Invariance Principle and ADRC Development

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Abstract. After reading a lot of data, the author believes that cybernetics will change from the model theory of direct control deviation to the cybernetics of controlling internal and external disturbances according to the invariance theory in the future. Since Watt’s steam engine in 1788, the theory of automatic control has developed rapidly. The PID controller represented by error estimation has been in the dominant position for a long time, but it needs to adjust and adjust the parameters constantly, and new theoretical methods are urgently needed. ADRC will build a bridge between the perceptual thinking of industrial paradigm and the rational thinking of model paradigm. A flexible and intuitive grey-box method is established between the black-box method and the white-box method with disturbance as the core. The control theory will be rewritten by the invariance principle.

1. Background analysis
Since the invention of Watt steam engine in 1788, the success of Watt's invention has demonstrated the basic principle of automatic control, that is, Watt's principle (closed-loop control [1-2]), which has caused a great sensation in the academic circles. Many scholars have tried to explain the principle of Watt steam engine, and the automatic control theory [3-4] has developed accordingly.

In 1919, W. Trinks, in his book GOVERNORS AND THE GOVERNING OF PRIME MOVERS [5], considered that the application scenario of automatic control was constantly changing, but the principle behind the project was unchanged, and expounded in the book. Therefore, he elaborated all the principles of automatic control in the book, and verified all the principles in the laboratory and industrial field, but did not get the desired results.

The French mathematician Jean-Victor Poncelet put forward "Principle of Invariance"[6]. He believed that the main reason for the vibration of steam engine was that the inertia of the flying hammer was too large. In order to improve the control quality of the Watt steam engine, the improvement of the lag of the flying hammer governor was proposed. The scheme is characterized by direct measurement of disturbance, adjusting steam flow rate and compensating disturbance before it affects the speed of steam engine [7]. Although Poncelet gave the design scheme, it failed to implement and put forward that only GOVERNORS (governor) can solve the vibration problem of steam engine, but it did not cause the shutdown of scientific circles at that time. Note. A hundred years later, it was discovered by Soviet scholar Shipanov that Shipanov put forward the invariance theory.
[8-10] in his doctoral dissertation with the intention of compensating the disturbance by measuring or approximating it so as to keep the dynamic characteristics of the controlled object unchanged [9].

The Soviet Union began to discuss self-control. With the deep understanding of the control problem by the Soviet scholars, the Soviet Union believed that the control problem was not the stability analysis problem but the invariability problem. How to keep the key variables and output variables of the control system unchanged under the influence of internal and external disturbances? It is how to keep the key variables and output variables unchanged when the control system has internal and external disturbances.

Among them, sliding mode control [11-13] is designed according to this idea. Invariance theory is the originator of sliding mode control. Invariance theory has two important conclusions [8, 9]:

- If the gain of the controller is infinite, the absolute indefiniteness can be achieved.

Another two-channel gain (the first satellite launched by the Soviet Union in 1957 was based on the two-channel principle).

The principle of dual-channel gain [14-17] is mainly to establish information channels of controlled and disturbed quantities in two channels without high precision. The Soviet Union carried out this work in 1953 and reached a climax in the 1960s when the Soviet invariance theory reached its climax. The first and second boundary meetings of the whole Soviet Union were held one after another, but they began in the 1970s and 1980s. Invariance theory disappeared after the 1970s. After two Soviet scientists immigrated to Israel in the 1960s, invariance theory was introduced to the West.

In 1954 Qian Xuesen was expelled from the country engineering cybernetics [20, 21]. The invariance theory in his book begins with a review of the control theory in the first 14 chapters in chapter 15. Chapter 15 begins to question the hypothesis of the most basic control theory. See Figure 2. The hypothesis is that the characteristics and characteristics of the system to be controlled are always assumed to be known. The state of the system is constantly changing and unpredictable. For example, when the wings of an aircraft freeze, this is the most effective control system. On the contrary, according to the model of the system design, the control quality can not be guaranteed. What kind of problem is the control problem? Qian Xuesen's view on automatic control is stable operation. Qian Xuesen was the first person to put forward the question of whether the system can run stably under the circumstances of internal and external disturbances. Donati, Francesco, Vallauri, Maurizio [22] also noticed this problem and published a paper entitled "Guaranteed Control of the System". Paper on "Almost-Linear" Plants.

In 1965, Chinese scholars discovered that the principle of guidecar [23] and the principle of invariance are in one continuous line. It adopts ingenious gear transmission. According to the difference of the left and right gears, it obtains the information of the change of the direction of the vehicle, and through the corresponding compensation, it enables the wooden Fairy on the combat vehicle to control accurately.

When Han Jingqing was studying in the Soviet Union in the 1960s, he came into contact with the unique control thought, which was represented by invariance theory and centered on disturbance problem. It laid the groundwork for the creation of ADRC in 1998. In 1997, he made a motion control experiment. The experiment results were very successful. In 1995, he kept in touch with Professor Gao Zhiqiang. Mr. Han Jingqing was in the late 1950s and in the late 1960s. In the early 1990s, optimal control began to be studied. In 1979, it was concluded that both linear and non-linear systems can be transformed into standard type [24] of series receivers through feedback.

In 1989, he published his famous work Cybernetics or Model Theory [25], which is also a pioneering article. It is also a turning point in his life. He began to reflect on the modern control system and questioned the "Model Theory". Mr. Han's ideas and the control of Qian Xuesen's theory can not be based on complete mathematics. The model coincides with each other, so it was implemented in the algorithm by Mr. Han Jingqing from 1995 to 1998. Through computer simulation, Active (Auto) "Disturbance" Rejection Control, ADRC key establishes ideal dynamic of standard input and output. This part of total disturbance with different ideal dynamic is equivalent to input signal offset. Elimination, real-time estimation of the total disturbance at the input, if it can be
estimated, it can be cancelled by the input system, eliminating the system is equivalent to the non-disturbance system, making the design of the control system very simple. This is the essence of ADRC and the connotation of ADRC paradigm.

Thus, the idea of disturbance rejection paradigm [26] is clear:

According to physical concepts, the standard type of control object is selected, for example $y' = bu$, the controller is designed according to the standard type. The controller is designed according to the standard type.

Real-time estimation of the total disturbance, i.e. the difference between the standard type and the control object, is offset by means of control.

2. Application development status

According to the concept of standard form of feedback system [24], the main body of system dynamics is the relationship between the derivatives of input signal and output signal, which can be described by series integrators. The complexity and uncertainty of system dynamics are reflected in the variation law of derivatives of each order and the influence of external disturbances on them. The input and output signals are estimated and then eliminated by the control signals. The controlled object is forcibly converted into Han's type, which greatly simplifies the design of the controller.

In industry, for Danfoss equipment manufacturers, normal production can be carried out without repeatedly adjusting the parameters of the production line controller [27]. Extrusion's dozens of production lines can save 58% [28]. Texas Instrument is an auto-disturbance rejection algorithm in motion control chips, which is released globally [29].

In military field, the original system is transformed into a nominal integral series system with linear extended state observer to design BTT missile decoupling controller [30]. A linear auto-disturbance rejection controller (LADRC) is designed to realize the optimal control of the system for the coordinated control system of ultra-supercritical units. The study of linear auto-disturbance rejection optimal control [31] has fewer tuning parameters and has a wide application prospect. At the same time, it is also introduced into the four-axis system because of its strong stability and real-time performance.

It can be seen that ADRC control, with the continuous development of invariance principle, has been successfully applied in many fields due to the exploration of non-mathematicians and continuous testing in industrial field. Including fast tool servo control in precision lathe, micro-electro-mechanical sensor, time-delay system, spacecraft attitude control, boiler combustion and load frequency control in power system, etc., all show great potential of ADRC technology.

3. Conclusion

ADRC theory has been adopted by several large foreign companies in the field of motion control and temperature control, including domestic large power plants, high-energy physics accelerometers and other professional fields. These applications show that ADRC is not a specific dedicated controller, but a general control concept. According to the general control concept, other key control problems can be solved in many fields, and the knowledge of specific physical processes can not be replaced.

Science is human's stage cognition of objective things. The field of automatic control is no exception. The world is neither a "black box" nor a "white box". ADRC's proposal provides a brand-new method and idea for industrial control design, reflects another practical way of thinking to solve practical problems, and establishes the relationship between perceptual thinking of industrial paradigm and rational thinking of model paradigm. Bridges; a flexible and intuitive grey-box method has been established between the black-box method based on error model and the white-box method based on disturbance. We do not need to get to the bottom of the problem any more. We must make the controlled system clear and redesign the controller. We do not need to adjust the PID like scratching the boots. Active disturbance rejection (ADR) provides a practical method for the development of control theory in the future.
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