will always produce the optimal solution but may take an unacceptable amount of time. The heuristic approach will generally produce an acceptable solution within a much shorter timeframe.

The most popular and effective way to express heuristics has been in the form of pattern/action decision rules, called "production rules"[10]. This methodology centers on the use of statements of the form IF condition THEN action. Production rules are a superior paradigm for use in describing situations or processes driven by changing data. Production rules can specify how the program should behave in the presence of changing information without detailed advance knowledge about the flow of control. Symbolic reasoning, heuristics, and the use of production rules are an appealing approach to problems that are resistant to mathematical approaches or algorithmic solutions such as the EMI prediction problem.

In late 1986, the Naval Ocean Systems Center (NOSC) San Diego, California, began exploring alternative approaches to EMI prediction. At that time, NOSC initiated the Adaptive Electromagnetic Control System (AEMCS) project. The focus of this effort was to develop a prototype decision aid that would forecast potential EMI problems on individual U.S. Navy destroyers. AI programming techniques and rapid-prototyping were the research and development approaches selected to explore both the problem and various partial solutions. The prototype itself was written in C and PROLOG programming languages and ran on IBM ATs. An EMI expert was consulted in the beginning of the AEMCS project to ascertain EMI prediction heuristics. Surveys were conducted on several ships to obtain information regarding the equipment and current EMI problems. The AEMCS prototype system required the operator to enter into an IBM AT computer the frequencies for all operating transmitters and receivers. Other EMI prediction factors, such as transmission power and transmitter location, were addressed implicitly within the production rules. Once the operator wanted an EMI forecast, facts about transmitters, receivers, and their respective frequencies would be asserted into the PROLOG EMI analysis system. If a production rule concluded there was a possible EMI conflict, then "a possible conflict fact" would be asserted into working memory and text concerning the problem would be sent to the terminal. If the operator wished to get further information on a potential conflict, the conflict would be selected and a description of the effect with possible resolutions would be displayed.

When the AEMCS system prototype was installed aboard the first ship, it was well received. Later, the AEMCS system was enhanced in response to suggestions from the users and was installed on several other ships.

EXPANSION OF THE AI APPLICATION

During 1989 NOSC initiated work on an EMI prediction system (EPS) prototype with a much larger scope than the AEMCS project. The focus of this effort was to better define the tactical EMI prediction problem and develop an embeddable prototype decision aid that would forecast potential ownship and ship-to-ship EMI. The project was to apply and expand the knowledge gained from the AEMCS project to the prediction of EMI problems within a preselected group of naval vessels. The EPS prototype was intended to be embedded within an electronic warfare command, control, and communication program, the Electronic Combat Module (ECM).

A number of different expert system development tools and languages were considered. The C Language Integrated Production System (CLIPS) was finally selected as the development tool for the project, using a SUN 4 as the development platform. CLIPS was selected because of its forward chaining inference method based on the Rete algorithm and its performance. It was expected that up to 150 EM devices might have to be considered at one time. Analyzing 150 devices was a formidable and computationally intensive problem and the expectation was that CLIPS would exhibit superior performance while analyzing a large number of different devices for potential EMI conflicts.

After CLIPS was selected as the development tool, a rudimentary knowledge base design was established. The design incorporated into the EPS prototype the heuristics for predicting historically known EMI problems among various ship classes. See Figure 1. The prediction of historical EMI problems were focused on since the problem forecasts could be verified and the historical information forecasts were the most useful to shipboard personnel. Ownship EMI problems were also concentrated on since these problems currently represent the most mission inhibiting collection of EMI problems. Heuristics for determining general receiver EMI, such as adjacent channel interference and odd-order IMI, were also incorporated.

```
(defrule SPS94-SSR13
"The broadband noise that is generated by RF transmissions
illuminating metal-to-metal contacts raises the ambient noise level
surrounding the ship throughout a wide spectrum of frequencies.
This reduces the signal-to-noise ratio of the incoming desired
signals resulting in reduced receiver sensitivity and loss of
signal reception."

   ;; If the SPS-94 radar and the SSR-13 receiver are
   ;; operating simultaneously on a Ticonderoga class
   ;; cruiser then assert the existence of a possible
   ;; EMI problem.

(?d1&:(eq ?d1 sps-94) ?
             ?ship1
             ?shipclass&:(eq ?shipclass cg-47)
             ? ? ? ? ? ? ? ?)

(?d2&:(eq ?d2 ssr-13) ?
             ?ship2&:(eq ?ship2 ?ship1)
             ?shipclass&:(eq ?shipclass cg-47)
             ? ? ? ? ? ? ? ?)
=>

   ;; Bind a pattern matching variable
   ;; and assert a possible EMI problem.

(bind ?gen (gensym))

(assert (emi SPS94-SSR13 ?gen ?d1 ?ship1 ?d2 ?ship1
        "Lost or reduced ssr-13 reception")))
```

Figure 1. Historical EMI Problem Rule.

After many design refinements, the current design of the EPS prototype encompasses historical EMI problems for most classes of surface ships. This design is similar to the AEMCS design in that the EMI forecasts concentrate on individual ships rather than ship-to-ship EMI problems.

The architecture of the initial EPS prototype was not complicated. A file containing a list of facts, or characteristics, about all transmitters and receivers operating on the various ships was created by the ECM program. A fact list is made up of the device name, device type, ship name, ship class, function, frequency in MHz, 3db-bandwidth, receiver bandpass, auxiliary received frequency, relative priority, power, and antenna gain. See Figure 2.

```
(DEVICE-1 TRANSCEIVER YORKTOWN CG-47 ECM 9000.0 15.0 10.0 0.0
HIGH 200.0 UNKNOWN)

(DEVICE-2 TRANSMITTER MERRILL DD-963 TACAN 286.5 2.0 1.0 316.7
MEDIUM 15.0 UNKNOWN)

(DEVICE-3 RECEIVER OBRIAN DD-963 COMMS 245.3 2.0 1.0 0.0
LOW 15.0 UNKNOWN)
```

Figure 2. Facts are Lists of Device Characteristics.

Upon execution, the EPS prototype asserts facts into working memory and the EPS is then run. Another file is created during execution that contains the resulting EMI problem forecasts. In this case the EMI forecasts are lists. The first element in Figure 3 is a pattern matching symbol, followed by rule name, conflict index, source device name, source ship, victim device name, victim ship, and effect.

```
(EMI URN54-SPS92 GEN1 URN-54 YORKTOWN SPS-92 YORKTOWN
"INTERFERENCE TO THE VIDEO OF THE SPS-92 RADAR")

(EMI HF-SPS5 GEN2 T2213 RAY SPS-5 RAY "SPOKING")
```

Figure 3. EMI Problem Forecasts are Represented as Lists.

The ECM takes this file with the EMI forecasts and displays them through the ECM's man machine interface (MMI). In some cases there are workarounds to the EMI problems and these can also be displayed through the MMI.

The current version of the EPS prototype is completely embedded within the ECM program. Files are no longer used to assert facts or capture EMI forecasts. The EPS system is controlled through a

C program that obtains the required information, asserts it into the system and takes the EMI forecasts and displays them through the MMI. As devices are shut off or frequencies are changed, the EPS system responds by creating a new fact containing the change and asserts it into the EPS facts list. Production rules retract old facts and EMI forecasts change when a frequency, power level, or ship distance changes.

Efforts currently focus on obtaining heuristics that relate to the function and priority of various shipboard devices. In a high-threat area, all shipboard self-defense systems are given the highest operating priority. Suppose a high powered high frequency (HF) communication transmitter interferes with a shipboard self-defense system. In the context of ship survival, tactics dictate securing the HF transmitter rather than the self-defense system, if no workaround is available. The result of incorporating these heuristics into the system is that the system has judgement concerning possible solutions to EMI problems.

Information about historical EMI problems is obtained from the Shipboard Electromagnetic Compatibility Improvement Program (SEMCIP). SEMCIP is at the forefront of efforts to correct Naval shipboard EMI problems. Most historical EMI problems concern simultaneous operation of multiple shipboard systems. In the SEMCIP database, which contains various problem descriptions, one of these systems is considered the source of the EMI and the other is the victim. Figure 4 translates this source-victim format into a production rule.

```
(defrule SPS94-HFRECEIVERS
"SEMCIP reference number 414-82. The transmissions from the SPS-94
radar can cause broadband noise (BBN) to be generated around the
topside of a Ticonderoga cruiser. This occurs when there is arcing
across loose metal-to-metal junctions due to illumination of the
junctions by transmissions from the SPS-94. This BBN raises the
ambient noise level surrounding the ship across a wide spectrum of
frequencies, reducing the signal-to-noise ratio of incoming signals
and consequently reduces the sensitivity of any HF receiver(s).
The solution is to eliminate the BBN by insulating, grounding, or
removing loose metal-to-metal junctions where induced RF energy has
caused arcing."

  ;; The following clause will be true if the SPS-94 is
  ;; operating on a Ticonderoga class cruiser.

(?dl&:(eq ?dl sps-94) ?
            ?shipl
            ?shipclass&:(eq ?shipclass cg-47)
            ? ? ? ? ? ? ? ?)
```

```
  ;; If there are High Frequency (3 - 30 MHz) receivers
  ;; operating on the same cruiser at the same time,

(?d2 ?type&:(eq ?type receiver)
            ?ship2&:(eq ?ship1 ?ship2)
            ?shipclass&:(eq ?shipclass cg-47)
            ?
            ?frequency&:(&& (<= ?frequency 30)
                            (> ?frequency 3))
            ? ? ? ? ? ?)

  ;; then assume a possible EMI problem exists
  ;; with the source of the EMI being the SPS-94
  ;; and the victims being any HF receivers.

=>

(bind ?gen (gensym))
(assert (emi sps94-hfreceivers
            ?gen ?d1 ?ship1
            ?d2 ?ship1
            "Possible mild to severe EMI/IMI to HF receivers"
            )))
```

Figure 4. Source-Victim Production Rule.

The prototype EMI prediction system has over 100 production rules, most of which describe severe historical EMI problems. The prototype can analyze 75-100 transmitters and receivers within a matter of minutes, using a SUN 4 under UNIX. Shipboard testing is scheduled to begin in the Fall of 1990. The system will be used by shipboard electronic warfare commanders.

CONCLUSION

Over the last 40 years, the U.S. Navy has become increasingly dependent upon systems that exploit the electromagnetic environment. Electromagnetic technology has evolved from vacuum tube technology in the 1950s to very large scale integration technology in the 1990s. More capable and sophisticated shipboard communication equipment, radars, and other sensors have evolved. As a result, shipboard EMI has become a severe problem. The traditional approaches to EMI prediction and the achievement of system electromagnetic compatibility are impractical for shipboard use and are frequently too costly and time-consuming to use in tactical or day-to-day operational situations. In an effort to create a low-cost, effective EMI prediction system, alternative approaches are being explored using AI technology. AI technology is currently being applied successfully to portions of the shipboard EMI prediction problem. These research efforts have resulted in better Naval shipboard frequency management and are serving in the continued effort to mitigate shipboard EM interference conflicts.

REFERENCES

[1] Li, S., Logan, J., and Rockway, J., "Ship EM Design Technology," Naval Engineers Journal, May 1988, p.154.

[2] Orem, J., "The Impact of Electromagnetic Engineering on Warship Design," Naval Engineers Journal, May 1987, p.210.

[3] Grich, R. and Bruninga, R., "Electromagnetic Environment Engineering - A Solution to the EMI Pandemic," Naval Engineers Journal, May 1987, p.202.

[4] Maia, P. and Smith, J., "A Method for Predicting Intermodulation Product Levels," IEEE 1985 National Symposium on Electromagnetic Compatibility, June 1985, p.408

[5] Mieth, W., "A Cost-Effective Solution to Measurement of Hull-Generated Intermodulation Interference on U.S. Navy Ships," IEEE 1989 National Symposium on Electromagnetic Compatibility, May 1989, p.186

[6] Duff, W. and White, D., "A Handbook Series in Electromagnetic Interference and Compatibility," Vol. 5, Germantown, Maryland: Don White Consultants, 1972.

[7] Waterman, D., "A Guide to Expert Systems," Reading, Massachusetts: Addison-Wesley, 1986.

[8] Calabough, J., "Software Configuration - An NP Complete Problem," ACM Special Interest Group on Business Data Processing, Computer Personnel Research Proceedings, Conference on Expert Systems in Business, March 1987.

[9] Kunz, J., Kehler, T., and Williams, D., "Applications Development Using a Hybrid AI Development System," The AI Magazine, Fall 1984, p.53.

[10] Fikes, R. and Kehler, T., "The Role of Frame-Based Representation in Reasoning," IntelliCorp Technical Article from the special issue of Communications of the ACM on Knowledge-based Systems, September 1885, p.4.