The Chaos Panaceas

Keynote Address

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Abstract — **In this talk we review the work in the field of chaos applications, especially in the formulation of solutions for practical engineering problems. Using a few case studies we illustrate the various common pitfalls in the reporting of chaos applications in engineering. Our objective is to promote the prudent use of engineering judgments and proper exercise of scientific principles when applying the theory of chaos in analyzing and solving engineering problems.**

Keywords — Chaos, application of chaos, engineering system, model validity, analysis approach.

1 INTRODUCTION

Use of chaos in solving engineering problems has been one of the most productive areas in scientific and engineering research in recent years [1]–[4]. Indeed, a huge number of research papers with an unprecedented amount of novelty claims have been produced in the past two decades. Chaos applications is still one of the trendiest topics of research. Proposals, reports and papers addressing the applications of chaos-based methods in solving practical problems are generally well received by funding bodies and journal reviewers. However, in many such proposals, reports and papers, misunderstanding and omission of the real underlying causes have led to mistaken analysis and possible misuse of chaos. It is therefore of interest to review the current state of research in this field and to clarify the various possible misunderstandings so that chaos-based applications can be developed with strong engineering judgments and consistency with scientific principles.

Undeniably, chaos does offer a range of desirable features for doing certain engineering tasks, but analysis and thorough exposition of the basis of accomplishing certain tasks is still insufficient. The problem often lies in the researchers' attitude in the way they report their work. Two aspects are not uncommon among authors in this field. First, annotating the solutions with chaos terminologies may divert reviewers' attention away from comparing with conventional methods, hence more readily justifying a novelty claim. Second, analysis of the actual cause in a conventional sense may be uninteresting or could honestly make the solutions sound too trivial.

Figure 1: A drunk man was searching under the lamp pole for his key which he knew was dropped elsewhere. When asked why, he replied, "because it's bright here."

Another very fruitful area of research related to chaos applications is the discovery of new (unreported) exotic phenomena from engineering systems. This is a very worthwhile research area as better understanding of the system behavior can lead to higher reliability and improved functionality of the system under study. However, the lack of engineering judgment may drastically reduce the credibility of the reported phenomena. For instance, if the models are invalid for those conditions under which exotic behaviors are found from simulations or numerical studies, the entire body of results can be meaningless and the real systems actually never behave in the ways predicted by simulations or numerical studies.

Also commonly pursued in this field is the reexamination of old solutions from a chaos theory viewpoint. Controlling chaos is among the most widely studied areas. Turning some theoretical work in the chaos control literature into engineering use seems to create a never-ending publication cycles. This is undoubtedly an area of research of much worthiness because conventional viewpoints may fall short of novel insights into some complex problems. However, again, the field still suffers from inadequate engineering judgment. Some authors put their blind faith on oversimplified or invalid models, while some actually end up with the same old solutions that have been used for years in practice, of course with the old solutions hidden under new chaos terminologies.

Notwithstanding the many working blunders, the field of chaos applications is still a very worthwhile area of research as many potential applications are yet to be discovered and investigated. In the process of investigating new applications, however, a healthy amount of engineering judgment is needed, especially in terms of identifying the underlying mechanisms that lead to the apparent successful applications. With the theoretical foundation of chaos being a mature scientific discipline, it makes no sense that engineers are only using it as a gimmick in getting their projects funded or papers published.

In this talk, we will review the problems mentioned above, using a few case studies to illustrate the various common pitfalls in the reporting of chaos applications. Our objective is to promote the prudent use of engineering judgments and proper exercise of scientific principles when applying the theory of chaos in analyzing and solving engineering problems

2 PITFALLS AMID APPARENT BEAUTIES

Chaos provides a lot of free features for many practical applications. Researchers were able to exploit those features and pioneered the early developments, but some soon realized the pitfalls that could be hard or practically impossible to get around. However, being ill informed, many new researchers continued to drill in the wrong direction. Researchers in the field still prefer to present themselves very positively, as many reports tend to emphasize the potential advantages rather than to highlight the difficult problems that are virtually unsolvable. The following case studies may serve to illustrate a typical course of development in this field.

Case Study 1:

The recent research efforts in applying chaos in telecommunications have clearly exposed an interesting course of development. By virtue of its extremely high sensitivity to parameter changes, chaos provides an attractive solution to secure coding and communications. However, the same feature creates a technical difficulty in coherently decoding and demodulation under realistic channel conditions, namely the impossible task of synchronizing chaos in real world environment. We should note that digital communication systems are sometimes required to perform satisfactorily under noisy condition typically down to a signal-to-noise ratio of 0 dB. Obviously, there exists no method to synchronize chaos when the noise level is as large as the signals. Neither can any noise-cleaning algorithm separate the useful chaotic signal from the noisy sample under such a condition. The problem should be clearly known to engineers [5]. Despite the efforts of some (perhaps unpopular) researchers who pointed out this virtually unsolvable problem and instead promoted noncoherent chaos-based methods, the application of coherent methods in telecommunication based on chaos synchronization is still being pursued!

Case Study 2:

Deterministic chaos has been used in cryptography, again, taking advantage of the inherent parametric sensitivity. However, the determinism may itself be the biggest pitfall that allows attack algorithms to be derived for each specific encryption scheme. Typically, a deterministic (possibly chaotic) function is designed to encrypt a message using a certain system parameter as the key. The decoding algorithm “reverses” the process in some way and recovers the message. In practice, both encrypting and decrypting algorithms are open to the public. The method is secure provided that an intruder can recover messages only through an exhaustive search of the key, as is true for existing cryptographic methods. Thus, for digital implementations, the number of bits used to represent a key is the ultimate security. So far, although there have been no proofs of the general attackability of chaos-based cryptographic methods, deterministic schemes have kept being broken by specifically designed attack algorithms (not through exhaustive key search). The average time delay between a scheme proposal and its reported attack is about 11 months. It is counter-intuitive that research activities are directed more to deriving new chaos-based schemes rather than to a rigorous study of the possible general attackability of deterministic cryptographic methods.

3 RANDOMNESS VERSUS CHAOS

Chaos has been compared with randomness: beat it, publish it! Very often, the use of chaos has been unscientifically understood or explained. Essentially, the important question of “what makes it work” was not clearly addressed.

We should point out that "randomness" is a statistical concept, but its actual generation must rely on a specific form of determinism. In this sense, comparison between chaos and randomness is nothing but a comparison of different statistical properties of two different deterministic processes (if a comparison has to be made at all). Further, it makes no sense to compare chaos with randomness because there are many kinds of chaos. If a particular chaotic function (based on Lorenz's or Chua's) is used in an application, such comparisons can at best be between the particular chaotic function and the random function used.

Nonetheless, chaos does offer the necessary features for doing a range of useful tasks, but it is not chaos in general that makes it work! Obviously, certain features of the specific chaotic function used have made the crucial contribution. The problem, however, lies in the researchers attitude in the way they report their work. Typical paper titles are like "Solving ... by chaos", giving an impression that chaos worked exclusively! This is somewhat misleading. If the reason for it to work is clearly identified, chaos could be irrelevant.

Case Study 3:

In EMI reduction, chaos is used to randomize the switching frequency so as to avoid high fixed spikes in the frequency spectrum. The same trick was used many years ago in RF engineering, though the word chaos was not mentioned. As argued above, comparing chaotization and randomization of switching frequency is meaningless. (Recently, more sophisticated and focused research has been performed in finding the relationship between the resulting frequency spectrum and the form of chaotic functions used for randomizing the switching frequency [6].)

Case Study 4:

In fluid mixing, chaos has been shown to lead to better mixing with reduced power consumption [7, 8]. The real problem could be the distribution of the frequency components of the fluid velocity and the frequency of its change of sign that are necessary to guarantee good mixing. Here, researchers have to be careful when comparing "a chaos method" with a regular mixing, since the specific chaotic driving signal used can give specific conclusion which is not necessarily true in general. Claiming that chaos uses less power has to be carefully reviewed since for the same rms power the question really is how the power is effectively distributed to facilitate mixing. Intuitively chaotic driving signals that have strong periodic and/or DC components would not give very good results. So, the real question is how to get the appropriate mixture of high frequency and low frequency signals to stir a particular kind of fluid. Chaos may not be the key point here. Anyway, as chaos contains a wide spectral mix, it would be a good starting point to investigate [8].

Case Study 5:

Chaos was thought to help eliminate striation in fluorescent lamps effectively. Specifically it has been found that a good low frequency mix of the spectrum of the driving signal is crucial. If the particular driving signal used contains sufficient low-frequency mix, striation in fluorescent lamps can be eliminated. Chaos is basically irrelevant. Some experiments have been reported [9].

4 MODELS FOR THE SAKE OF CONVENIENCE

In some engineering systems, exotic behaviors are found theoretically and by simulations. Many authors managed to package them with enough chaos and bifurcation terminologies and surely get them published. The trouble is that these behaviors could turn out to be only observable from the mathematical models used to find them. In the parameter ranges under study, however, the real systems are not consistent with the mathematical models and hence do not exhibit such behaviors.

The use of invalid models for controlling engineering systems is common, especially in the control literature. Control researchers first got the models from engineers, assumed that the models were good, and derived control strategies based on the models. However, very often, when real systems exhibit chaotic behavior, the underlying mechanism could be more complex than it would have been observed from the mathematical models. Typically, amplifier saturations leading to some forms of border collision can create totally different kinds of chaotic behavior. In some cases, the predicted bifurcations simply do not show up in the real systems. The following case studies illustrate some common inconsistencies between models and observations.

Case Study 6:

Some simple voltage feedback dc-dc converters were shown analytically and by simulation to exhibit period-doubling as a fast-scale bifurcation phenomenon [10]. But such a phenomenon never shows up in practice! The problem is with the assumption of the use of proportional feedback in the analysis and simulation. In practice, feedback compensation network is also designed based on some form of low pass characteristic. This low pass characteristic destroys any high frequency signal that goes around the loop. Period doubling at the switching period is essentially a high frequency phenomenon which relies on signal feedback around the loop at a frequency as high as the switching frequency. Clearly, no period doubling would occur in practice because of the low pass characteristic of the feedback loop.

5 REPACKAGING WITH CHAOS

Some theories have been beautifully written for control of chaos. The novelty of their use in real systems is sometimes questionable, however, despite the proliferating rate of publication in claiming that chaos has been controlled in specific engineering systems. In fact, many engineering systems, when unstable, are operating chaotically. The fact that they are controlled to operate in a regular regime in a normal industrial setting clearly shows that the existing control schemes are controlling chaos quite well. In many cases, the existing methods turn out to be most elegant. On the other hand, lack of engineering judgment and blind application of chaos control methods may end up with absurd proposals.

Case Study 7:

The method of parametric resonance has been shown in the mathematics and physics communities to be an effective chaos control method. Basically, application of the method involves injecting a small sinusoidal oscillation to a critical parameter which causes the system to stabilize. Switching dc-dc converters under a common current-mode control scheme are known to exhibit subharmonics and chaos for duty cycles which are greater than 0.5. Study has shown that applying the method of parametric resonance to the reference inductor current can stabilize the system. However, closer examination reveals that the method of parametric resonance is actually equivalent to a ramp compensation which has been proposed some 30 years in the power electronics community. Essentially, the method of parametric resonance is simply a varying ramp compensation and can be very sensitive if the phase angle of the applied sine signal is not adjusted appropriately. On the other hand, the traditional method of ramp compensation is a lot more robust.

Case Study 8:

It is not uncommon to see absurd chaos control solutions being derived for specific engineering systems. When dc-dc converters are openloop, i.e., operating at a fixed duty cycle, they are always period-1 stable. However, openloop systems are never used in practice because of their inferiority of transient response and line regulation. Some seemingly sophisticated mathematical derivation of the control equation, blending the system equations and some chaos control methods, ends up with a scheme whereby the duty cycle is given by an expression which is essentially constant. The claim of stability is obviously valid because it is just equivalent to an openloop system; however, the method is totally unacceptable by engineers.

6 CONCLUSION

In this talk we point out several problems in the formulation of solutions for practical engineering problems. Using a few case studies we illustrate the various common pitfalls in the reporting of chaos applications in engineering. Researchers tended to "sell" chaos as a "panacea", but often failed to look into the actual way in which the particular chaos works in the particular situation. We conclude this talk with the cartoon of Fig. 1: A drunk man was searching under the lamp pole for his key chain which he knew was dropped elsewhere. When asked why, he replied, "because it's bright here."

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