APPLICABILITY OF ARTIFICIAL INTELLIGENCE LANGUAGES TO SOLVING THE SCATTERING AND DIFFRACTION PROBLEMS USING A PERSONAL COMPUTER

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ABSTRACT

The applicability of the AI mathematical packages to EM theory is examined with the high frequency ray-theoretic problems as specific examples. It is possible to generate expressions in both readable and FORTRAN format so that the task of computer code generation is greatly simplified. Although some of the mathematical operations available have a limited range, the users can nevertheless employ such packages to cross-check their mathematical analyses.

Introduction

The mathematical analysis in EM theory often leads to lengthy vector, tensor and dyadic expressions which are cumbersome from the computer code generation point of view. Developing computer software packages manually is beset with the problem of veracity of the codes. On the other hand, an accurate generation of the computer codes is a prerequisite to getting the theoretical results before one could judge the accuracy of a particular theoretical model.

In this paper, the possibility of applying Artificial Intelligence (AI) languages to the EM theory is examined in order to overcome the complexity of the mathematical expressions involved in the computer programming. The example chosen for this purpose is REDUCE which is an AI software package.

Programming via Non-numeric Logic

In contrast to the common higher level languages like FORTRAN, PASCAL and BASIC etc. with which the scientists are usually familiar, there exists a set a languages such as LISP and PROLOG which are essentially non-numeric in nature. Such languages are ideal for developing rule-based systems, commonly known as the Knowledge based Systems.

One such example of the rule based systems could be mathematical packages which are capable of generating explicit algebraic expressions, performing mathematical operations like differentiation, integration, matrix inversion etc., symbolically and obtaining closed form solutions for set of simultaneous equations. REDUCE is one such software package which is written in LISP.

Although we choose REDUCE as an example for the purpose of further discussion, several other software packages such as MATHCAD and MACSYMA are also well-known to carry out these operations equally well. In the discussion below we concentrate on the applicability of REDUCE to the EM problem. The particular

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example chosen is that of high frequency ray-theoretic analysis such as those applied in the GTD and UTD [1].

Applications to EM Theory

A common feature of most of the non-numeric AI languages is that they can be used to generate explicit algebraic expressions.

Example 1: If $u = (al+bm+cn)$ (1)

then find $v = u^3$ (2)

In this case the answer is returned in the readable format as

$$V := A^3*L^3 + 3*A^2*B*L^2*M + 3*A^2*C*L^2*N + 3*A*B^2*L*M^2 + 6*A*B*C*L*M*N + 3*A*C^2*L*N^2 + B^3*M^3 + 3*B^2*C*M^2*N + 3*B*C^2*M*N^2 + C^3*N^3 \tag{3}$$

The mathematical analysis is greatly simplified by the options in REDUCE to expand as well as factorize these algebraic expressions besides writing them in a particular order of occurrence. While the capability of most of the packages to integrate is necessarily limited, most of them can return elegant expressions upon differentiation. This may be used by the scientists and engineers to verify the expression that they might have derived.

Example 2: Cross-checking the expressions

$$\text{TERM1} = \frac{d\phi}{du} = \frac{+h_{mm}(4u^2+a^2)^{1/2}}{au(a^2u^2-h_{mm}^2)^{1/2}} \tag{4}$$

which has been integrated by the authors as [2]

$$\text{TERM2} = \phi = \frac{h_{mm}}{a^2}\ln\frac{a[4u^2+a^2]^{1/2}+2[a^2u^2-h_{mm}^2]^{1/2}}{a[4u^2+a^2]^{1/2}-2[a^2u^2-h_{mm}^2]^{1/2}} + \sin^{-1}\left[\frac{a[a^2u^2-h_{mm}^2]^{1/2}}{u[a^4+4h_{mm}^2]^{1/2}}\right] + h'_{mm} \tag{5}$$

It is possible to check the veracity of this integration since differentiating eq (5) gives symbolically

$$DF(TERM2,U) = (HRM*SQRT(A^2 + 4*U^2))/(SQRT(A^2*U^2 - HRM^2)*A*U) \tag{6}$$

which is same as equation (4).

AI packages such as REDUCE are often compatible with other languages in the sense of computer code generation. For example, the same expressions which are be generated during the mathematical analysis can also be obtained in the FORTRAN compatible form. While, eq (3) provides an example of the readable format, we now present an example of the FORTRAN code generation which has been actually used in high frequency scattering problem.

Example 3: To show the FORTRAN code generation.

The explicit expressions for the surface magnetic fields $d\mathbf{H}_m(P|S)$ at the observation point P due to a radiation source $d\mathbf{p}_m(S)$ at the source point S are obtained in terms of the dyadics of the Frenet-frame field vectors and other ray geometric parameters as given below. The symbols are explained in [1].

$$
\begin{aligned}
d\mathbf{H}_m(P|S) = \frac{-jk}{4}\, d\mathbf{p}_m(S) \cdot \Big\{ 2Y_0 \Big(\hat{b}\hat{b}\Big[& \Big(1 - \frac{j}{ks}\Big)\tilde{V}(\xi) \\
& + D^2\Big(\frac{j}{ks}\Big)^2 \big(\Lambda_s \tilde{U}(\xi) + \Lambda_c \tilde{V}(\xi)\big) \\
& + \tilde{T}_0^2 \frac{j}{ks} \big(\tilde{U}(\xi) - \tilde{V}(\xi)\big) \Big] \\
+ \hat{t}\hat{t}\Big[& D^2 \frac{j}{ks} \tilde{V}(\xi) + \frac{j}{ks} \tilde{U}(\xi) \\
& - \Big(\frac{j}{ks}\Big)^2 \big(\Lambda_s \tilde{U}(\xi) + \Lambda_c \tilde{V}(\xi)\big) \Big] \\
+ (\hat{t}\hat{b} + \hat{b}\hat{t}) \Big[& \frac{j}{ks} \tilde{T}_0^2 \big(\tilde{U}(\xi) - \tilde{V}(\xi)\big)\Big]\Big)\Big\} \cdot \mathbf{DG}_0(ks)
\end{aligned}
\qquad (7)
$$

The corresponding FORTRAN code generated by REDUCE for the x-component reads as

```
 ANSX3=2.*BLENDS*GHFEXI*J**2*TXF*PMXS*TXS+2.*BLENDS*GHFEXI*J
. **2*TXF*PMYS*TYS+2.*BLENDS*GHFEXI*J**2*TXF*PMZS*TZS-
. GHFEXI*TRSNFC**2*J*K*BXF*PMXS*BXS*ARCLNT-GHFEXI*TRSNFC**2
. *J*K*BXF*PMYS*BYS*ARCLNT-GHFEXI*TRSNFC**2*J*K*BXF*PMZS*
. BZS*ARCLNT-GHFEXI*TRSNFC*J*K*BXF*PMXS*TXS*ARCLNT-GHFEXI*
. TRSNFC*J*K*BXF*PMYS*TYS*ARCLNT-GHFEXI*TRSNFC*J*K*BXF*PMZS
. *TZS*ARCLNT-GHFEXI*TRSNFC*J*K*TXF*PMXS*BXS*ARCLNT-GHFEXI*
. TRSNFC*J*K*TXF*PMYS*BYS*ARCLNT-GHFEXI*TRSNFC*J*K*TXF*PMZS
. *BZS*ARCLNT-GHFEXI*J*K*TXF*PMXS*TXS*ARCLNT-GHFEXI*J*K*TXF
. *PMYS*TYS*ARCLNT-GHFEXI*J*K*TXF*PMZS*TZS*ARCLNT
 ANSX2=-GSFEXI*BLENDC*DIVFCT**2*J**2*BXF*PMXS*BXS-GSFEXI*
. BLENDC*DIVFCT**2*J**2*BXF*PMYS*BYS-GSFEXI*BLENDC*DIVFCT**
. 2*J**2*BXF*PMZS*BZS+2.*GSFEXI*BLENDC*J**2*TXF*PMXS*TXS+2.
. *GSFEXI*BLENDC*J**2*TXF*PMYS*TYS+2.*GSFEXI*BLENDC*J**2*
. TXF*PMZS*TZS-GSFEXI*DIVFCT**2*J*K*TXF*PMXS*TXS*ARCLNT-
. GSFEXI*DIVFCT**2*J*K*TXF*PMYS*TYS*ARCLNT-GSFEXI*DIVFCT**2
. *J*K*TXF*PMZS*TZS*ARCLNT+GSFEXI*TRSNFC**2*J*K*BXF*PMXS*
. BXS*ARCLNT+GSFEXI*TRSNFC**2*J*K*BXF*PMYS*BYS*ARCLNT+
. GSFEXI*TRSNFC**2*J*K*BXF*PMZS*BZS*ARCLNT+GSFEXI*TRSNFC*J*
. K*BXF*PMXS*TXS*ARCLNT+GSFEXI*TRSNFC*J*K*BXF*PMYS*TYS*
. ARCLNT+GSFEXI*TRSNFC*J*K*BXF*PMZS*TZS*ARCLNT+GSFEXI*
. TRSNFC*J*K*TXF*PMXS*BXS*ARCLNT+GSFEXI*TRSNFC*J*K*TXF*PMYS
. *BYS*ARCLNT+GSFEXI*TRSNFC*J*K*TXF*PMZS*BZS*ARCLNT+GSFEXI*
. J*K*BXF*PMXS*BXS*ARCLNT+GSFEXI*J*K*BXF*PMYS*BYS*ARCLNT+
. GSFEXI*J*K*BXF*PMZS*BZS*ARCLNT-GSFEXI*K**2*BXF*PMXS*BXS*
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. ARCLNT**2-GSFEXI*K**2*BXF*PMYS*BYS*ARCLNT**2-GSFEXI*K**2*
. BXF*PMZS*BZS*ARCLNT**2-BLENDS*GHFEXI*DIVFCT**2*J**2*BXF*
. PMXS*BXS-BLENDS*GHFEXI*DIVFCT**2*J**2*BXF*PMYS*BYS-BLENDS
. *GHFEXI*DIVFCT**2*J**2*BXF*PMZS*BZS+ANSX3

 ANSX1=CEXP(-J*K*ARCLNT)*DIVFCT*J*Y0*ANSX2

 DHMX=ANSX1/(2.*K*PI*ARCLNT**3)
```

The authors have extensively used REDUCE to cross-check their expressions derived for the ray geometric parameters for the complete class of convex quadrics as well as several Non-Eisenhart surfaces such as ogive [3] which are extremely important scatterers from the aerospace engineering point of view [4]. These ray geometric parameters can be readily used in the UTD analysis of the antenna characteristics of antennas in presence of convex scatterers.

Summary

In the high frequency ray-theoretic approach as indeed in the entire field of electromagnetics, the expressions obtained at each step of the mathematical analysis are often quite complex and unwieldy. It is now possible to consign most of these operations to such AI packages as REDUCE to accurately generate the symbolic codes.

Finally, once the analysis has been verified, the same program can be used to generate the familiar FORTRAN codes. Hence, non-numeric logic and AI languages can be used as valuable tools for antenna analysis and design problems.

REFERENCES

[1] P.H. Pathak and N. Wang, "Ray analysis of mutual coupling between antennas on a convex surface", IEEE Trans. Antennas & Propagat. (USA), vol. AP-29, no. 6, pp. 911-922, Nov. 1981.

[2] R.M. Jha, V. Sudhakar and N. Balakrishnan, "Ray analysis of mutual coupling between antennas on a general paraboloid of revolution (GPOR)", Electronics Letters (GB), vol. 23, pp. 583-584, May 1987.

[3] P. Moon and D.E. Spencer, **Field Theory Handbook**. Berlin: Springer-Verlag, 1971.

[4] R.M. Jha, **Surface Ray Tracing on Convex Quadrics with Applications to Mutual Coupling between Antennas on Aerospace Bodies**, Ph D Dissertation. Submitted to Department of Aerospace Engineering, Indian Institute of Science, Bangalore, India, Nov. 1988.