FINAL TECHNICAL REPORT

AN ANALYSIS OF THE POTENTIAL APPLICATION OF HIGHER ORDER SPECTRA TO THE STUDY OF SHIP MOTIONS IN WAVES

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INTRODUCTION

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This final report, written by L. J. Tick, is the result of the further study of the papers at the Vail Conference. It is also the result of our attending seminars at the Courant Institute and a conference at New Jersey Tech. on related subject areas. We have met many times during the past year to discuss these matters and to formulate a number of different approaches to the study of nonlinear waves and nonlinear ship motions in nonlinear waves.

Our learning process has not yet ended. We believe that completely new approaches need to be developed and applied to this subject area, both from the theoretical and data analysis point of view.

Higher-Order Spectra and Ships in Waves

Leo J. Tick

This report is of a somewhat personal nature in that it presents the author opinions on a variety of topics connected with the potential application of various non linear spectral techniques to the study of ship motion analysis with feedback to the design process. It is the case that the largest volume of activity with respect to non linear spectral techniques arises from researchers who identify themselves with the area of "signal processing" and the scientific and engineering journals of the IEEE (Institute of Electrical and Electronic Engineers) are the major locations for papers in this area.

This point is strongly made because the author came to spectral analysis from an entirely different tradition. The arguments to be presented are strongly colored by this tradition. If the reader chooses to apply to this situation the word "prejudice", he is welcome to do so. It is the author's hope that by making these predispositions explicit the reader will be better able to evaluate the arguments which are presented.

The author received his graduate education in theoretical statistics and most his work in statistics involved the application of statistical methods to various technical areas. Often the methods were developed by the writer. The reader of this document will be most interested in knowing that two of these areas are oceanography-surface waves and ship motions.

For some time now, the model of a stationary, homogeneous, Gaussian random process satisfying the linearized water wave equations and linear ship motion theory has proven to be a useful approximation to reality for some of the computations required in ship design and motion analysis One would be less than ingenuous to not mention that we have indeed been fortunate that these simplifying assumptions worked as well as they did.

To paraphrase a line from "Oklahoma", "we'd gone about as far as we could go" (linearly speaking, that is). For some years now the subject of non-linear mechanics has been under intense development. The availability and the rapidly decreasing cost of computers of sufficient arithmetical power has allowed the use of non-linear dynamics methods in ship design and motion analysis.

A recent meeting of the H-7 and H-11 panels of the SNAME in Washington, DC was devoted to just this topic and it was clear that much progress has been made . Much more could be expected over the next few years with some of these developments finding their way into standard design packages.

Since spectral techniques are an important tool in the study of ship motions in real seas, it is reasonable to consider the use of their "non-linear extensions". Though the work statement of this project calls for the evaluation of the papers and discussion that were given at the Vail workshop on "Higher Order Spectral Analysis" in June 1989, sponsored by the Office of Naval Research and National Science Foundation in cooperation with the IEEE Control Systems Society, Geoscience and Remote Sensing Society and Acoustics, Speech and Signal Processing Society, this report will not be restricted by this limitation.

The Vail conference was organized by, the presentations were given mainly by and attended mostly by members of the electrical engineering profession.

It will be argued that:

1. The papers presented at the Vail conference (as well as the research activities behind them are) irrelevant to the needs of the subject of non-linear wave and ship motion analysis and the attendant design process.

2. The papers presented the Vail conference and similar work as found in the EE literature are important to the subject of non-linear ships and wave processes.

At this point the reader may feel that 1. and 2. seem to be in contradiction but it will, hopefully, be seen that the two statements are orthogonal that is, they refer to different dimensions of the subject.

It's irrelevant - -.

The nature of most of the papers is one of the following:

There is some complex phenomenon, process, etc. that it is desired to model by a random process. The class of analytical models is chosen to capture whatever "essence" is believed to be relevant. A most important characteristic of the model is that it possess a large degree of tractability.

To make this discussion less abstract we choose an example very far from the interests of the intended audience of this report; image processing. In image processing, a goal is to develop operators which "improve" the image for whatever. In the end the goodness" of the procedure will depend on (literally in this case) an observer.

The development and selection process requires some analytical machinery. A two-dimensional random process is often chosen. There is no intention that an image IS a random process. In some sense what this type of assumption does is to focus on that set of parameters which will be used to characterize the random process (really the class of objects which are to be subjected to the set of operations developed) e.g the spectrum.

Some property of the process becomes the focus and operators are derived. It should be noted that for complex systems (really models) the hardest task is to get any operator. Any modeling procedure that has the ability to generate a procedure (statistic) by some optimization process is most welcome. If there are competing operators the one that give a better result with respect to some population property can be chosen. But, in the end, it is the performance of the operator on the data that counts. In the example of the images -- how does that lady with the hat look to an human visual observer. It is not overly important whether the mathematics was done correctly. The operators for the class of objects stand on their own. They could just as easily come from divine revelation. It is not intented to be facetious here, but to make the point strongly that the model and the mathematics is not the justification for the result. It does not seem far-fetched to the writer that a defective derivation could produce a "better" operator, etc. than a "correct" one. The reader should not be overly surprised by this statement. Since the postulated model is only a (perhaps ?) mild approximation, a mathematically correct result is no greater guarantee of a useful result than a than one with modest algebraic mistakes. In the end the researcher justifies the operator or process by demonstrating its utility in representative cases. Thus the paper may report useful or even important results without being "correct".

The reader may wonder why so much is being made about this point. The author motives should become clearer when the other evaluation of the conference is argued.

Another group of papers deals with what I like to call the "black box" situation.[1] Here there is a complex system that is either not understood or too complex for the understanding to be made operational. The inputs may be reasonably modeled as a random process. Often the input is assumed to have a simple structure. This is very reminiscent of what has appeared in the statistical literature through the years. We notice here the extensive use of linear systems and in particular ARMA (Auto-Regressive Moving

[1] It becomes a "problem" when it is formalized.

Average) formulations.

The reader should be aware that in the stationary case, ARMA corresponds to rational function system transfer functions. These have a long history in electrical circuit theory since they follow from lumped parameter passive networks. This model is also very popular in the statistical cum econometrics literature so that there is a considerable body of methodologies available to anyone taking this path.

The model may have some non-linear elements added to it or have random parameters. The various studies of underwater acoustics and "direction of arrival" and the oil prospecting fall here. [2] In this group the hope is that the model is reasonable so that it may be used for among others for control. The subject of systems identification come into use here since, obviously, we need the parameters of the system to assert control.

A third type of work presented at the conference uses a random process model and the statistics that goes with it to characterize some complex "signal". Although the statistic chosen, the reader might keep in mind the spectrum as an example, could have some relationship to what is inferred to be the underlying characteristics of the system being studied this is secondary to its role as a "rich" and compact descriptor. This descriptor is then related to some other system characteristic which is of importance. This type of application is usual in electrophysiological signal analysis, e.g. electroencephelography[3]. Many of the papers of interest to the Navy fall under this grouping. They involve the detection of some "signal" in "noise" or how to tell a humpback whale from something else.

Why does the author of this report believe that these kinds of activities have little to offer to the subject of ship motions? A reading of the previous descriptions shows a constant theme of "ignorance" of the underlying phenomenon or system. In ship hydrodynamics (one is tempted to interject the word unfortunately) we do not have this extent of ignorance. We have equations which, it is generally believed, do properly describe the systems of interest[4]. In fact we have a linear approximation (derived from these equations) which has served very well. We do not have the "luxury" of the black box. We must struggle with the equations and extract some more from them. This discussion will be continued below.

The papers are potentially useful and it is worth being aware of their contents.

Many of the papers contain (potentially) useful and even important results. This statement my coexist with the previous since we do not refer to the technical problem studied. In order to conduct the analyses made in many of the papers, the researchers had to develop methodologies.

It is these methodologies that can be useful. To get concrete: A standard technique in dynamics of non-linear systems is the perturbation expansion. When this technique is applied to the gravity water wave equations, the homogeneous stationary solution takes the form of a Volterra series.

By good fortune or chance, whatever, the Volterra series as a general representation for systems was suggested many years ago by N. Weiner and worked on at the RLE at MIT. In a sense, the Volterra expansion is a functional power series.

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[2] This last comment is somewhat less true today as the knowledge level on the geology grows.

[3] The author feels he speaks with considerable experience and authority here. For many years researchers have tried to relate the spectrum of the EEG with disease states or states of consciousness. now they try it with higher order spectra. The author is one of this "gang".

[4] We are not here referring the "operational spectrum" of a ship and that class of problems which fall under the general heading of operations analysis or operations research. In these types of studies less "physics" based models are the usual.

This model has become popular for mildly non-linear systems in a wide range of application areas.[5] Those papers which use this model can provide useful methods and more important useful experiences in the computation, estimation and identification of the kernels of this type of functional expansion. An example is the paper by the group in EE at U. of Texas, Austin. The utility of this work with respect to the engineering problem that it addresses is not under review at this point. However for those situations where expansions of the Volterra type are used an awareness of what problems other workers have had is important. One should not infer that this conference was a prime or even good source of such experiences.

Actually the whole subject of bispectral (and higher) estimation is a treacherous one and by extension functions of them are more so. The situation of the spectral matrix and functions thereof are in my view not in such good shape, and this is an old and ought to be a stable subject. Though the author and others more than 25 years ago pointed out pit falls in simply using sample analogues of population functions for coherence estimation, one continues to find nonsense quantities computed and reported. In cases of delicacy I doubt that the spectra are computed too well. Caution should be the order of the day in estimating the higher order ones.

Among the tool-makers, the author is of this group, there is too often the solution out looking for a problem. Years ago there was the let's compute the spectrum. With the availibility of the computing, software and most especially the display capability I am sure the same will happen with the higher-order spectra.

I think the ship-wave people should leave this to the tool makers for a while. The understanding of how to introduce a managable and yet useful degree of non-linearity into the wave field and the ship that moves through it is the critical problem not estimating bispectra and ruminating as to its meaning. The notion of "frequency of encounter" which was so important in linear theory loses it meaning. A numerical operation of the Green's function on a random wave field seems not to be the route.

Taking a larger view, the writer does not believe that signal processing as practiced by the EE community has a lot to offer to the wave and ship world. I believe this results from the nature of the important problems of the area. There is a heavy accent on speed of procedures since many of the application are in "real-time", e.g. HDTV. The subject of system identification will be of increasing importance as acceptable non-linear models are developed into use. The "automatic control" literature seems a better source for ships-waves researchers.

[5] The author derived just such a solution for the second-order long-crested case many years ago, and is currently engaged in some preliminary work toward its extension and to remove what is now seen to be some imbalances.