



Pioneers of Automatic Control Systems

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PIONEERS OF AUTOMATIC CONTROL SYSTEMS

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The theory of automatic control systems is an idea closely related to feedback concept. A system is a combination of components that act together and perform certain objectives. In a feedback system the output signal is fed back in order to increase or reduce the input signal¹ (Figure 1).

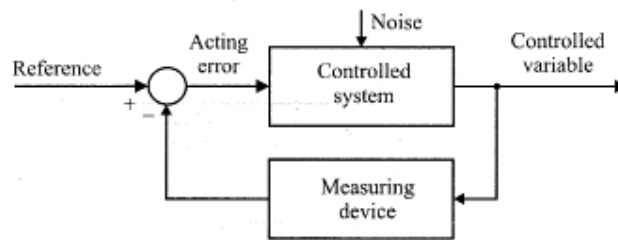


Figure 1. A feedback system.

Although, the feedback concept which is lying in the foundation of dynamic systems has been perceived relative recently (at the end of the 19th century), it is known that the idea has been understood and applied correctly since the ancient times. In the engineering, the aim of control is to guide the system to a desired direction or kept constant at a certain value. A feedback control system is one which tends to maintain a prescribed relationship between the output and the reference input by comparing these and using the difference as the means of control. Thus, in an automatic control system, the variable to be controlled is first measured, secondly compared against a reference value and at least the difference applied to the system input, in order to influence the system in a desired manner. In the block diagram of an automatic control system, the controlled system take place in the forward path and the measuring device of the controlled variable take place in the feedback loop. A disturbance is a signal that tends to affect adversely the value of the output of a system (Figure 2).

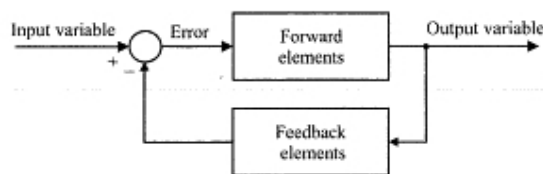


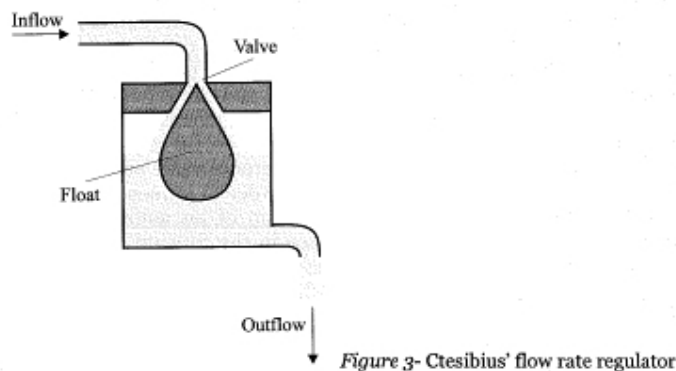
Figure 2- An automatic control system.

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¹ Benjamin C. Kuo, *Automatic Control Systems*, Prentice Hall, New Jersey 1995. See also Turkish translation Atilla Bir, *Otomatik Kontrol Sistemleri*, Literatur Yayinlari, Istanbul 1999.

To differentiate an automatic control system, realized and used unconsciously during centuries from the open loop control system, one has to check the existing system for the feedback characteristic (Figure 2). The oldest automatic control systems technically mindfully designed and tested for their operational merit, date back to the Hellenistic era². The oldest applications are flow rate control in water clocks. The system created by Ctesibius of Alexandria around the third century B.C regulates the water level in a vessel and is similar to the carburettor system of the modern car that regulates the flow of the gasoline (Figure 3). The purpose of this system was to keep in a clock the flow of water in the container at a constant rate and independent of level and pressure deviations, by using a floated valve. Although, Ctesibius left no written documents, a reconstruction of his control system is possible through the accounts of the Roman engineer Vitruvius.



Philo of Byzantium, a generation younger than Ctesibius (ca 200 B.C), in his work titled *Pneumatica* gives examples of automatic oil level control systems in oil candles. In these systems, the oil level h is controlled and taken constant by the amount of air entering the airtight oil vessel (Figure 4). It is interesting that today *Pneumatica* is known only through its Arabic translation now finding in the Suleymaniye Library (Ayasofya 2755 and 3713).

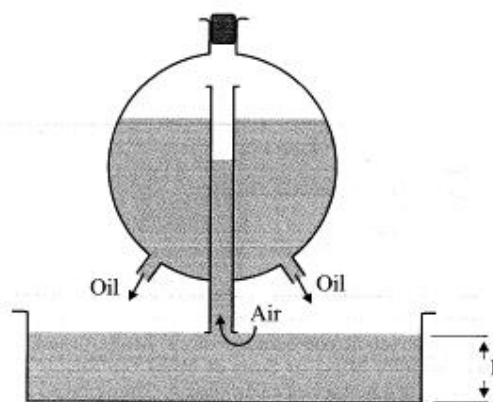


Figure 4- Philo's level regulator

² Otto Mayr, *the Origins of Feedback Control*, M. I. T. Press, Cambridge, Massachusetts and London, 1970.

The third important name in the history of automatic control is Hero of Alexandria who lived in the first century B.C. In his work *Pneumatica*, Hero describes automatic control systems as well as automata in the modern sense. These automata, were designed to amuse, to arouse interest in the ancient temples or to water supply the bathhouses, attracted the attention of various circles and especially of the Islamic scholars in the following centuries. Among many control systems using principles mentioned above, the float siphon device, which causes a constant outflow v of liquid is an interesting application of a flow regulator (Figure 5). One can estimate that float siphons were successfully used in water clocks.

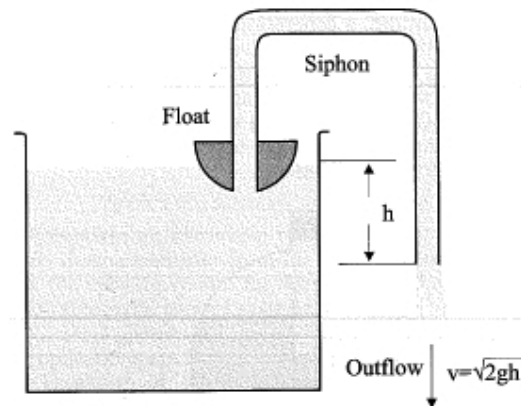


Figure 5- Constant outflow regulator

Scientific advancement, which reached its peak in the Hellenistic age, lost its luster in the palaces of Byzantium; the Abbasid Caliphs in Baghdad once more let lit the science torch. Muhammad, Hassan and Ahmad known as Benu Musa or Sons of Musa bin Shakir of Khurasan, are very famous in the history of technology³. They played an important role in the advancement of mathematical sciences during the reign of Abbasid caliph al-Ma'mun (813-833 A.D) and the succeeding caliphs. Ahmad's interest in technology might have led them to write the book titled *Kitab al Hiyal* (Book of Mechanical Devices) (850 A.D). The manuscript in the Ahmed III Library at Topkapi Palace is almost a complete copy (A 3474) and includes magical vessels, water jets, oil lamps, a densimeter, a bellows, and a lifting device. This science of 'ingenious devices' and 'ingenious automata' created by the use of matter, water and air is known as 'ilm al-alat al ruhaniyet': science of pneumatic devices. According to Akfani, "the science of pneumatic devices deals with the construction of various devices based on the principle of the 'horror of vacuum'. The purpose is to educate the mind while designing these systems that deal with measured cups, siphons and other elements."

Kitab al Hiyal of Benu Musa brothers describes 100 systems of which 18 are automatic control systems. On close inspection, these control systems are technically perfect and applicable to modern use. Since it is not possible to look into all these systems, we will examine Model 7 in the book which is introduced with the title 'A trough of approximately 2 litres of water that preserves its level, even if 20 small animals drink water from it, but loses all its water when a bull drinks' (Figure 6).

³ Donald R. Hill, the Book of Ingenious Devices (*Kitab al-Hiyal*) by the Band (sons of) Musa bin Shakir, D. Reidel, Dordrecht-Boston, 1979. Atilla Bir, The Book '*Kitab al-Hiyal* of Band Musa bin Shakir, interpreted in sense of modern system and control engineering, IRCICA, Istanbul 1990.

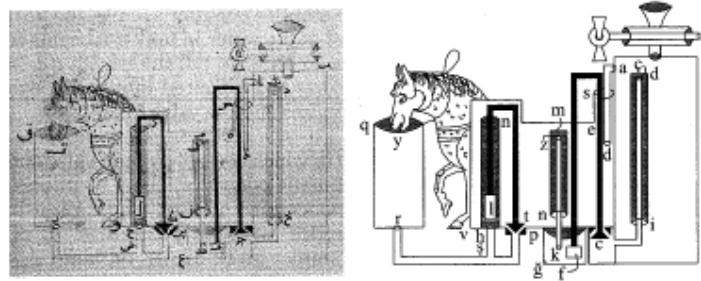


Figure 6- An example of a level control from Benú Músá's book titled *Kitáb al-Hiyal*
a) Original drawing, b) Computer drawing.

Water is fed into the tank at the funnel like tab b . When the level of the water in the tank $a-b$ reaches the end g of the siphon $i-d-g$, the water runs through valve c into the tank $e-v$. At the beginning valve c is closed, the level of water in this tank rises until the lower end d of the pipe $a-d$ is plugged with water or the entrance of air into tank $a-b$ is prevented.

After the filling is finished and the airtight tab b is closed, one pours also some water into the trough $q-y$ from which the animal drink. Some of the water poured into the trough goes through the pipe $r-s$ and raises the float l in the tank $h-n$. By this way, the valve t opens and one realize a connection between trough $q-y$ and tank $e-v$. Thus, the water level in the trough rises up to the level of the tank $e-n-z$. As requested when small animals drink water from the trough, the water level of the trough is continuously regulated by the amount of air passing through pipe $a-d$ to tank $a-b$.

If a big animal like a bull or a horse puts its head into the trough $q-y$ for a drink, the level of water in the tank $e-v$ raises for a moment with the amount of water that the animal splashes back with his mouth. When the level of the water in the tank $n-m-z$ rises over the level z of the siphon $n-z$, the water in the tank quickly starts running over the siphon $n-m-z-k$ into the tank $k-g$. At the same moment, the buoy f , which is in the tank k rise and close the valve z . Thus, the regulating of the water level in the tanks $a-b$ and the trough $q-y$ is prevented. All the water in trough $q-y$ and tank $e-v$ empties down to the level $r-v-p$ level. In addition, float l drops and removes the connection between the tank and the trough. The water poured into the tank $k-g$ flows out through the hole g at the bottom of the tank. When the tank $k-g$ empties out after a while, the float f drops, the valve z opens and the level of the water in tank $e-v$ begins to be controlled again from the tank $a-b$. In order to put the trough $q-y$ in connection with the tank some water has to be poured into the trough from outside. By this water, the float l raise and the valve t reopens.

This system is a perfect example in which control by float valve and air is successfully applied. Other automatic control systems mentioned in the book are similar to earlier applications of float valves used in modern toilet siphons. Another practice is keeping the level of oil constant in oil lamps. Among the examples given are an oil lamp that trims its wick automatically and another oil lamp turning its body continuously against the wind in order to keep the wick burning.

Ancient Egyptian water clocks continuously improved during the ancient Classical period reached monumental dimensions in the Hellenistic period. This tradition continued into the period of Islam and reached its height with al-Jazari, who introduces himself in his manuscript as Badi'al- Zaman abu al-'Izz

Ismail al-Razzaz al-Jazari⁴. He served in the Artukid capital Amid (Diyarbakir) as court engineer. He is famous for his book *Kitab al-Hiyal*, 'Book of Ingenious Devices' where he explain the design, construction and working principles of fifty different systems of practical use and aesthetic value such as water clocks, automata, water jets, vessels for blood collecting, water raising devices and ciphered keys. In the foreword of his manuscript, he mentions that he served the Artukid rulers Sultan Nasir al-Din Mahmud (1200-1222). For twenty-five years he had been in the service of the royal family, served first for the father of the king Nur al-Din Muhammed (1174-1185) and then for the brother Kutb al-Din Sokman II (1186-1199). He completed his book in 1206. Today, Ahmed III Library at Topkapi Palace houses a second-hand copy of the original manuscript (A 3472). In six sections, the book describes fifty different systems.

From the eleven clocks explained in the book, two are automatic flow-rate controlled water clocks. These clocks use regulators invented by Ctesibius. However, due to the Islamic principle of dividing the time between the rising and the setting of the sun into twelve equal parts, it was necessary to add a reference regulating mechanism to the system (Figure 7)

(Figure 7)

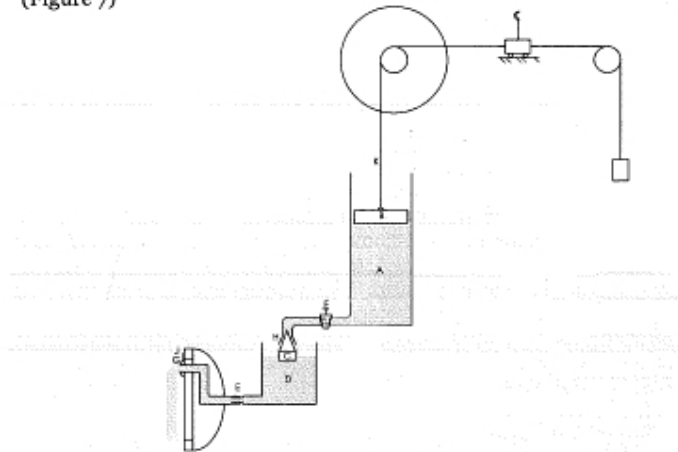


Figure 7- Al-Jazari's water-machinery and reference regulating flow rate control mechanism. A: water reservoir, B: float, K: string, F: tap, D: flow rate regulator, C: float, H: floated valve, J: pointer, G: orifice, E: turn junction.

The amount of water necessary to move the clock mechanism for the period of one day or for twelve hours is stored in a container. If the water flows out in a constant rate, the level of the water in the vessel will determine the passage of time from sunrise or the time left until the sunset. The level of the water in the tank is transmitted to the screen of the clock by a rope attached to the float. A counter weight attached at the other end of the rope ensures the friction required to rotate the clock screen. At sunrise, one open the valve at the bottom of the vessel and the water begins to flow in the flow regulator vessel, containing a float valve. Since, the exit pipe of the regulatory vessel is narrower than the entry pipe, the water level rises and the float valve blocks the entry pipe. Thus, in a short time a steady state condition takes place, where the income and outcome flows are equal. However, the flow of the water from the vessel or the level of the water in the regulator is proportional to the difference between the level of the float valve and the position of the outflow pipe. For this reason, the outflow pipe rotate freely around the centre of an adjustment disk recording the positions where the point of the exit pipe should be according to the day or season of the

⁴ Donald R. Hill, the Book of Knowledge of Ingenious Mechanical Devices, D. Reidel, Dordrecht, Boston, 1974.

year. During the summer months when the days are longer, the point of the exit pipe turned to the top and during the winter months when the days are shorter to the bottom of the disk. Thus, the water level in the regulator tank is adjusted according to the season, which in turn determines the outflow time of the water. In a control system, this means a change of the reference value.

As in Al-Jazari example, during many centuries they used and developed traditional automatic control systems with great success. However, at the end of the 13th century, following the Mongol invasion, the scientific thought in the Islamic world reached a stagnation and decline period. On the other hand, for the first time with the Crusades, the West met the Eastern world. The transferring of scientific and technical knowledge from the Eastern world began and during the age of Renaissance, the gap rapidly closed. Meanwhile through the conquest of Spain the Christian established the second important contact between the East and the West.

Taqi al-Din (1521-1585) was one of the last original engineers and scholars of the East world. He built the Istanbul observatory during the reign of Murad III (1564-1595), and wrote numerous books mainly on astronomy and mechanics⁵. His work on the construction of mechanical clocks is a testimony to competition with the West. When in 1583 the Sultan has ordered the destruction of the observatory, the last research centre of the East closed for more then 200 years.

In the West, initially only the alchemists designed automatic control systems. Since, they were trying to produce synthetic gold from ordinary elements; they believed that the ambient temperature for a reaction has to be constant. Thus, Drebbel (1610) developed the first autoclave. In later centuries, they used the heat regulators in incubators (Reaumur 1750) and eventually in steam boilers (Henry 1750, Bonnemain 1777). In spite of its glorious past in the Hellenistic and Islamic era, to use level control in steam boilers the method was reinvented in the 18th century (Brindley 1758, Polzunov 1765). Papin in 1707 first applied pressure control to a container resembling a pressure-cooker. Similarly, methods developed by Delap in 1799, Murray in 1799, and Bulton and Watt in 1820, found applications in steam engines. Speed control methods were first applied to windmills in England. The method inspired by a local technology employed rotating balls. This controlling element called a governor was the subject of many patents given at that time (Mead 1786, Hooper 1789). Watts' steam engine used a governor for speed control of his machine (1788). The mathematical study of governors by Maxwell (1868) and Routh (1877) set the grounds for theoretical control engineering. Many concepts related to the stability analysis of systems have been possible with the inventiveness of these pioneers and the progressive insight of the first theoreticians.

⁵ Suheyl A. Unver, *Istanbul Rasathanesi*, Turk Tarih Kurumu, Ankara 1969.

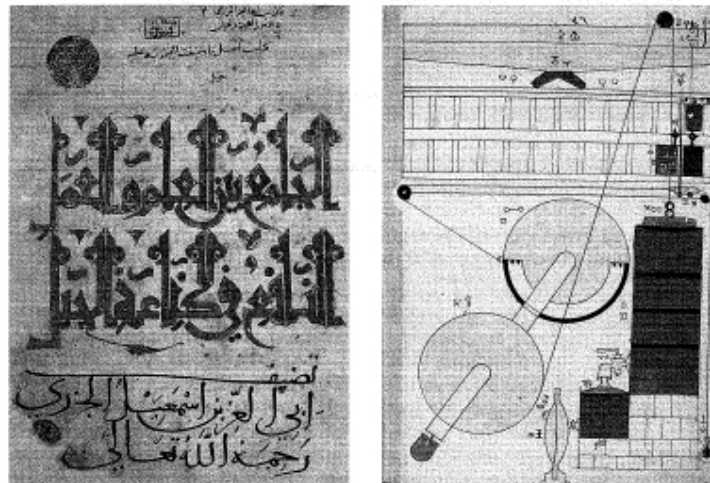
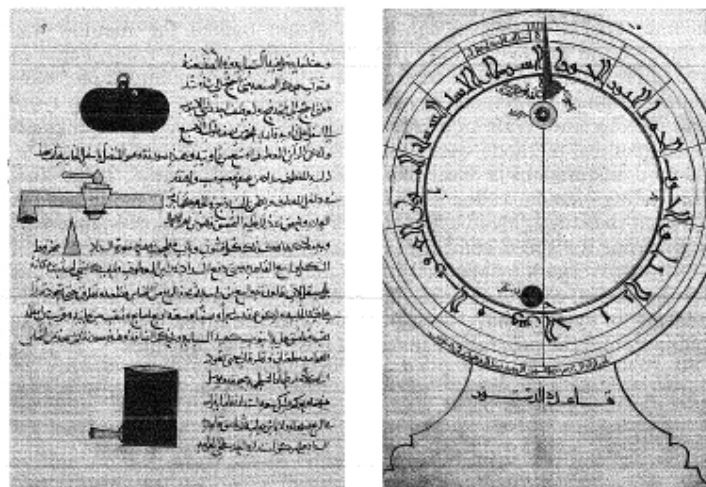


Figure 8-

- a) First page of al-Jazari's book *Kitâb al-Hiyal* (Topkapı Palace Library, A 3472, fol. 1a).
- b) Rear view of the water clock mechanism (A 3472, fol. 18b).



c) Detail figures of the float (*tafafa*), tap (*fitum*), float regulator valve (*avvama*) and the regulator vessel (*rub*) (A 3472, fol. 7a).

d) Front view of the regulator disc with zodiac signs, the marker and the outflow end of the pipe (A 3472, fol. 8a).

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