PLAY OF WATER AND FUNCTION IN THE MEDITERRANEAN

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ABSTRACT
Water is of great importance for life and culture in the Mediterranean. In the early Muslim age, with the advent of Islamic technology, different historical types of water devices developed in the Mediterranean basin, making use of the aesthetic and psychological potential of water. This paper focuses on hydraulic *automata*, particularly "surprising" fountains, as devices that were very popular in the Islamic courts. The hydraulic mechanism, hidden in the device, was able, through the application of physical principles, to amaze people because of the spectacular water movement it created. The exceptional knowledge of the Greek engineer's mechanical application has played a fundamental role in the evolvement of the hydraulic *automata* from the Hellenistic Society to the Islamic Age, and has been essential for the development of innovative methods. By establishing a picture of the development of the studies that led to the creation of these wonderful mechanisms in the Islamic Golden Age, the paper will also attempt to underline the fact the hydraulic *automata* sustain a significant position in the history of Islamic fine technology.
Keywords: automata, hydraulics, table-fountains, ḥiyal.

1 INTRODUCTION

Hydraulic *automata*, as Greek inventions, were very popular in the courts during the Islamic age. Small hydraulic devices, as means of "surprising" fountains, were used as eye catching table centerpieces. They were intended to provide amusement and aesthetic pleasure.

The relationship between Hellenistic and medieval Arab studies in the fields of hydraulic *automata* is evident. In Hellenism, starting from the end of the 4th century BC, in Alexandria Egypt, the most important center of Greek culture, theoretical studies promoted applied sciences. In the *Alexandrian School*, important scholars, such as Ctesibius, Philo of Byzantium and Hero of Alexandria, carried out their studies [1]. Following Alexandria's Arab conquest in 642 AD, studies by Greek scientists related to medicine, physics, astronomy and mathematics developed in the Muslim empire. The Abbasid Caliphate, which ruled over most of the Arab world between 758 and 1258 AD, emphasized and encouraged the development of science and technology. With its new capital in Baghdad, the Abbasid caliphate invested huge amounts of resources in cultural activities and scientific scholarship.

A substantial portion of Greek texts were translated into Arabic, especially between the mid-8th century until the mid-11th century. In particular, Hero's *Mechanica* was translated into Arabic in 864 by Qustā bin Lūqā [2], while we do not know the name of the translator of Philo's *Pneumatica* nor the translation date [3]. The principal driving force behind these translation-initiatives was the establishment of the library, *Khizanat al-Ḥikma*, (The Treasury of Knowledge) and a research institute, *Bayt al-Ḥikma*, (House of Wisdom) [4]. Thus, Philo and Hero's experiments became reference points for Arab scientists; in particular, those Arab scientists, whose hydraulic studies had a relationship with Greek studies, are the Banū Mūsā brothers, al-Kindī and al-Jazarī. Their interest in Greek authors is to be found in manuscripts describing accurate and sophisticated *ḥiyal* (*automata*) like water-clocks, syphons, mechanical toys and "surprising" fountains, showing the development of the Hellenistic studies through innovative methods and the use of detailed technical drawings. The Arabic

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word *ḥiyal*, as applied to mechanics, can denote almost any machine from a small toy to a siege engine.

2 FROM CTEBISIUS TO ARAB INVENTORS

The hydraulic pumps invented by Ctesibius, as well as his study of valved piston pumps to supply fountains from underground water, should have been the reference points for the functioning of Hero's fountains. Hero was also inspired by experiments on evacuators and the principle of the siphon described in *Pneumatica* by Philo of Byzantium, who moved from the principle enunciated by Aristotle in his *Physica* in about 350 BC, that "nature contains no vacuums because the denser surrounding material continuum would immediately fill the rarity of an incipient void". Philo also referred to Ctesibius' studies (which we know through the Philo's descriptions), transmitting to Hero the physical principles on which he based his invention of the first miniature fountain, as described in his *Mechanica.* Thus, Hero adapted Philo's experiments to fountains for the purposes of entertainment.

The Banū Mūsā brothers (Ja‘far Muḥammad, Aḥmad and al-Ḥasan), scholars of the *Bayt al-Ḥikma* in the 9th century, devoted much of their wealth and energy to the quest for the works of ancient writers, and sent missions to Byzantium to seek out material and bring it to Baghdad. Muḥammad is said to have made a journey to Byzantium in person, bringing Greek works to the *Bayt al-Ḥikma*, where they were translated into Arabic. They wrote the *Kitāb al-ḥiyal* (Book of Ingenious Devices). We cannot say with certainty which of the Greek works were known to the Banū Mūsā, with the exception of Hero's *Mechanica*, which was translated into Arabic by Qustā bin Lūqā. Among the 100 *ḥiyal* invented (which include fountains, self-trimming lamps, an automatic musical instrument and a mechanical grab for extracting objects from underwater) there are seven "surprising" fountains, which are described in detail with texts and accurate drawings; instructions for the construction of the devices are also included. According to Donald Hill, many of the Banū Mūsā's machines are elaborations of basic ideas contained in the works by Philo or Hero, or both. We should also take into account the possibility that Greek texts would have not been the sole inspiration of the Banū Mūsā and their successors, although they were perhaps the main inspiration. This is due to the fact that, between the time of Hero and the time of the Banū Mūsā, there is a span of eight hundred years during which there could have been scientific and technical advances which would have influenced the studies on Arab engineering [5]. Thus, it would be significant to investigate the fact that there could be other works by Hero available to them, as Donald Hill has asserted, since his reputation among the Arabs was already high in the 10th century. In terms of operation the Banū Mūsā's fountains are similar to the devices described by the Greek writers, and are almost certainly derived from them.

It is opportune to note some differences between the Banū Mūsā fountains and those described by the Greek writers. Apart from the greater complexity of their devices (compared to the Greek ones), the Banū Mūsā make use of properly fitted cone-valves, whereas Philo and Hero mention only crude clack-valves and plate valves [6].

Of the seven fountains, described in the *Kitāb al-ḥiyal*, the fountain pouring water in the shape of a "lily of the valley" or a shield can be considered as a prototype for other devices described in the manuscript (Fig. 1). According to the description of the device, the fountain receives water from a small tank. Through a U-shaped pipe water enters the jar-shaped fountain, which is divided by a plate with many small pipes close together and connected to a cone which is erected over the plate. Water running through the small pipes comes out of the cone forming a shape of a "lily of the valley". Water flowing outside the cone comes out through a gap on the perimeter of the jar-mouth in the shape of a shield.

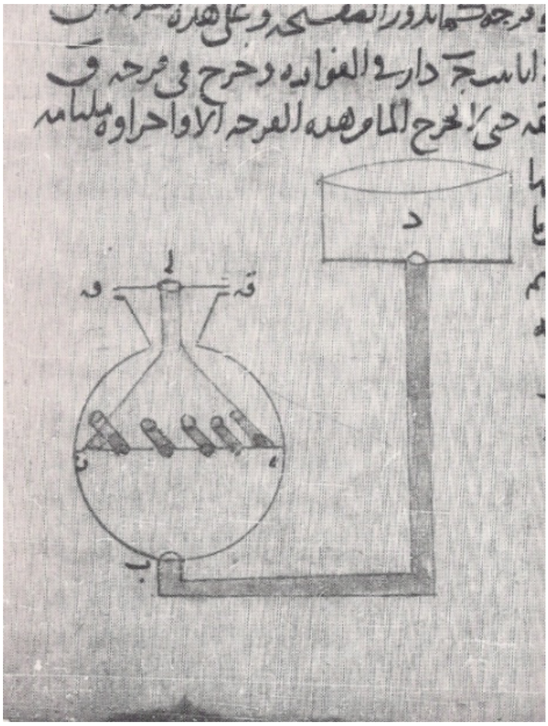
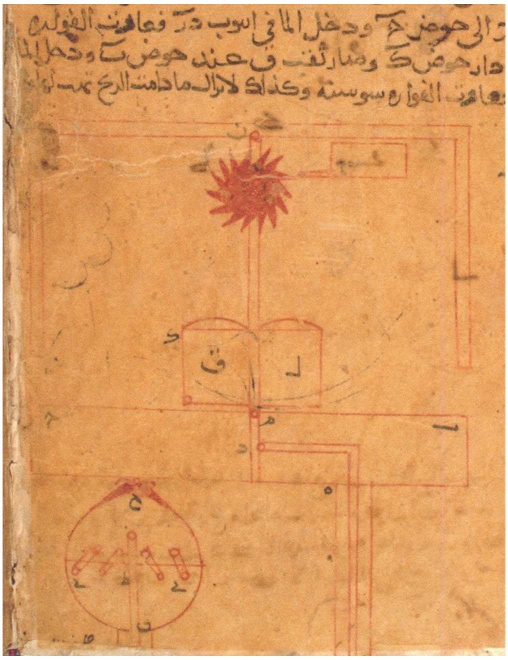
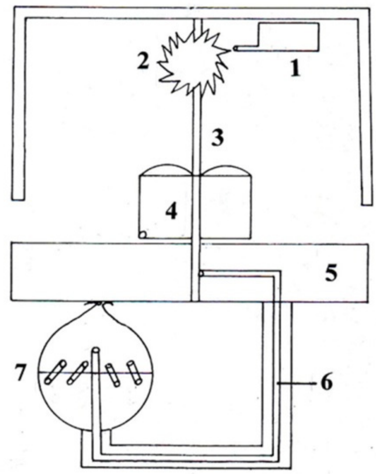


Figure 1: Banū Mūsā, fountain pouring water in the shape of a shield or a “lily of the valley” (folio 50 recto, Ahmet 3474, Topkapu Serai Müzesi Kütüphanesi).

Particularly ingenious is also the fountain operating by wind or water discharging a single jet or a jet in the shape of a “lily of the valley” (Fig. 2). The device includes a paddle wheel that is moved by the water coming from a tank or by the wind. A vertical axis, connected to the wheel, moves a further tank (to which it is attached) that is filled with water. On the base of the tank there is a hole through which, during the rotation of the axis, water is poured, alternately, into two containers that are connected, through cone valves, to the jar-shaped fountain. Water comes out, alternately, in the shape of a “lily of the valley” or in the shape of a lance. The vertical axis that moves the tank represents an innovation for *automata* devices, as it allows rotary movement to be converted into reciprocal movement. The use of fitted cone-valves employed to control the quantity of water flowing into the device is also innovative.

The Egyptian 9th century ʿUmar Ibn Muḥammad al-Kindī, in his *De automatis et thaumantiis*, a technical treatise on the hydraulic *automata* [7], mentions Hero’s texts on pneumatics by describing “surprising” fountains. The work is lost, but it is mentioned in the 10th century *Kitāb al-Fihrist* by Ibn al-Nadīm [8]. There are Latin excerpts from it in the 15th century *Bellicorum instrumentorum liber cum figuris et fictitys literis conscriptus* [9] by the Venetian scientist Giovanni Fontana, who had seen the Arab manuscript, underlying that fountains by al-Kindī were inspired by the physical principles of Greek authors [10]. According to Donald Hill, al-Kindī may have also known Arab translations of Philo’s *Pneumatica* included in the Hagia Sophia 3713 [5].





1 pipe to provide water to the wheel; **2** water-wheel; **3** vertical axis to transmit the rotation to a small tank; **4** small tank which pours water into a big tank; **5** big tank; **6** pipe to transfer water from the big tank to the fountain; **7** fountain.

Figure 2: Banū Mūsā, fountain operating by wind or water (folio 37 verso, Arabus 317, Vatican Library). On the right is a scheme of the function of the device.

Of the table-fountains by al-Kindī described by Giovanni Fontana, the device described in the folio 46r. is characterized by a set of curved pipes through which water – supplied from a source at the top – arrives at a cylindrical basin at the bottom. From the basin, water rises through a pipe and is poured into a funnel from which it is directed to the cylindrical basin to continue its perpetual motion. The latter part of the device is represented in detail in folio 47r., showing a fountain driven from below, where the cylindrical basin is set. Through a vertical twisted pipe, water arrives to the top of the fountain and dischargers a vertical jet and two gushes directed downwards. Water is collected into the funnel to be directed to the cylindrical basin and continues the perpetual fluid circulation system (Fig. 3).

In the early 13th century *Al-jāmi' bayn al-'ilm wa al-'amal al-nāfi' fī ṣinā'at al-ḥiyal* (A compendium on the Theory and Practice of the Mechanical Arts) by Ibn al-Razzāz al-Jazarī, there are studies on 50 devices including six "surprising" fountains described with accurate partially three-dimensional drawings, enabling future craftsmen to construct the machine. The specific mention to Greek works is the "Construction of the machine of the flute player" by Apollonius of Perga, referring to the function of an instrument for perpetual flute. However, by showing the fountains, al-Jazarī refers to the Banū Mūsā as one of his sources. Considering that the hydraulic mechanism of the fountains by the Banū Mūsā was directly derived from the works of Hero and Philo, our line of transmission is complete. On the other hand, al-Jazari's opinion is that the Banū Mūsā's devices could not work properly because of the short time-interval for the change of the water-jet shapes [6]. For instance, with regard to the Banū Mūsā fountain operating by wind or water, he underlines that the time during which water flows through each pipe, in order to be transferred from each tank to the fountain,

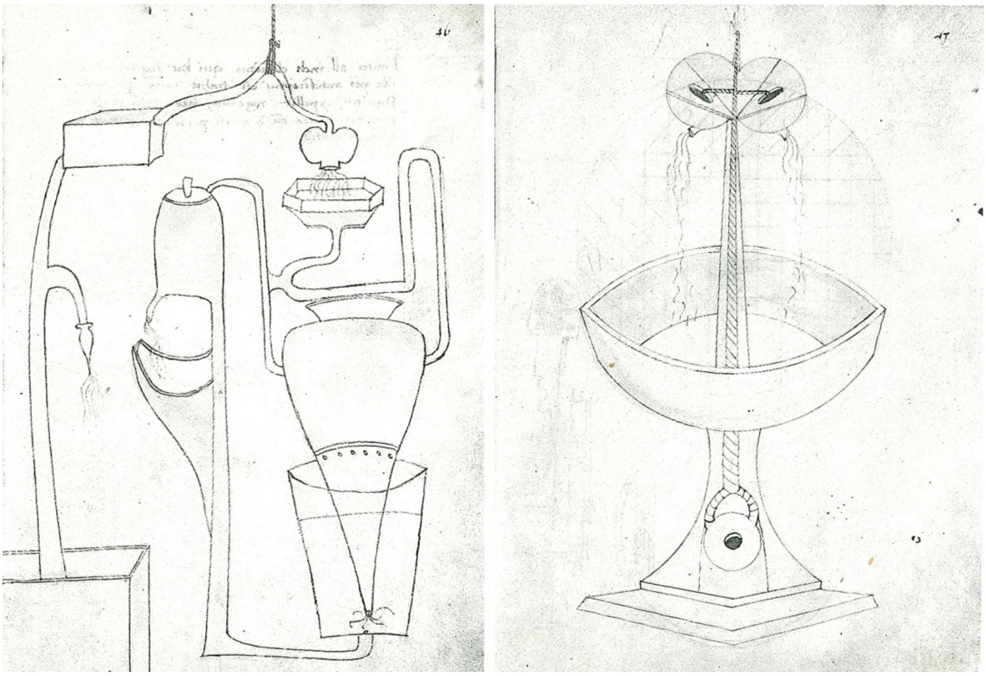


Figure 3: Al-Kindī, fountain redrawn by Giovanni Fontana (folio 46 recto (left); folio 47 recto (right), Icon. 242, Bayerische Staatsbibliothek).

is not long enough for a complete rotation of the tank. Thus, in his projects he creates the necessary water pressure to determine the height of the gushes, the time necessary to obtain them and the shapes of the jets, such as an arched-shape, an umbrella-shape or a “lily of the valley” shape. By providing the fountains with one or two bowls to receive the quantity of water to drive the device, it is possible to check the time of the fountain in operation. He also intends to balance the quantity of water driving the device with that flowing through the pipes and that filling the bowls in a precise time.

The fountain with two floats (Fig. 4) is divided into two sections: an upper part consisting of the main device, and a lower part with the pipes to evacuate the water. The upper section consists of a container divided into four small containers. The two external containers house a float with a projecting knob on the top. On each base of the two internal containers there is a valve to allow water – by opening the valves alternately – to pass through, and arrive at a U-shaped pipe connected to a spherical terracotta bowl. From the left U-shaped pipe water gushes in the shape of an arch; from the right U-shaped pipe water gushes in a shape of a “lily on the valley” through a set of radial holes of the bowl. The use of floats, which derives from Ctesibius’ invention of a water-clock, allows water to be maintained at a constant level, and guarantees a constant water-flow inside the device [11]. From the top of the device water is poured into a horizontal copper cylinder through a funnel, which – due to its oscillation while receiving water – pours water into each of the two internal containers alternately. This mechanism derives from that studed by Philo of Byzantium in his *Pneumatica.* Water fills the right section causing an arch-shaped gush for fifteen minutes; in the meantime the left

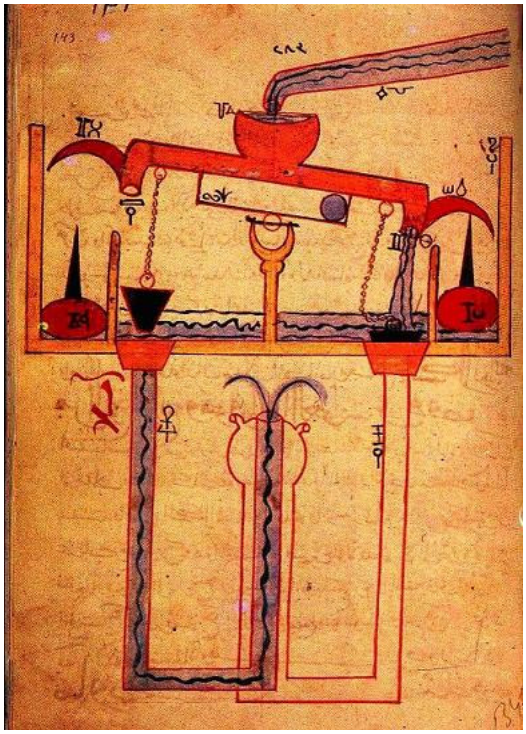


Figure 4: Al-Jazarī, alternating fountain with two floats (folio 91 recto, Ahmet 3606, Topkapu Serai Müzesi Kütüphanesi).

container discharges. The float rises and the horizontal pipe oscillates towards the left and water enters, for fifteen minutes, into the left section, causing a gush in the shape of a "lily of the valley". On both ends of the horizontal cylindrical pipe there are two half-moon shaped extensions that touch the floats because of the oscillation, causing the pipe oscillation to reverse. As a chain connects each valve to the ends of the cylinder, the chain raises the corresponding valve during the oscillation to allow water to enter into the U-shaped pipe. In the meantime, on the opposite side, the other chain goes down, thereby closing the corresponding valve. Consequentely water coming from the cylinder fills the corresponding container, while the float rises up to the half-moon extension causing – after fifteen minutes – the reverse of the cylinder oscillation. Within fifteen minutes water is channeled into the U-shaped pipe creating a "lily of the valley" gush. Water coming from the funnel fills the opposite container until the float rises and touches the half-moon end. This causes the near chain to extend and raise the valve to allow water to enter into the U-shaped pipe and gush out creating a shape of an arch for the follwing fifteen minutes.

A similar hydraulic mechanism in employed in the *ṭarjahār* fountain to create gushes that change shape at regular intervals of time (Fig. 5). This fountain includes a hemispherical bowl, i.e. the *ṭarjahār*, that oscillates because of the weight of the water filling the cup. For thirty minutes water gushes in the shape of an umbrella, then – for the following thirty minutes – the gush has the shape of a tree. From a hemispherical tank, at the top of the device,

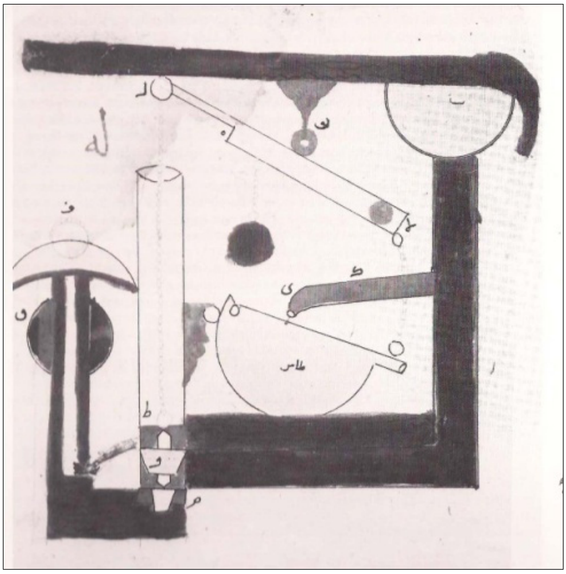


Figure 5: Al-Jazarī, ṭarjahār fountain (folio 93 recto, Graves 27, Bodleian Library).

water is poured into a cranked pipe whose end is provided with a bidirectional valve. By moving the valve, up and down alternately, in thirty minutes water is channelled into the lower section-pipe (thus into two vertical channels parallel each other, on both sides of a vertical pipe) and then into the large vertical cylinder into which a chain is inserted. The chain is connected to the valve at the lower end; the upper end of the chain is connected to a barbell in order to move the valve up and down. Water gushes in the shape of an umbrella from the two vertical pipes. In the following thirty minutes, because of the water-weight during the filling, the *ṭarjahār* tilts and discharges, extending a right chain that tilts the barbell towards the right. The left chain raises the upper valve allowing water to enter into the vertical channel, between the two pipes. The waterjet has the shape of a tree.

According to Hill [5], it is possible that the Islamic ideas were transmitted to Europe by contacts between craftsmen, by travelers' reports and by the inspection of earlier constructions, whether in disrepair or still working. The most fruitful area for such contacts must have been the Iberian Peninsula during the long period of the *Reconquista*.

3 CONCLUSION

By studying the works by the Greek predecessors, Islamic inventors were able to apply innovations to the application of the mechanical principles of the hydraulic *automata*, such as "surprising" table fountains. Practical aspects of the devices were of primary importance. An important contribution to the comprehension of these hydraulic *automata* is the use of impressively detailed drawings – accompanying the descriptive text – which did not exist in Greek works. In addition, the Arabs also paid particular attention to the accuracy of assembling the device components, and to the definition of their size, which were not provided in Greek description, in order to obtain different water-jets at defined intervals of time. The Arab inventors show that the immediate comprehension of the function is essential. This is allowed by employing drawings representing the internal apparatus of the *hiyal* in detail, making the instrument easy to build.

Technical innovations include the use of small water-pressure variations and the use of conical valves such as an automatic flow-regulator that al-Jazarī introduces in his "alternated fountain", in order to balance the change of the water-level, referring to the float-valve that Ctesibius had invented for his project for the water-clock. It is interesting to note how al-Jazarī has assembled different mechanisms, deriving from Greek predecessors, in a single hydraulic apparatus, making its use simple and easy, as shown in the alternated fountain, where he employs the escapement mechanism which derives from the "automatic faucet" by Philo of Byzantium, and the floats that recall Ctesibius' inventions.

The technical intuition of the Banū Mūsā, with regard to the use of a crankshaft driven by a water-wheel or a wind-wheel, is of great importance. The crank was then perfected by al-Jazarī in order to convert rotary movement into reciprocal movement.

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