

Preface

The most interesting phenomenon in nonlinear dynamics and certainly one of the most important changes in the understanding of the world in the last five or six decades, is the discovery of chaos. In 1961, Yoshisuke Ueda discovered the so-called Ueda Attractor as a young researcher using an analog computer, when he was studying the responses of a nonlinear circuit described by a special type of Duffing oscillator. This discovery undoubtedly changed the way of looking at the world, which until then was perceived either deterministic or random. It is now in the common knowledge that it has had fundamental effects in the many theories including oscillations, wave propagation and control, in any field of physics, in fluid mechanics, in meteorology, in astronomy, in biology, in economics, in populations dynamics and others. In essence, the world is really concerned with the discovery of chaos as a milestone in current knowledge and research perspectives.

In 1963, Edward Lorenz proposed a new model of the weather system, which became known as the Lorenz attractor by trying to extract the main properties of the atmospheric turbulence through a truncation of Navier–Stokes equations. This model of turbulence followed its previous observations of the extreme sensitivity to initial conditions. It is now associated with the so-called butterfly effect, which again brought a new outlook on what was previously taken as randomness. A few years later, a simplified model having the same objective of understanding turbulence has been proposed using iterates of maps and gave the Henon attractor. Lots of works then followed in the fields of mathematics and theoretical physics to deeper our understanding of the mechanisms which lead to chaos, period doubling bifurcations, transitions to torus of higher dimensions, intermittency, and others nonlinear phenomena.

An archetypal mechanical oscillator was firstly proposed in 2006, which has the fundamental property of a system of being either continuous and smooth or discontinuous depending on the value of a certain parameter. This system is now defined as the SD oscillator to refer to this property with the generalised Hook's law of the stiffness might be positive, negative or zero (quasi-zero) depending on the geometrical configuration of the system. It is a simple mass-spring system in which

the only difference with what has been done before, for example in vibration or buckling models, is that the change of the geometry during the motion was taken into account without any approximation whatever in the displacement or frequency, exactly in the same way as if the equation of a simple pendulum keeps $\sin x$ in the right-hand side instead of any polynomial expansion.

The SD oscillator can be seen as archetypal system, by which we mean that it is a prototype of a dynamical system where the nonlinearity is irrational. Which follows from the fact that there are no approximations in the large displacements, and secondly where the nonlinearity is either smooth, as long as a geometrical parameter related to the relative positions of the spring and the mass is different from zero, or discontinuous when the geometrical parameter reaches zero. In the smooth regime, it bears significant similarities with classical types of nonlinear oscillators, but at the nonsmooth limit it involves substantial departures from the standard ones. The ability of the SD oscillator to provide a new outlook on nonlinear phenomena relies upon any feature of qualitative analyses: sets and properties of equilibria, periodic solutions, co-dimension bifurcations, and the chaotic attractors, etc., all these features involving the transition when the nonlinearity changes from smooth to discontinuous.

The main purpose of this book is to provide an unconventional way to understand qualitative phenomena of the natural world, through the dynamics of a simple mechanical system which may have either a smooth or a nonsmooth nonlinearity. In other words, following the steps of the discovery of chaos, it aims at showing that a deep analysis of an appropriate simple model may have important consequences in the understanding of the world. This book is also strongly motivated by an invitation to professionals in science and engineering to pay special attention to the modeling, the analysis, and the applications of nonlinear phenomena. The authors would like to give a real encouragement to students and researchers who are interested in developing a cross-discipline of nonlinear science at the intersection of mathematics, theoretical physics, and engineering sciences.

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