

Al-Jazari: The Ingenious Inventor of Cybernetics and Robotics

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ABSTRACT In early civilizations, technology has developed independently from philosophical ideas and scientific theorems. Different civilizations have participated in the evolution of technologies throughout history. Technological developments are elaborated by successive civilizations and transmitted with written documents. There have been many scientists who have made an extraordinary contribution to technological development. Al-Jazari (1136-1206) was one of the scholars who were trained in this state. He was an inventor and mechanical engineer who invented ingenious inventions in robotics and control them with the hydraulic and gear systems. In addition, the crankshaft, which is the most important mechanical device after the wheel, is one of the invention with high technological significance invented by Al-Jazari. He has drawn many mechanically proper designs in his hand-written book. It is understood from this book he was one of the pioneers of cybernetics and robotics. In this study, firstly, a short description of the biography of this inventor is given and its place in the history of technology is emphasized. Then, the subject of cybernetics science was discussed. The effect of the cybernetic on the machines invented by Al-Jazari is shown here. The control of the developed robot systems is related to cybernetic philosophy and methodology. A set of ideas bearing on the self-regulation of action and emotion such as cybernetic is described. In the last chapter, the structures that form the milestones of today's technology history, from the machines invented by Al-Jazari, are discussed. Finally, information is given about why Al-Jazari was a master and pioneer in cybernetics and robotics.

KEYWORDS: Al-Jazari, Cybernetic and Robotic, Crankshaft, Hydraulic and Gear System

1. INTRODUCTION

Technological developments have evolved with the contributions of different civilizations and nations throughout history. The contribution of advanced societies to technology in terms of philosophical analysis and rational thinking is faster. Technological developments at large scales are detailed by successive civilizations and turned into written documents. Those who survive from these documents are well-defined and defended civilizations. One of them is the forgotten masterpieces of Muslim technological devices in Al-Jazari's hand-drawn mechanical systems. He pioneered many modern technological concepts, but unfortunately due to the lack of communication, his work and mechanical devices were not well recognized for a long time [1-4].

Al-Jazari, a Muslim scholar, mechanical engineer, and inventor who is remembered for his design of water-raising machines and many automata, which worked by waterpower hydraulically. His full name was Badi Al-Zaman Abul-Izz Ibn Ismail Ibn Al-Razzaz Al-Jazari. Al-Jazari is his nickname. The name of the region where he lived in the name of the region between the Euphrates and the Tigris, which is known as "el-Cezire". He had lived during the 12th century and drawn many mechanical special designs in his hand-written book [3-5]. Prof Eilhard wiedemann (1852-1928) is the first scientist to bring his book to the world of science. The first person to talk about this scientist in Turkey is the

historian Ibrahim Hakkı Konyalı [6]. The most comprehensive study on Al-Jazari was done in 1974 by Donald R. Hill. Donald Hill has translated his book (The Book of Knowledge of Ingenious Mechanical Devices) from the original Arabic to English, and added some explanations [7]. The Cultural Ministry of Turkey was printed in its original form in Turkish Language 1990 [8]. This book includes a whole range all the terminology of devices and machines, with a multiplicity of purposes. Al-Jazari spent nearly 25 years in Diyarbakır. One of his creation is a water pump using a crank-slider-like system, which was the first known machine to use a crank [9-11]. After searching the literature and consider the book written by this engineer, a glance through brings to one's mind the question of who is the leader in cybernetics and robotics in terms of controllable handy mechanical devices closest to today's technological level. Considering the resources that reach us as a written document, the book of Al-Jazari is actually regarded as the technological accumulation of the Islamic period. In the Muslim civilization, it is seen that, technological development and vending machines that served many social purposes compared to other civilizations [12]. These are important evaluations to understand who owes the origin of today's technology. They built further advances in the history of technology with their original ideas to make technology better. The book of Al-Jazari has an important written source identity in order to understand the technological level of the time. It is unique in reflecting the current technological level of humanity. It is accepted that Muslims climbed to the top of technological developments with the work of Al-Jazari [13]. A significant study on Al-Jazari has been given by Wiedemann [14]. It is understood that Al-Jazari's book concentrates more on engineering design than social and cultural situations. Considering the Physical descriptions of the robots he made, it is possible to build Al-Jazari's devices even today, because he has written in Arabic and understandable to every aspect of the elements and their common operations [15]. The best of technological advances were brought together in a book written by Al-Jazari and translated by Hill during the Medieval Islamic period [7]. Jazari has provided visual and intellectual descriptions for the further development of technology, with work on hand-drawn mechanical devices in his book.

The aim here is to help researchers, engineers, and scholars to demonstrate key scientific and technological principles of the Muslim civilization in a hands-on and minds-on fashion that is accessible to younger audiences. Also, it is aimed to highlight the technology history of Al-Jazari's system used in lifting water to show its place and importance in today's technology and the internal combustion engine and piston structure we use today.

This paper is organized as follows. Al-Jazari and Technology are described in section 2. The subject of cybernetics is discussed in section 3. Section 4 include the inventions of Al-Jazari. Finally, the paper conclusion is given in section 5.

2. AL-JAZARI AND TECHNOLOGY

This section will highlight the success of Al-Jazari, who designed devices for humanity about 800 years ago, but unfortunately has not been revealed until recently, showing the importance of automatic mechanical devices powered by water pressure and wind energy. In his technology, cybernetics may be considered as the core of the automation of robotic and mechanical devices. He expressed his ideas and opinions on objective grounds, with drawings that anyone can convince. The hand-drawn mechanical devices in his book and the comparisons with today's robots will give at first glance the machines that are powered by water power. These drawings gave rise to servo-mechanical thoughts and, as a result, cybernetics, which has emerged as a science in recent years. In the 19th Century, his thoughts and drawings gave intuitional feelings towards mechanization. Al-Jazari's inventions were the prototypes for many of the technological tools that we use daily. For instance, four-stroke engines, gears system, crankshafts, pneumatic and hydraulic systems, automats and control systems; these are all the technological innovations that we are used in our daily technology had been invented by him [16]. Al-Jazari has implemented all the experience and experimental works in his original designs of mechanical devices although calculations were not available at that time. These innovations was the most important work of engineering written before the Renaissance centuries later [12]. The best of the technological developments were gathered in his book named as “Kitab fi ma'rifat al-hiyal al-handasiya” which was translated by Hill [5] as “The Book of Knowledge of Ingenious Mechanical Devices” where here he described 100 types of mechanical devices and instructions on how to do them. These and many other inventions are described in scrupulous detail in his Book. The robots or automation was developed by Al-Jazari 250 years before Leonardo da Vinci, with some excellent examples. Hill emphasized that this work contributed significantly to the advancement of civilization and that mechanical technology was studied in all areas. The work of Al-Jazari has an invaluable place in the history of human technological developments. It is an exception because its book contains not only detailed drawings but also a description of the working mechanisms of the devices [4,13,14,17]. The most remarkable and sophisticated of all invented machines in terms of historical sources of today's technologies are briefly explained below.

Crankshaft and crank-slider mechanism

The crankshaft was first invented by Al-Jazari who employed it in water-rising machine which he incorporated with a crank-connecting rod the mechanism in twin-cylinder pump. The crankshaft, defined by Al-Jazari, converts the rotary motion into linear reciprocating motion and forms the basic mechanism of modern machines such as the steam engines, internal combustion engines, and automatic controls. He used the crankshaft with a connecting rod and crank-driven double-acting piston push and suction pump with a crank slider mechanism in water elevation machines. In Al-Jazari's work, some important concepts were seen in both design and manufacturing [5]. Innovations such as the use of wood stencils, models for creating paper use designs, casting of metals in the closed mold with sandpaper powder to achieve water tightness [18].

Segmental gear

A segmental gear is a piece for receiving or communicating reciprocating motion from or to a cogwheel, consisting of a sector of a circular gear. The segment gear is an interesting part is has encountered in Al-Jazari's water-raising machines. It was not so sophisticated in the use of gears that appeared in Europe before the mid-fourteenth century [18,19].

Saqiya chain pumps

Pumps are ingenious and most important ideas, which are components in water-raising machines introduced by Al-Jazari in 1206. His water-raising mechanism was connecting the main gear to a suction able to dual motion. He also had achieved the double-action suction pump with valves and reciprocating piston in his invention. He had used this system hydraulic power to pump water to another drain system. He used the flowing water river to move a turbine with the help of a water absorption system and several gears [18,20]. The first known use of the crankshaft was in the chain pump, one of Al-Jazari's Sativa machines. The implementation of this system is aimed to minimize intermittent operation to maximize the efficiency of the Saqiya chain pump. This system used as a saqiya chain pump for hydropower driven water elevation [18,19].

Automata

Automata are strong and consistent structures that are caused by the urge to represent the mechanism by mechanical means. Automata are another activity of Al-Jazari that is used for various devices such as hydropower driven and automatically moving peacocks, humanoid robots, automatic doors, water clocks. Al-Jazari is credited with creating the earliest forms of a humanoid robot. Al-Jazari's automaton was originally a boat with four automatic musicians that floated on a lake to entertain guests [20]. Automata, which is mechanically powered by water power, is considered to be the ancestor of Europe's detailed water clocks. It is noteworthy that this mechanical technology is a product of not only the construction of instruments but also water-raising culture. Fountains and musical automata where water flow varies from one large tank to another at hourly or half-hour intervals are other vending machines defined by Al-Jazari. In addition, Al-Jazari made various water clocks and candle clocks. The elephant water clock was an important medieval invention invented by him. He invented the monumental water-powered astronomical clocks displaying moving models of the Sun, Moon, and stars [14,18].

3. CYBERNETICS

Cybernetics was first used as a term by Norbert Wiener in 1948 as a common view of general science of control and communication in animals and machinery [21]. Communication refers to information transfer and control tools to produce desired changes using information [22]. Cybernetics is the science that studies systems that act like living things [23]. Depending on how the model and control actions are used, it is aimed to direct the systems to the most appropriate target. Cybernetics can be used to understand, model and design any system. Researchers are interested in the science of cybernetics turned to developing machines to study the functional mechanisms of living systems and to

make them autonomous or act as living systems [24]. Over the years, cybernetics has found application in many fields and has made natural progress through the application of various modern sciences to real-world problems, the development of theories and methods [22, 25].

Cybernetics is an interdisciplinary science. Control theory, communication theory, operations research, Mathematics, logic, semiotics, physiology, and others are the fields of cybernetics. Interdisciplinary communication enables the rapid realization of new results in order to combine efforts in different disciplines and focus on uniform solution of similar problems [26]. In 1948, a new synthetic science emerged with the integration of results from different sciences, also known as Wiener cybernetics (see Fig. 1) [21].

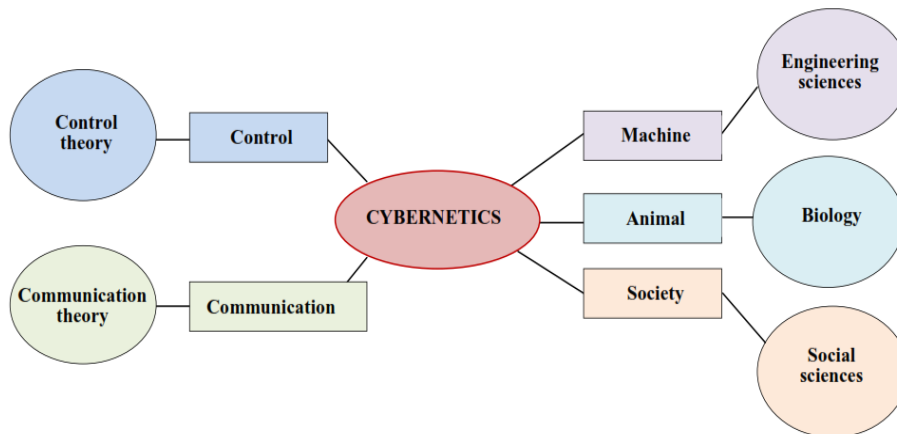


Figure 1. The phylogenesis of Wiener’s cybernetics ([21])

Cybernetics attracts the attention of hundreds of private research centers, and scientific journals through worldwide at the present time. The technology of electronics, automated machines, telecommunication, and the science of robotics are all products of Cybernetics.

When talking about cybernetics and robotics in Anatolia, Al-Jazari should come to mind. Although the science world has heard of cybernetics from the Wiener, Al-Jazari has had a profound impact on this science going back to 800 years ago. Research in the field of control theory that emerged in the 1206s led to the emergence of other meta-sciences, namely cybernetics and system analysis. Automatic machines made by Jazari, the first scientist to study cybernetics and robotics in terms of the world history of science, formed the cornerstones of today's mechanical and cybernetics sciences. Al-Jazari has created milestones of today's technology by using science and technology in an extraordinary way according to the conditions of the time, and the importance of the balance or adjustment system in the machines that it has made has inspired today's automatic control science. Cybernetics or different cybernetics types are shown chronologically in the table below. The rest of this table can be viewed in [23] this source. The concept of "hydropower cybernetic" is mentioned here for the first time. The main reason for using this concept is that I understand from my literature research that Al-Jazari has realized the cybernetics philosophy with "hydroelectricity" and does not use it as a concept.

Table 1. Different types of cybernetics

Type	Authors	Period
Hydropower Cybernetics	Al-Jazari	the 1136-1206's
Cybernetics	N. Wiener W. Ashby S. Beer	the 1948-1950's
Second-order cybernetics	M. Mead G. Bateson H. Foerster	the 1960-1970's
Autopoiesis	H. Maturana F. Varela	the 1970's
Homeostatics	Yu. Gorsky	the 1980's
Conceptual cybernetics of third and fourth orders	V. Kenny R. Mancilla S. Umpleby	the 1990-2010's
Neo-cybernetics	B. Sokolov R. Yusupov	the 2000's

Cybernetics has always received a wide variety of evaluations by experts. Şen [2, 12] states that Al-Jazari is an indisputable pioneer and scientist in the initiation of today's cybernetic and robotic studies, and has no rival in any culture. Akman [27] drew attention to the different balance principles used by Al-Jazari on a wide variety of machines. The machines working on the principle of balance and power are used with hydro-mechanical effects and stated that an automatic system is used between the buoy and the hoists.

When the machines made by Al-Jazari are examined, the transmission of the work done with water power, the devices with the hydro-mechanical system it creates, and the feedback that it provides with the interaction between the pulleys and the gear wheels, constitutes the scope of the definition of cybernetics. Not only was it possible to install automatic systems, but Al-Jazari realized the automatic balance of these systems not with electric power, magnet power or electromagnetic power, but with water power and pressure power [28, 29].

It is understood that the devices made by Al-Jazari operate with hydraulic and mechanical cybernetic systems, and in some, they use interactive structures using gear wheels between the buoys and pulleys. He has made an important contribution to automation by developing automatic balance systems with water and pressure power [30]. Al-Jazari was able to use the conditions of his life in the best way and introduced himself in the modern era with the cybernetic system he made in his field. Although electricity and electromagnetic power are not available and have limited possibilities, Jazari has made devices that work with magnificent hydro-mechanical systems, taking advantage of water power and pressure [31].

Jazari expressed his philosophy as follows. "Techniques that cannot be translated into practice will fall between right and wrong". It is understood from this philosophy and the book he wrote that it is possible to say that all the vending machines he invented were created with the principles of balance.

This situation can be confirmed from the sources mentioned above. Consequently, considering all these evaluations, it is possible to say that Jazari is one of the pioneers of cybernetics.

4. INVENTIONS OF AL-JAZARI

Al-Jazari technology had three different goals: creativity, aesthetics, and vending machines that offer practical solutions for people's daily use. Al-Jazari has described the best mechanical devices he has invented and designed throughout his life in his book. The book contains many mechanical devices and descriptions on how to make them. The descriptions of the construction were very convincing. Even today, it is possible to redesign the original inventions of Al-Jazari inspired by personal information, comments or writings. The automation history that Al-Jazari invented the first robotics, water clocks and other mechanical devices dates back to 1206. The machines described in the book are classified into six categories; the first three categories consist of ten chapters and the last three categories consist of 5 chapters [5, 18].

1. Water and candle clocks (10 chapter)
2. Vessels and figures suited for drinking sessions (10 chapters)
3. Pitchers and basins for phlebotomy and washing before prayers (10 chapters)
4. Fountains perpetual flutes (10 chapters)
5. Five water raising machines (5 chapters)
6. Five miscellaneous devices (5 chapters)

Details about these machines and their drawings is given in [2, 4, 10, 11, 18, 32].

Al-Jazari's most interesting machine is a water lifting machine that uses Piston, cylinder, valve and wind energy with the importance it gives to today's technology. This system takes advantage of wind energy, which has an important role in the development of the machine's steam engine and pumping machines, and is converted into mechanical energy through panels radially placed around an axle. More information about the working principle of this machine is given below.

4.1 Water-Raising Machines

When people were supplying water from wells and rivers as the water source, Al-Jazari invented mechanical devices that helped create a water supply system. Al-Jazari invented five machines and introduced his most important ideas and components in these water elevation machines in 1206. Al-Jazari successfully operated the invented devices with great precision and accuracy. This system, which forms a few foundations of mechanical engineering today, consists of four main devices. This vehicle had a high economic value as well as an advanced technological value under the conditions of that day.

Many believe that the two-stroke piston, the ancestor of the two-stroke engine, was the invention of the 20th century. If gas was used instead of water or air power, this vehicle, which has today's engine working principle, was originally developed by Al-Jazari in the 12th century. This two-cylinder vehicle with two-stroke pistons moving left and right is actually a two-stroke suction pump. It is an oscillating and grooved rod connected by two-piston rods operated by a water wheel operated through the pump-gears system. Pistons operating in cylinders are horizontally opposite each other is a single outlet

system, each of which has suction and discharge pipes operating with a valve. The water pump facility of Al-Jazari is shown in Figure 2. It takes action by using the natural flow heat of a water and pumps the water upwards.



Figure 2. Wind- or water-powered flume-beam sweep

The water wheel in the stream creates a uniform rotational movement that continues on a shaft with the force applied by the water to the tracks. A gearwheel connected to the shaft transfers this movement to another gearwheel with an axle shaft connection. A crankshaft, which is movably connected with the axle shaft, mechanically converts the rotary movement into the thrust movement. Important points that stand out in this design, which is the first source of mechanical energy that replaces human or animal power; energy was obtained from the water wheel, the circular motion was converted to linear motion and the efficiency was doubled by using two reciprocating pistons.

Al-Jazari invented suction pipes, suction pump, double-acting pump and double-cylinder piston suction pump and used these mechanisms and crankshaft connecting rod. This pump is driven by a water wheel by means of a gear system by driving an oscillating slit rod to which the rods of the two pistons are connected. The pistons are equipped with horizontal opposite cylinders, suction and discharge pipes, each of which operates with a valve. Distribution pipes are connected to the center of the machine to create a single outlet to the irrigation system.

This water-raising machine, which has a direct importance for the development of modern engineering, is remarkable for the following reasons: It has an important place in modern engineering due to its characteristics such as the first known use of a real suction pipe, the conversion of rotation to the reciprocating motion through the crank-connecting rod mechanism, the first application of the double-acting principle.

With this invention, Al-Jazari succeeded to invent;

- A gear that drives water to operate other devices.
- Using a unique gear combination, he was able to change the direction of movement from vertical to horizontal.

- By connecting the main gear to a suction pump, it was able to create a piston-like bidirectional movement. These are shown in the Figure 3.



Figure 3. water-raising machine (include Piston, cylinder, valve) ([6])

The double-action suction pump with valves and reciprocating piston is implemented in this invention. This pump was used to pump water into another drain system using hydraulic power. He used the flowing water river with the help of several gears to move a turbine. He used cylinders and a caps to create the hydraulic effect. The visualized form of this piston mechanism is shown below.

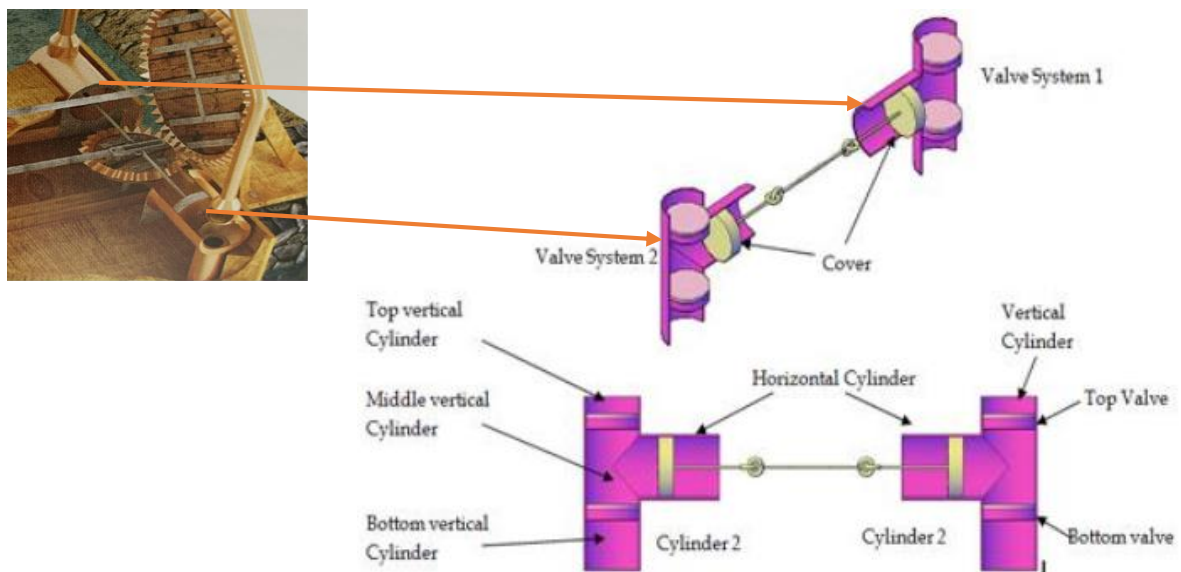


Figure 4. An illustration of hydraulic and gear system [20]

The material used is a copper suction pump that is resistant to corrosion and does not pollute the water. Gears were made of mulberry wood. Al-Jazari's creativity in using and manipulating water and air pressure power can be seen from this system. He automatically performed the flow of water from the pump source to a pipeline. This system is fully automated without the need to use manpower. The working principle of the system is briefly as follows.

The shaft of the wheel installed in the water rotates a gear wheel in the vertical position. It rotates a gear wheel in a horizontal position. The vertical shaft in the axis of this wheel is bedded from two places at the bottom of the wheel. When the horizontal impeller rotates, the pin on it makes a circular motion. This movement, as seen in figure 4, moves back and forth to the end of the special slit rod. The arms connected to both sides of this slotted end act on the pistons of the fixed cylinders. Each of the pistons is pushed to the bottom of its cylinder while the other is pulled to the mouth. In this arrangement, the cylinders act as suction and compression pump. Thus, while each piston moves towards the mouth of the cylinder, it creates an airless gap at the bottom of the cylinder. The flap of the suction pipe at the bottom opens and the flap of the discharge pipe at the top closes. The piston moves back after the water is filled from the suction pipe to the cylinder. The lower flap is closed and the upper flap opens so that the water is pressed up. In this vehicle two cylinders are operated mutually. This system is the first form of today's double-acting pumps. The mechanism that moves the piston rods is the first form of the lever-connecting rod mechanism used in today's engines. This extraordinary machine is regarded as an ancestor of today's double-acting coveralls, crankshaft and steam machines, in terms of working principle.

5. CONCLUSIONS

Al-Jazari, who lived in the 12th century, is the father of robotics and cybernetics, which works hydraulically with water power. He has made a significant contribution to modern technology, has made many inventions that work with water and air pressure power. This is the first person to produce and use mechanical gears and hydraulics, Al-Jazari lived before Leonardo da Vinci. It deserved to be one of the pioneers of cybernetics with the feedback control balance system used in the mechanisms it established. The transfer of technological developments among civilizations can be permanent if they are in the form of written documents. Al-Jazari made drawings of his designs in his handwritten book, translated (to English) by Donald Hill in its original form. Al-Jazari's book is an important resource in the history of automata, mechanics, mechatronics, automatic control, robotics and cybernetics.

The purpose and functioning of the machine given in his book are important for our technology. He describes, step by step, the manufacture of its component parts, setting out, assembly and fitting, joints and connections, and testing. He was a master craftsman, fully conversant with all branches of his trade. If we list what Al-Jazari has brought to science;

- He has developed automatic machines, robots, and hydro-mechanical systems by making mechanical tools powered by water power.
- He has developed the cybernetics science by using the automatic-control-balance system together.
- By making use of the water pressure, the lifting force of the fluid, the flow rate of the water, and the shifting of the center of gravity, automatic moving machines have been developed.
- The crankshaft and piston mechanism used in today's motor vehicles were used by Al-Jazari.

- Using a unique gear combination, he was able to change the direction of movement from vertical to horizontal.
- Al-Jazari invented suction pipes, suction pump, double-acting pump and double-cylinder piston suction pump and used these mechanisms and crankshaft connecting rod.
- Carburetor float circuits used in pressure valves, composite containers, hydraulic pumps and gasoline engines used in today's industrial hydraulics are designed based on the drawings of Jazari.

In the 12th century, humanoid, entertainment and cooperative multiple robots made by Al-Jazari became an inspiration for today's robots. In today's technology, robots that can imitate human abilities with artificial intelligence are being developed and the history and importance of cybernetics science is better understood. It is important to interpret the works of Al-Jazari today and to emphasize the methods of Jazari as physical programming in robotic programming.

The main aim of this article is to report the importance of Al-Jazari in our technology history and to emphasize the importance of the machines invented in today's technology. At the same time, it is aimed to show why the genius engineer who lived in Anatolian lands was one of the pioneers of robotics and cybernetics. Our belief in our civilization and cultural values increases with the works of Al-Jazari. The devices of this scientist, who reached us through inheritance, are important in that they show where the origins of civilizations are based.

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