

Preface

When I give lecture to my students, I prefer to introduce the history of inventions in engineering development rather than to state only theoretically significance. It seems that my students very like to hear these stories which make them be interested in the teaching materials presented in the classes and understand the engineering background. Hence, I spent lots of time to read and collect these stories; of course, most of them were written by Chinese.

I think the development of control theory may be divided into three phases.

From the book of Joseph T. M. Needham, south-pointed cart designed and manufactured by Chinese people before Christ was an automatic mechanic device. On the cart, there was a puppet made of wood, one arm of the puppet always pointed to the south no matter how to turn the cart. Needham said it might be the first automatic device in the world.

However, the south-pointed cart was a legend. Nobody has seen the design or sketch drawing and heard any information from archaeological experts. A great invention of automatic device was the centrifugal governor for the steam machine. James Watt held three inventions for steam machines; the centrifugal governor was the last one by which the Industrial Revolution solved the problem of power and then happened. Many researchers agreed that the centrifugal governor was the first automatic control device and used until now. Until the invention of centrifugal governor by Watt, there had been several controlled devices, but no control theory.

After the invention, lots of physicians investigated the reason why the small device could make the speed stable for a huge steam machine. It was said that J. Maxwell also considered the problem, but I did not find any valuable results about his investigation in this area. The problem was solved by mathematicians who worked in the field of differential equations; they established the theory of stability and found the conditions for the stability. Using their words, the governor made the plant stable. Among these mathematicians, two people, Jules H. Poincaré and Aleksandr M. Lyapunov, have to be mentioned. They independently presented the stability theory for differential equations and gave vital effects for the subsequent investigation of the stability of differential equations.

In all fairness, the research of stability of differential equations is a part of control theory. The governor is a controller, the controlled steam machine is a control system, and the controller stabilizes the plant by the words of the twentieth century. Till now, every classical textbook of control theory has to state the stability of control systems. However, at the years of Poincaré and Lyapunov, there was no such a subject of control theory. On the other hand, the theory of differential equation liked the sun at noon so that its bright would make others lose their colors. Hence, I called the phase the *Pregnancy Period of Control Theory*. There existed controller design and the researches of stability and stabilization, but there was no terminology of control theory. It is remarkable that the mathematical model used in this pregnancy phase was differential equations.

It was commonly recognized the birth of control theory was in World War II. By 1938, two excellent experts disappeared from the public field of vision. Herdrik W. Bode and Norbert Wiener were recruited by the army to improve the control of the radar and anti-aircraft fire. From the film of *Eagles over London*, one may understand the contribution of the control of anti-aircraft systems. After the war, MIT opened a course of *Principle of Servo Motors*. The course revealed the theory used in anti-aircraft system control. It was also remarkable that the research used the transfer function as mathematical model to analyze and design controllers. The control theory established at that time was called by *Classical Control Theory* in China. It also was called as 2P theory since the design could be completed by using Pencil + Paper. 2P has great significance because it solved the control system design in the computerless era.

Most people love the new and hate the old. When a new theory was born, people were happy and celebrated its birth, and then they found lots shortcomings of the theory, and then started to complain. The classical control theory can handle single-input-single-output (SISO) systems very effectively, but it is hard to treat the multi-input and multi-output (MIMO) systems. By 1960, Rudolph E. Kalman applied state space description to research the properties of control systems, so that the MIMO systems could be treated as the same as SISO systems. Two important concepts, controllability and observability were defined. When Kalman proposed his paper, his invention was not attached enough importance. About 2 years later, the Kalman filter was successfully applied in aerospace technology, people then looked the state space method with new eyes and called it *Modern Control Theory*. In 1982, Kalman visited China, after his presentation, one person asked a question about the difference between the Kalman filter and Wiener filter. After thinking a while, Kalman answered the question with a new question, he said: Do you know the reason why the Soviet Union launched manned spacecraft before USA, but USA arrived in the Moon first? With one more minutes silence, Kalman answered the question himself, "It was because the Soviet Union people did not understand Kalman filter." As an evidence, I knew in the aerospace engineering Chinese scientists are applying Kalman filter to process the information sent back by Chang'e. It is no doubt, the modern control theory uses state space model in its investigation.

What can we conclude from the history of control theory? I draw two conclusions: The mathematical model is the mark for the developing phases of control theory; The birth of new theory needs an engineering background.

Since 1980s, I have heard many times that the third-generation control theory has been born, such as the theory of large-scale systems, the theory of intelligent control systems, the theory for complex networks, etc. Except the mathematical models have been renewed, the birth of a new theory was not accepted by most people.

In the turn of this century, the word of *uncertainty* appeared on the desks of many scientists who were working on different research areas. It is very usual that the same action will lead to different results. For example, there are ten resistances made in a production line at almost the same time. They are all labeled 1 K, and set on ten baseboards. After working 10 h, their resistance values may be similar, after 10 days, difference starts to happen, after 10 months, it is certain that these resistances may have more than seven values. It is necessary for us to use a set to describe these resistance values. The value of a simple resistance is a variable what can be said for a natural phenomenon? When we deal with the design of control system, the differential equation $\dot{x} = f(x, u)$ is applied as the description of control systems, where x is the state and u the control. The above discussion asserts, for a determined control u , you cannot expect the state is determined although the initial condition is fixed. The inner parameters, the environment conditions and other unknown causes lead to the uncertainty of function $f(x, u)$, and the change shows irregularly. Therefore, it is much suitable to treat $f(x, u)$ as a set-valued mapping, and the dynamic model becomes $\dot{x} \in f(x, u)$. This is a differential inclusion, and is a new mathematical model of control systems. Does the introduction of differential inclusion model result in a new era of the development of control theory? My answer is “no, I do not know.” The present research results cannot support such a conclusion, but it probably leads to a new generation if there is a vital social necessary.

Before 1980, several authors applied differential inclusion to deal with control systems. At this period, they tried to extend the maximum principle to the differential inclusion systems. Similar conclusion has been established. By Year 2000, lots authors were interested in the controllability of such systems. In the twenty-first century, researchers applied differential inclusions to deal with Luré system and polytope system. This is the simple history of differential inclusion control theory. In the past almost four decades, the development of differential inclusion control theory is very slow. There are two excuses for the researchers working in the area. One is the development of differential inclusion theory is quite slow related to other fields of mathematics. The another reason may be the lack of engineering needs. In China, I could only find two books for the theory. One is *Differential Inclusions – Set-Valued Maps and Viability Theory* written by J-P Aubin and A. Cellina, and the another is *Introduction of the Theory of differential Inclusions* by G. V. Smirnov. In Amazon, I did not find other more. These facts motivated authors to spend almost 5 years to write this book, we really wish it can generalize the investigation of differential inclusion control systems.

The arrangement of the book is as follows. The first chapter provides preliminaries, and focuses on convex analysis which is elemental for further investigation. Chapter 2 introduces set-valued mappings and differential inclusions. The authors required themselves that the chapter can contain basic knowledge of differential inclusions so that readers can carry out farther research with a massy base. To understand the conclusions presented in this chapter needs knowledge of functional analysis and differential equations. The third chapter deals with convex processes which can be treated as an extension of linear mappings. The fourth chapter considers polytope control systems which can be looked as a convex hull of several linear systems. The last chapter is about Luré differential inclusion systems. Most of the chapter deals with the design of observers for the systems.

Both Ms. Xiushan Cai and Mr. Jun Huang were my students who studied under my supervision for their Ph. D. degrees. When they studied in Shanghai Jiao Tong University, they made many studies for the control of differential inclusion systems. Now they joined Zhejiang Normal University and Soochow University, respectively, and still are interested in research of such systems. My students Wei Zhang, Leipo Liu, Junfeng Zhang, Hai Wu, Shaojie Shen and Peiquan Wang joined seminars and discussions when they studied in my lab. We are grateful to their contributions.

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