CONTRIBUTIONS OF MUSLIM MECHANICAL ENGINEERS IN MODERN AUTOMATA
(IN LIGHT OF KITĀB AL-ḤIYAL OF AL- ĞAZARĪ)
A DESCRIPTIVE ANALYTICAL STUDY

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ABSTRACT

Were the Muslims in ancient times highly proficient in mechanical engineering? Did they have a head start over the West in this field? Unfortunately, it is noticeable nowadays that Arabs and Muslims all over the world became just consumers; exploiting all technological developments of the West that are rapidly growing. Here we had to wonder whether the Arab Muslims, long ago, was in this manner. This research hypothesizes that Muslims had attained an advanced level of mechanical engineering and were the inventors of the self-moving artifacts; recently known as automata. Accordingly, this research has undertaken the mission to prove that assumption. This paper focuses on automata machines, in light of «*kitāb al-Ḥiyal*» of the Muslim engineer *al- Ğazarī*. This book -initially a manuscript- included a detailed description of these machines accompanied by painted illustrations known as «miniatures». The paper begins with a preface dealing with the meaning of fine technology and automata, followed by the story of automata since the antique ages and until the medieval epochs. The latter element is an indication of Muslims' contributions to mechanical engineering in general, and automata in particular. This is supported by previewing samples on automata «self-moving» machines according to the miniatures of «*kitāb al-Ḥiyal* ». This is followed by briefed biography of the book's author *al- Ğazarī* and a historical and artistic analysis of the book itself. Finally, there is a concise scientific analysis of the chosen samples of automata and their relevance to modern machines and advanced technology industries. Conclusively, concerning the value of «*kitāb al-Ḥiyal*» which is dated back to the 7th century AH/ 13th century AD, this research accentuated that automata machines are not a Western invention, they are an outcome of the Golden Age of the Islamic civilization, proving their supremacy in mechanical engineering since the medieval epochs.

KEYWORDS: Mechanical engineering, Automata, Miniatures, Manuscript, Islamic civilization, *al-Ğazarī*, *kitāb al-Ḥiyal.*

I. INTRODUCTION

RESEARCH PLAN:

I. Preface.
II. Story of automata since antique ages and onwards .
III. Contributions of Muslim mechanical engineers in automata.
IV. Muslims' automata mechanisms according to miniatures of «*kitāb al-Ḥiyal*».
V. Historical and Artistic analysis for the publication of «*kitāb al-Ḥiyal*».
VI. Concise scientific analysis for the chosen automata mechanisms.
VII. Conclusion.

I. PREFACE

This research paper illuminates Muslims' contributions to producing self-moving artifacts known as «automata». This is incorporated under the title of fine technology, recently known as mechanical engineering, referring to multiple mechanisms modeled basically for amusement, for timekeeping, and for the diverse needs of scientists.[1]

Unfortunately, due to their fragile composition; few remnants of fine technology mechanisms can be tracked. Thus, their construction and operating systems had been extracted from iconographic sources[2]. The earliest information about the origins of fine technology occurs in the writings of the Roman architect *Vitruvius*[3], who attributed the invention of the organ and monumental water clock to an Egyptian engineer named *Ctesibius*, who worked in Alexandria around 300 BC[4]. Later achievements in fine technology had been attributed to *Philo* of Byzantium, nearly dated back to 200 BC, and *Hero* of Alexandria almost from the mid of 100 BC[5].

These antique sources confirm that automaton mechanisms had been known since antique civilizations; all had produced primitive samples, almost, in the form of jointed figurines. The further phase was the Hellenic civilization which is ascribed the success in producing real automata samples[6]. Nevertheless, Muslim engineers had managed to manufacture more advanced automata artifacts; the mechanism of which is still exploited in modern ones, developed under virtue of industrial revolution in the West[7].

Hence, this paper espousals the idea that Muslim engineers had the priority in presenting such advanced technology to the universe.

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[1] DRACHMANN 1948: 63.
[2] HILL1993:112-140.
[3] He is Marcus Vitruvius Polio; a Roman architect and engineer, who was widely famed during the 1st century BC; CECCARELLI 2014: 307–44.
[4] HILL 1993:112-140.
[5] DRACHMANN 1948: 1-197
[6] BERRYMAN 2003: 344–69.
[7] HILL 1993:122–48.

This is confirmed by the manuscripts of Muslim scientists such as *Banū Mūsā* and the Muslim engineer *al- Ğazarī,*
whose works are still preserved in several libraries all over the world.

Despite such historical indications, several Western scientists are denying Muslims' favor in the emergence of modern automata. Across this research paper, the author attempts to disclaim these allegations by describing – through painted miniatures- real samples of automata mechanisms from «*kitāb al-Ḥiyal*» for the Muslim engineer *al-Ğazarī*.

Although several academic studies had dealt with the achievements of Islamic civilization in sciences as a whole, none have been conducted to shed light on Muslims' supremacy over automata. Accordingly, this research paper has the priority in conducting a concise scientific analysis; accentuating how the Muslim automata samples had paved the way to the emergence of the recently advanced counterparts. Furthermore, it illuminates how several technical applications became well-known, and are still in use under the antique automata mechanisms built by *al- Ğazarī*.

II. STORY OF AUTOMATA SINCE ANTIQUE AGES AND ONWARDS

The story of automata is deep-rooted, since man was eager to simulate the universe through graphics and plastic art. Ancient grotesque figurines[8] and idols found in burials testify to this inspiration's age-old in primitive religions. Although automata are almost renowned to have begun in the Hellenic civilization, it is clear that man managed to elaborate pictorial representations with automata long before[9]. It is documented that proto-automata samples in the shape of dolls with joined arms and other articulated figurines were early known from the ancient Egyptian tombs of the 12th dynasty onwards[10].

One of these jointed figurines among the properties of the Metropolitan museum of arts is an Egyptian small and precisely carved wood statuette, representing a wholly naked woman, with a heavy shoulder-length wig **[FIGURE 1]**. The statuette's right hand is maintaining its propriety by covering the genital parts; however, the breasts were to be masked by the missing left arm. A simple technique had been applied; the arms were designed to be raised and so uncover the feminine genital and other charm organs. This statuette is a rare sample of proto- automaton, resembling an infrequent level of mechanical superiority in the archaeological record of the Nile Valley. According to preliminary examination, this small statuette was attributed to the Egyptian middle

[8] The word «Grotesque» is derived from the Italian *grotteschi*; referring to the grottoes in which these decorations were found *c.* 1500. Such decoration was either mural or sculptural, represented in unfamiliar combined shapes, inclined to be unreal, comical and even caricature.
BARASCH 1971: 9.

[9] DE SOLLA PRICE 1964: 9–23

[10] CHAPUIS & DROZ 1958: 13–29.

kingdom, almost the 12th dynasty (ca. 1981-1802 BC). Though, due to the high profession of sculpting, further examinations tended to attribute this statuette to a later date; about the 18th dynasty (ca. 1550-1295 BC). However, shortly, the 12th dynasty again had been favored.

The mechanism applied in this statuette is composed of a rotating axle introduced into the torso through a square-cut hole in the right shoulder **[FIGURE 2]**. This hole gives access to a large, precise vacuum cut and a small, drilled exit hole. One end of the axleis fashioned as a tenon????, where the statuette's right arm is attached. The axle's other end preserves the remnants of an identical tenon???; where the missing left arm was once attached **[FIGURE 3]**[11].

The purpose for which ancient Egyptian craftsmen exploited this mechanism is still unclear. However, some historians interpreted that to be a simulationfor a comic dance of the goddess «*Hathor*» to bestow pleasure on the «*Sun God*» as a ritual performance.[12] Conclusively, the mechanical nature of this ancient Egyptian statuette renders it a particular significance[13].

A further record of automata self-moving artifacts -as numerous historians of technology stated- had been revealed in ancient Homeric literature[14], which dealt with self- moving devices as a personification of their Gods[15]. By the beginning of the Hellenic culture, the natural exaggeration in mythology had produced the concept of simulacra with multi abilities that exceed proto-automata figurines; just talking or moving their arms. Hellenic Daedalus[16], managed to imitate the flight of birds, and fashioned guarding statues that moved and walked in front of the labyrinth[17]. Another case is Archytas of Tarentum[18], who succeeded in making a wooden flying dove function with counterweights and air pressure[19].

From at least the 4th century AD, a growing body of techniques and ideas gathered under the label «mechanics». In Hellenes times, mechanics had been considerably developed in theoretical and practical means as well. In advanced natural philosophy,

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[11] REEVES 2015: 42–61.
[12] SCHARFF 1927: 61.
[13] REEVES 2015: 42-61
[14] Homer is one of the most influential Hellenic authors during the 9th or 8th century BC. He was presumed as the authorof the Iliad and the Odyssey, two hugely influential epic poems, FOWLER 2004: 254–71.
[15] IRBY-MASSIE & KEYSER 2002: 150–78.
[16] Daedalus, (Hellenic: «Skillfully Wrought») mythical Hellenic inventor, architect, and sculptor, who was said to have built, among other things, the paradigmatic Labyrinth for King Minos of Crete. WHITE & et ALL. 1959: 558-60
[17] Labyrinth was the name given by the ancient Hellenics and Romans to a structure of bewildering maze of passages designed by Daedalus in the command of King *Minos* of Crete. WHITE & et ALL. 1959: 558-60
[18] Archytas of Tarentum, Hellenic scientist, philosopher, and major Pythagorean mathematician. HUFFMAN 2005: 255-82.
[19] DE SOLLA PRICE 1964: 9–23

the mechanical versions of «self-movers» were the reason for thinking that human beings' organisms, and the natural world in general, might work just like that [20] Thus, the emergence of automata had been greatly accepted and welcomed by the Hellenics, especially those who were resided in Athens, where slavery was widespread, and they rapidly understood that automata, self-moving robots, could substitute slaves [21]. Thus, the existence of slavery produced the raw materials for the development of a piece of technology; the «imaginary robots» automaton. As a result, turning to automata virtually became a must[22].

III. CONTRIBUTIONS OF MUSLIM MECHANICAL ENGINEERS IN AUTOMATA

The roots of every new civilization must be supported by the achievements of its ancestors. In the case of Islamic civilization, ancestors were the Hellenistic, Greco-Roman, and Byzantine civilizations, besides minor influences from China and India. By their conquest of Egypt and Syria in the first half of the 1st century AH/ 7th AD, the Arabs fell as inheritor of the Hellenic civilization. This heritage was eventually to bear fruit in the transmission of scientific literature and in the diffusion of traditions in the construction of machines, hydraulic works and masonry structures [23].

Furthermore, from the mid of the 1st century AH/ mid of the 7th AD century, Muslim Arab armies built communication with the Chinese civilization during their conquest of Central Asia. In addition, China had long been a commercial and diplomatic representative in the area. Yet, the Indian influence on Islamic civilization had long occurred when Muslims established a vast subcontinental empire and arrived on the south Indian coasts as missionaries and merchants. In 93 AH/ 711 AD, the Umayyads annexed that part of India in the north, now known as *Sind*, which came into direct contact with the caliphate and was the main channel through which the ancient Indian sciences passed to Baghdad [24].

The legacy of scientific and technological knowledge from the conquered regions had remarkable results in the new society. With the translation from Hellenic and other languages, there was tremendous openness in the early centuries of Islam. In addition, the organized sponsorship of translation under the great '*Abbasside Caliphs*, which continued until the middle of the 5th century AH/11th century AD, reflects the great attention the rulers paid to adopt all valuable knowledge of the pre-Islamic cultures

[20] BERRYMAN 2003: 344–69
[21] WILSON 2008: 337–68.
[22] DEVECKA 2013: 52–69.
[23] HILL 1993: 1–14.
[24] AL-ḤASSAN & HILL 1986: 29–31.

as a matter of expediency. By about 442 AH/1050 AD all valuable scientific works of the Hellenistic period were available in Arabic. In addition, original Arabian works became an extension of Hellenic scientific systems and participated in improving them[25].

Talking directly about «fine technology» in the Islamic epoch; there are plentiful evidence of edited texts, besides some surviving instruments that testify to Muslims' contributions to producing mechanical devices[26]. Although the Muslim scientists had taken the Hellenic works as their starting point, they became considerably more advanced. According to references from Hellenic, Roman and Arabian historians, constructing ingenious devices had occurred in the Eastern Mediterranean from Hellenistic times and through the periods of the Roman and Byzantine empires into the world of Islam. Written sources that describe machines are very rare. In Arabic, likewise, there were some short treatises, only two are of great importance[27].

The first is that of *Aḥmad* one of the three brothers known as the *Banū Mūsā*, sons of *Mūsā b. Shakir; Muḥammad, Aḥmad, and al-Ḥasan* [28]. *Mūsā b. Shakir* was so advanced in the field of engineering and astronomy; thus, he was one of the fortune-tellers during the reign of the 'Abbasside Caliph *al-Ma'mūn* (198-218AH/ 813-833AD). His three sons were superiors in mathematics, astronomy, and tricks «*Ḥiyal*».[29]

Although these three brothers undoubtedly took the works of *Philo* (200 BC), and *Hero* (mid of 100 BC) as their starting point, their work revealed a greater mastery over physical media that even excessed their Hellenic predecessors. They were the pioneers of Islamic engineers to demonstrate a preoccupation with automatic controls[30]. They had about twenty scientific books, in mathematics, astronomy, and mechanics; the most famous of these was the «*Book of Ingenious Devices*» which had been dated to the 3rd century AH/ 9th century AD and particularly attributed to *Aḥmad b. Mūsā*[31]. This book included ahundred ingenious devices that helped in initiating technological refinements and offered new applications. It is critical here to mention that the mastery of *Aḥmad b. Mūsāb. Shakir* in the field of aerostatic and hydrostatic pressures, besides his employment of automatic controls and switching systems placed him in advance of his Hellenistic predecessors. Although his work in this field is limited in scope; it -his work- was not exceeded until modern times [32].

[25] Hill 1993: 2–14.
[26] De Solla Price 1964: 9–23.
[27] Hill 1994: 25–43.
[28] An-Nadīm 2014: 224 – 6.
[29] Ibn al-Qifṭī 1903: 315, Al- Andalūsi, 1912: 55, Ibn Khalakān 1977: 161-3.
[30] Sarton 1927:545–6; Brockelmann 1936: 382.
[31] Sezgin 1974: 246–52; Sezgin 1979: 129–30.
[32] Rāshid 1996:1–31; Sezgin 2001:107-298.

However, the most important Arabic treatise in mechanical engineering is the great book of ingenious devices of *Ibn al-Razzāz al- Ǧazarī,* which was accomplished in 602 AH/ 1206 AD. In *Diyarbakir.* It encloses fifty machines, distributed into six categories; water-clocks and candle-clocks, wine dispensers, phlebotomy measuring devices and water dispensers, alternating fountains and musical automata, water-raising devices and miscellaneous[33]. Several of the mechanisms and their techniques that appear for the first time in *al- Ǧazarī's* work were later to enter the vocabulary of European mechanical engineering[34]. This work is almost important, since *al- Ǧazarī* described, accurately, the methods of manufacturing and constructing his machines, accompanied by a practical study. This is a unique performance in earlier centuries, and thus, allowed later craftsmen to reconstruct his mechanisms [35].

In the comparison between the work of *al- Ǧazarī* and that of *Banū Mūsā*, it was stated that the work of *al- Ǧazarī* reached a higher level of maturity than that of *Banū Mūsā's*. In addition, according to Western scientists, the mechanical devices of *al- Ǧazarī* were of great significance not only for achieving daily life functions, but for their importance in recognizing principles of natural physics as well[36]. The book of *al- Ǧazarī* is the most detailed in its type, and the peak of Muslims' achievements in mechanical engineering[37].

British engineer Donald Hill stated: «*Until recent centuries; the book of al- Ǧazarī is unique in its designs and detailed methods of manufacturing and forming machines; null documents from any other civilizations all over the world that corresponded to it*».[38] Muslim engineers were almost in close contact with constructors; and only a few of them had gathered between engineering and constructing machines; *al- Ǧazari* was a dynamic engineer and a professional constructor as well [39]. Conclusively, the book of *al- Ǧazarī* presented a full scene of Arabian mechanical technology[40].

Getting to the impact of Muslim engineering on European technology; most Western historians deny Muslims' priority. They suppose that European culture is the direct descendant of the classical civilizations of Greece and Rome. However, according to Charles Singer, the 19th- century British historian of sciences, the Greco-Roman heritage was built upon the great civilization of the Near Eastern achievements due to the scholars and artisans of Egypt and Syria. The pre-Islamic civilizations from Spain to Central Asia and northern India were inherited by Islam. Under the influence of Islam and the Arabic language; all scientific achievements of these regions have been

[33] SEZGIN 2001: 43-106.
[34] HILL 1994: 25–43.
[35] SARTON 1975: 510.
[36] SALIBA 2007:193–232.
[37] SARTON 1975: 510.
[38] HILL 1978: 222–37.
[39] SARTON 1975: 510.
[40] ALǦAZARĪ & et ALL -ḤASSAN (ed.) 1979: 49.

developed and improved [41]. Hence, the influence of Muslim mechanical engineering on the development of European machine technology can be verified by examining the antecedents of a single machine[42]. This indicates that the ideas of Muslim engineers in fine technology in general, and particularly the utilitarian inventions of *al- Ǧazarī* were transmitted to the West[43].

Here, we shall ask about the routes from which Muslim scientific ideas reached Europe, Muslim Christian Spain was the first entry point, and from there directly to northern Europe [44]. The second entry point for Muslim sciences to Europe was Sicily when it was part of the Muslim Empire, due to its proximity to mainland Italy. An additional way for transferring Muslim sciences and technologies to Europe was the crusaders, through their stay in the Near East, for they were admired with technological ideas and transferred them to Europe[45]. Furthermore, the translation movement which commenced in the 6th century AH/ 12th century AD greatly benefited from the collaboration of Muslim, Jewish and Christian scholars, as it facilitated the transfer of technological ideas, and intensely motivated the scientific evolution in Europe[46]. Though, there is no evidence that the Islamic treatises in fine technology ever translated into any European language before modern times[47].

Some researchers had, incorrectly, assumed that Arabian mechanical technology was based on aesthetic pleasure devices[48]. Nevertheless, contemporary historians of technology had stated that precise components of the ingenious devices of the *Banū Mūsā* and *al- Ǧazarī* and their practical functions became the core stone for the development of European mechanical technology and the entire industrial evolution[49]. One of the most important components used by *Banū Mūsā* was conical valves since the 3rd century AH/ 9th century AD[50], which first appeared in Europe in the notebooks of *Leonardo da Vinci*[51]. Remarkable mechanical water clocks of *Banū Mūsā*; their identical samples had entered Europe later in the mid of the 6th and 7th centuries AH/ 12th and 13th

[41] AL-ḤASSAN & HILL 1986: 31-34.
[42] HILL 1994: 25–43.
[43] CIGOLA & GALLOZZI 2000: 335–40.
[44] HILL 1994: 25–43.
[45] AL-ḤASSAN 2005: 1–30.
[46] ROMDHANE & ZEGHLOUL 2010:1–22.
[47] HILL 1993: 229-235.
[48] ALǦAZARĪ & AL-ḤASSAN (ed.) 1979: 50.
[49] DE SOLLA PRICE & HILL 1975: 81–83; SEZGIN 2001:43-106
[50] WIEDEMANN 1906: 6-8
[51] Leonardo da Vinci is an Italian painter, sculptor, architect, and engineer who lived through the 2nd half of the 15th century A.D and the 1st half of the 16th century A.D (1452-1519A.D). His painting known as *Mona Lisa* (*c.* 1503–19) is among the most widely popular of the Renaissance. His notebooks reveal that he had advanced mechanical ingenuity preceding his time.
FARAGO 1999: 70–76, 230–59.

centuries AD. Reaching medieval Europe, all of these Muslim mechanical techniques were further stimulated by the craft leagues[52].

Furthermore, the achievements of *al- Ǧazarī* are another superb ring among the Arabian mechanical engineering chain. He was the innovator of mechanic and hydraulic mechanisms that are still affecting contemporary mechanical engineering[53]. His book is briefly entitled *«kitāb al-Hiyal»* was one of the sources that might have influenced *Leonardo da Vinci* in building some of his clocks[54], this besides a phlebotomy measuring instrument and the slot-rod pump that has been reconstructed by modern craftsmen using instructions of *al- Ǧazarī*[55].

In later epochs, several prototypes of *al- Ǧazarī's* mechanisms had been built[56]. Of these the mechanical man - robot- from metal, wax, glass, and leather constructed by the German theologian Albertus Magnus[57], in the 7th century AH/ 13th century AD. Thus, such a sample gives a positive image of the advance of automation in Europe[58]. Another sample is a mechanical clock in Padua dated back to 765 AH/ 1364, attributed to *Giovani de Dondi*[59]. This was a true mechanical clock with weight drive, linkwork to show all the astronomical motions, a fully automated calendar showing Easter and other holy days, and a little dial for telling the time[60]. Further simulated samples are recent imitations of mechanical clocks of *al- Ǧazarī,* which were on display during the *World of Islam Festival* in England in 1976 AD.[61] The first was a monumental water clock, which is now exhibited in Aston in the Netherlands. Other prototypes can be seen in Frankfurt, Germany and Aleppo, Syria. A full-scale prototype can also be seen in a mall in Dubai [62].

Conclusively, Muslim scientists had inherited all the sciences and technologies of the pre-Islamic civilizations in the Near East and all the lands, extending from Central Asia and northern India to Spain. All these sciences and technologies had been notably

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52 SEZGIN 2001:107-298, SEZGIN 2006:185–98.

53 HILL 1978: 233.

54 ROSHEIM 2016:117.

55 HILL 1993: 112–40.

56 ROMDHANE & ZEGHLOUL 2010: 1–22.

57 Albertus Magnus is a German philosopher, theologian, scientist, and writer of the 13th century A.D. He was called doctor Universalis for the great breadth of his knowledge. He studied liberal arts at the University of Padua.
SHAMPO & ROBERT 1985: 530.

58 DE SOLLA PRICE 1964: 9–23.

59 Giovanni de Dondi was an Italian physician, astronomer and mechanical engineer in Padua, now in Italy, who was born in 1330 A.D. He was particularly famed for his elaborate astronomical clock which he designed and spent sixteen years constructing, completing it in 1364 A.D
BEDINI & MADDISON 1966: 1-69.

60 UNGERER 1931: 163–65.

61 The World of Islam Festival is a unique cultural event that attempts to present one civilization to another. It included several exhibitions from more than 30 countries. One major exhibition, the first of its kind ever held, was on "Science and Technology in Islam".
SABINI & KEEN 1976: 2–4.

62 ROMDHANE & ZEGHLOUL 2010: 1–22.

improved due to the intensive consideration of the Muslim rulers[63]. Concurrently to the maturity of technological sciences in Islamic civilization, Europeans were still beginners[64].

Unfortunately, despite multiple indications to the favor of Arab-Islamic civilization in providing Europe with the basics of its scientific and technological advance, the majority of contemporary writings of the Westerners hardly acknowledged[65].

IV. MUSLIMS' AUTOMATA MECHANISMS ACCORDING TO MINIATURES OF «*KITĀB AL-HIYAL*»

The 1st miniature: A musical robotic band on a boat during a drinking party (4th chapter of the 2nd category), [FIGURES 4, 5, 6]

This device looked like a wooden boat with a domed platform on the stem. This boat was designed to float on a lake's surface to entertain guests during royal drinking parties. A seated figure of a king, made of paper mâché, is on the platform, his chamberlain «*ḥājib*» standing to his right-hand side, while his weapon- bearer standing to the left side. Before the king's figure is a slave holding a jug and a goblet. Figures of boon companions of paper mâché, as well, are shown seated to the left and right sides.

On the opposite side of the king is a platform, where four automated figures of paper mâché resembling musicians, two drummers, a harpist and a flutist, are seated. Behind the platform is a sailor holding the boat's rudder. Another sailor is standing on the boat's upper side holding an oar [66].

The core mechanism of this device is a rotating cylindrical beam with protruding pegs; these just bump into little levers operating the beating. The point of the model is to demonstrate that different rhythms and drum patterns could be originated by the drummer if the pegs are moved around [67]. The device is composed to perform a specific action; all musicians play their instruments, and then all of them get silent. This was to be repeated about fifteen times at intervals of about half an hour.

The movement of the hands of the slave girls and the instrument responsible for the flute's sound is a copper reservoir forming the platform, over which the slave girls are seated, and behind them is an inlet hole for the water. A tipping bucket is made, with a trough beneath it, where both are placed under the reservoir towards the boat's central part over a stable base. Beneath the reservoir's outlet is an axle in a crosswise direction.

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63 AL-HASSAN 2005: 1–30.
64 SINGER & AL. 1979: 756.
65 CIGOLA & GALLOZZI 2000: 335–40.
66 AL-ĞAZARĪ 1485: FOLIOS 16-19.
67 ÖREN 2001: 63–70.

A scoop wheel with a trough, beneath it, is fitted to the right end of this axle. Water discharges from a pipe in the tipping bucket's trough over the scoops of the wheel. The reservoir's bottom is perforated to let water dripp into the tipping bucket until it gets full, and then, all the water is discharged into the underneath trough. In the next step, water was drained out from the trough, through a pipe, and falls onto the wheel's scoops. Water has been collected on the trough beneath the scoop wheel and flows from it, through a narrow pipe, into a vessel. This vessel is made for the whistle, having a siphon and a pipe terminated with a whistling ball placed in the flute-playing slave-girl. Water discharged from this vessel was collectedon the boat's floor[68].

The platform, where the figures of the four slave girls (flutist, harpist, and two tambourine players) are seated, had been perforated. Parallel holes were vertically applied in the reservoir's floor. A piece of pipe was inserted in each hole, with their ends soldered to the reservoir's roof and floor as well. The pipe with the flute's ball is inserted into the hole beneath the flutist, the ball enters the hollow in the flautist, who is placed in position and soldered to the platform, the sound issues from her sleeve. The right hand and forearm of the tambourine-player moves about an axle whose ends are fixed in her sleeve. At its end is a hole where a copper rod «*shaẓīya*» with a ring-shaped end was inserted and moves in the hole at the end of the forearm. The rod's other end goes through the hole under the tambourine player below the platform, so close to the scoop wheel's axle. Then the rod's end is bent right in the axle'sdirection. A short peg is fitted to the axle, thus when the scoop-wheel rotates, the peg's end comes down to the bent-up end of the rod for the hand and presses it down causingthe hands move up and down. The other tambourine player is made similarly.

The harpist is made, like others, of jointed copper, in which the harp is placed vertically on the player's left thigh. The player's both hands are constructed to move with the fingers over the strings without touching them. A hole with a hanging down rod is applied in the extension of each forearm, similar to the tambourine player's rod. The two rods go down through a pipe underneath the harpist. For the movement of the right hand; three pegs, similar to the one fitted for the tambourine player's hand, are fitted to the axle. A board is installed behind all the rods descending from the slave-girls to prevent them from falling backward.

Thus, the logic sequence of this device working was beginning when the water reservoir, the slave-girls' platform as well, was filled with water; this drips from the reservoir's underside into the tipping bucket. The bucket gets filled with water in about half an hour, thus discharging water into the trough. As a result, water flows onto the wheel's scoops and thus the wheel turns. As a result, the pegs move the rods hanging

[68] AL-ĞAZARĪ 1485: FOLIOS 16 -19.

down from the slave-girls' hands. The water is sucked down into the pipe which connects the wheel's trough to the whistle's vessel, displacing the air from the vessel to within the whistle's ball. When the vessel is full, and the water has risen above the siphon, it flows out into the vessel's bottom, whence it returned to the reservoir the next day **[FIGURE 6]**[69]. Such a device is the first known automated musical band. Accordingly, *al- Ğazarī's* musical boat system is an inspiration for a musical robot live- coding system bearing his name[70].

The 2nd Miniature: A Pitcher for Wine (10th Chapter from the 2nd Category), [FIGURE 7].

The ingenious device discussed here is an automated drinking machine that was exploited by the rulers and the elites during parties. It is composed of a wooden cupboard with two brass leaves. Within the cupboard is a hollow papier-mâché figure of a slave girl grasping a glass and a towel while standing over a board with four rollers of cast- bronze fitted on axles cross-wise in slots at the board's corners.

At the same width of the cupboard, a copper reservoir, with an upper hole for pouring wine, is attached. Below the reservoir is a trough with a tipping bucket. The reservoir's floor was pierced, and a short pipe had been attached. Hence, the wine drips into the bucket, which in turn was pierced in its bottom and a short pipe is attached vertically to the board, so the wine is poured within the glass grasped by the slave-girl while inside the cupboard.

The mechanism of this device is based on the moving of the slave-girl's hands; the right hand grasps a wine glass, and in her elbow is an axle that is responsible for the elbow's move up and down. A rod is penetrating the slave-girl's back, causing it to be pushed back within the cupboard, because its -slave-girls'- weight with an empty glass is lighter than the bent-down angle of the rod. However, when a determined quantity of wine (or water) is poured into the glass, the slave-girl's weight became heavier than the rod, and thus, the angle lifts off the bar. The slave- girl runs rapidly towards the cupboard's door. As a result, the wooden leaves open; the slave-girl's figure emerges at intervals, about an eighth of an hour, while bearing a cup of wine in its right hand, and a small towel (*mandīl*) in her left hand. The king takes the cup and drinks the wine included, and then he puts the cup back into the slave's hand. In addition, he can use a small towel to clean his mouth, if he wishes, and then closes the wooden leaves. The same steps are repeated at equal intervals[71].

[69] AL-ĞAZARĪ 1206: FOLIOS 69-71, AL-ĞAZARĪ 1485: FOLIOS 16 -19.
[70] DIMAROGONAS 2001: 14.
[71] AL-ĞAZARĪ 1273: FOLIO [N.K], AL-ĞAZARĪ 1485: FOLIOS 35-38.

The 3rd Miniature: A Peacock-Shaped Hand Washing Device (9th Chapter from the 3rd Category), [FIGURES 8, 9]

The main occupation of this ingenious device is to work as a robotic machine for washing hands or performing ritual ablutions. Its performance is based on the peacock pouring a little amount of water from its beak on the master's hands.

This device is composed of a brass wide based basin resting on a pedestal. The basin's base is divided into two equal parts; one of which is equipped with four columns; two are attached to the basin's center; however, the other ones are supporting the basin's square corners. The right-hand column had been perforated and a tube was inserted, which -in turn- penetrates the basin's floor to discharge water away. The columns' upper edges are topped by a rectangular castle, its frontal side had been penetrated by two adjoining doors, each with two leaves moving on hinges. Behind the right-hand door, is a hollowed figure of a slave made of jointed copper. The slave figure is shown standing on an axle above the castle's floor, and holding a jar containing saltwort (*ūshnān*)[72]. An arrow is fixed rigidly to the axle, reaching to the topmost of the right-hand column, which had an opening to discharging water. The slave is slanted towards his rear, while bearing the jar behind the door leaves being locked. The castle's floor is perforated and connected with the columns' hollowed part reaching its foot. Thus, if the rod rises from the column; this will upraise the bar's end, which in turn slopes the slave forwards. As a result, the slave pushes the door leaves with the jar he is holding, thus, the door leaves open and the slave emerges, hence, the master could take what he needs.

The castle's left-hand door, similar to the right one, had a slave standing on an axle's attached bar, the end of which extends to the central point of the other, non-penetrated, column on the edge. Thus, a hole had been made in the castle's floor, which goes through into the column's hollowed core. If the end of a rod rises from the column's top; it will raise the bar's end, thus, tilting the slave forwards. As a result, the slave's hands which hold the small towel -for the master to dry his hands- open the door leaves, and the slave emerges out of the door [**FIGURE 8**][73].

The device's main basin is resting on a pedestal soldered beneath the four columns. This pedestal had been perforated with two holes; through the basin's floor into the two columns' hollowed cores. On the pedestal's floor is an average sized float with a vertical jar- shaped chamber, vertically beneath the column with the aperture in its foot. Then a light rod is fixed vertically to the float's top part. When water is poured into the basin's

[72] *Ūshnān* is a type of tree that is planted in sandy soils; used in washing both clothes and hands, useful for curing some dermal diseases such as itch. In addition, «*tā'shan*» means washed hands.
AL-FAIRŪZ ABADĪ 2008: 57-8.

[73] AL-ǦAZARĪ 1273: FOLIO [N.K].

floor; it flows out from the basin's floor hole into the float's chamber, causing it to rise, until the rod lifts the outermost part of the axle's bar, which tilts the slave, thus, opening the door leaves.

On the castle's roof, a hollow, big-sized peacock of jointed copper is standing, its neck curved down from its center to its lower end. Both beak and head are somewhat lower than their belly. The peacock's neck is penetrated, and a narrow siphon is inserted. The siphon's tip is on the peacock's back, while the other tip is on the floor of the peacock's belly. An opening is made between the cavity in the tail and that cavity in the peacock. Thus, if water was poured into the uppermost of the tail, it will flow inside the peacock's body. The tail is divided, vertically, by a thin plate into two parts (chambers), so when water was poured into the tail's uppermost, it will be filled since the water has no outlet. In the center of the dividing plate is a hole with a ground valve and awatertight is made. The plug goes down into the seat from above. On the plug is a rising rod, the end of which is bent towards the back of the tail, which had a ring that moves upwards firmly in a narrow slit. The tail's uppermost part has a wide opening to pour water. When water filled the peacock's body and half of its tail; water rises through the ground valve. Until now, the water has not reached the bent part of the siphon in the peacock's neck, but is slightly below it. Though, when the ring is pulled up, the valve is opened, thus, water in the tail's lower chamber is mixed with that in the upper one. Thus, the water rises above the bend in the siphon.

When the basin is needed, the real servant places it in front of his master, he pulls the ring quickly, and thus water flows from the peacock's beak onto the master's hands. The water flows and runs out from the opening in the perforated column on the basin's edge and fills the float's chamber. As a result, the float itself is raised, the rod is raised as well, the bar on which the slave stands to be raised, as a result, the slave bearing the jar with saltwort (*ūshnān*) comes out of the doors, the master takes what he needs, and performs his ritual ablution. When the rest of the water runs from the basin's floor down to the pedestal, the pedestal in turn became almost full; the second float has risen and in turn rises the axle's bar where the other slave, holding the towel, standing. Thus, the slave slopes, opens the leaves and emerges from the door **[FIGURE 9]**[74].

[74] AL-ĞAZARĪ 1206: FOLIOS 98-100, AL- ĞAZARĪ 1485: FOLIOS 60-65.

The 4th Miniature: A Hand Washing Automaton with Flush Mechanism (10th Chapter from the 3rd Category), [FIGURES10, 11].

This ingenious device was to work as a robotic machine for washing hands or to performing ritual ablutions. This device is composed of a square- shaped stage «*kursī*» of brass with a kneeling slave holding a brass pitcher in his right hand, while catching a towel and a comb in his left hand. On the stage's «*kursī*» corners, four columns are supporting a castle thoroughly soldered and serving as a tank. This castle is crowned by a dome and a standing bird on. Adjacent to the stage «*kursī*», directly under the pitcher, is a half basin, the floor of which is occupied by a handsome crouching duck, with neck raised, then bent down to the middle, thus its beak touches the basin's floor. A narrow siphon is inserted in the duck's neck, one tip of the siphon is in the bird's beak, while the other tip goes along its rear through the basin's side into the stage's «*kursī*» cavity, and then brought down lower than the basin's floor. The device had two valves one on top of the castle, and the other on the stage's «*kursī*» foot.

The mechanism of this device is as follows; when the master needs to wash his hands or perform his ritual ablution, the real servant brings this device in front of the master. The servant opens the castle's upper valve, and the water descends from the pipe and flows down to the pitcher, and the air into the pitcher is driven out through the other pipe. Thus, the ball whistles giving the impression that the sound comes from the bird's beak. Water flows from the pitcher's spout until the master performs his ritual ablution. Thus, the water accumulated on the basin's floor, and thus drunk by the crouching duck. Furthermore, the slave stretches his left a hand with towel and comb toward the master [**FIGURE 10**].

Concerning the mechanism of the whistle and the calculated time of pouring water; the pitcher is divided vertically into two chambers and sealed with a plate on its top. Below the pitcher's handle; there are two holes with jointed pipes. One pipe goes from the handle through the slave's palm into his upper arm, where a whistle's ball is fixed in its end, and topped with three columns, the castle, the dome, and the bird topping it. The other pipe, which was responsible for calculating time, was fitted through the slave's palm and bent down at his elbow, and then bent down his skirt along the stage «*kursī*». Again, the pipe rises through the castle's right-hand column. The valve's upper tip and its plug go up to the castle's top. At the spout's place is a hole, in which the siphon's end is inserted to touch the plate dividing the pitcher.

On the castle's floor a pipe is fixed, which goes down through the right-hand column behind the slave. This pipe is turned under the stage's «*kursī*» deck and rises within the slave's hollowed center. Its end is connected to the pipe's terminal, which comes up from the pitcher's handle and goes through the slave's palm and sleeve. Then a float is made, with a staple fixed in its upper circle, linked to a rope. This float is placed on the stage's «*kursī*» floor, with a hole in the deck below the staple in the extension of the slave's left arm. When the float rests on the stage's floor; its weight pulls the extension of the slave's elbow and lifts his hand with the towel and the comb. However, when water runs into the stage «*kursī*», the float rises and thus, the slave's hand sinks [FIGURE 11][75]. When the master finishes using them, he put them back on the slave's left hand. Finally, the real servant takes the basin away, and opens the side tap toextract water that had been drunk by the duck[76].

V. HISTORICAL AND ARTISTIC ANALYSIS FOR THE PUBLICATION OF «*KITĀB AL-HIYAL*»

Author's Biography

He is *al-Sheikh Rais al-ʿūmāl Badiiʿ al-Zamān Abu al-ʿIzz ibn Ismaʿil ibn ar-Razzāz al-Ǧazarī"*[77], He lived most of his life away from his homeland in *Diyarbakir* in upper *Mesopotamia,*[78]since the 2nd half of the 6th century AH/ 2nd half of the 12th century AD. He was called *al- Ǧazarī* due to his residence on an island '*ğazīrah*' between *Tigris* and *Euphrates* rivers. He was in the service of *Artuqid* rulers in *Diyarbakir* since *Nūr el-Dīn Mūḥammad ibn Arsilān* (570 -581 AH/ 1174- 1185 AD), then *Qūtb el-Dīn Sakman ibn Mūḥammad* who took control over *Diyarbakir* from 581- 597AH/ 1185 - 1200 AD, and later under the control of *el-Malik el-Ṣāliḥ Nāṣir al-Dīn Abu'l Fatḥ Maḥmud b. Muḥammad b. Qara Arslān b. Daud b. Sukmān b. Artuq* who ruled from 597 to 619 AH/ 1200 to 1222/3 AD[79] *Al- Ǧazarī* worked on his book «*Al- Jāmiʿbyna al-ʿilm wā al-ʿamal al-nafiaʿ fī Ṣināʿat al-ḥiyal*» by request of *Nasir el-Dīn Maḥmūd*. According to Oxford's manuscript, he accomplished it after about seven years; on the 4th of *Jūmādah al-Ãkhirah* 602 AH/ 16th of January 1206 AD. Nevertheless, it was recorded that his experience in mechanical engineering started from 571 AH/1175 AD, and basically in inventing and building mechanisms. Hence, he is the most famous mechanical engineer from the pre-medieval era.

Scientific Standing of «*kitāb al-Hiyal*»

This book known as «*Al- Jāmiʿ byna al-ʿ ilm wā al-ʿ amal al-nafiaʿ fī Ṣināʿ at al-ḥiyal*» presents a wide variety of ingenious devices and mechanisms employed for different purposes. Though, these devices' main objective, was sometimes, limited to amusement;they were skillfully modeled with delicate mechanisms, and highly precise controlsystems[80].

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75 AL- ǦAZARĪ 1485: FOLIOS 65-68.
76 AL-ǦAZARĪ 1206: FOLIOS 100-102.
77 ROMDHANE & ZEGHLOUL 2010: 1–22.
78 *Diyarbakir* was located in upper *Mesopotamia,* on the western branch of the *Tigris* river, now in southern Turkey. Anciently, it was called *'Āmid';* the walls of which were a marvelous calligraphic museum. ALǦAZARĪ & AL-ḤASSAN (ED.)1979: 37.
79 *Artiquid* dynasty is attributed to *Artuq ibn Aksab al-Turkumani*, one of the slaves of *Suljuq* sultan *Malikshah*, who took over control of Jerusalem after being conquered by *Suljuq* commander *Tech.* ALǦAZARĪ & AL-ḤASSAN (ED.)1979: 36.
80 ROMDHANE & ZEGHLOUL 2010: 1–22.

The Arabic word «*al- ḥiyal*» when used in a mechanical field almost refers to special sort of mechanisms; basically, those meant to bestow pleasure and amusement for the rulers and the elites. Although some of these devices were released as being insignificant, many of the ideas and components embodied in them had greatly contributedin to improving modern technologies[81]. The work of *al- Ğazarī* is the head of Muslims' achievements and deserves to be designated as the prior valid study in systematic machinery design[82]. This manuscript included 50 different devices, which can be concluded into six types, these are; different clocks, Automata vessels, water dispensers, fountains and musical automata, water-raising machines, besides other miscellaneous machines[83]. Mainly fountains and musical automata devices were designed by using several hydraulic switching techniques. Under these revolutionary devices, *al-Ğazarī* owed the title of 'the father of robotics'[84]. This book had been translated several times since the first quarter of the 14th century AH/20th AD, however, the most known translation is by Donald Hill in 1974, entitled «The Book of Knowledge of Ingenious Mechanical Devices» [85].

Historical Analyses for the Publication of «*kitāb al-Hiyal*»

Numerous copies of «*kitāb al-Hiyal*» are conserved in several museums worldwide, until 1979 AD there were about 15 copies. They are varied in date; from the 6th century AH/ 12th century AD to later ones of the 12th century AH/ 18th century AD. Another dissimilarity between these copies is their status, whether, complete or incomplete, in good, moderate or bad status, etc. Though, there are about six copies of extreme significance, these are to be described in detail as follows;

1. Top Kapi in Istanbul (*Aḥmad III* Nº. 3472)

It is the oldest known copy, which had been transcribed probably in 602 AH/ 1206 AD. The manuscript's folios are numbered in a later time technique from 1 to 356. It includes folios with both scripts and printings of styles more recent than the original ones. Nonetheless, such recent paintings are of minor artistic mastery than the original ones. New folios are about 11 making 22 sheets. This manuscript had been ended with a text referring that it was copied by *Mūḥammad ibn Ūthman al-Ḥaškafī* from an earlier copy of the original manuscript. However, figures, shapes and symbols of the copy earlier than that of *al-Ḥaškafī* had been prepared by *al-Ğazarī* -may God bless his soul- himself.

[81] AL-ḤASSAN & HILL 1986: 59–60.
[82] DIMAROGONAS 2001: 14.
[83] ROMDHANE & ZEGHLOUL 2010: 1–22.
[84] NOCKS 2007:152–55.
[85] ROMDHANE & ZEGHLOUL 2010: 1–22.

It could be stated that this copy is the best, although not void of faults; it is almost complete in good calligraphy and fine paintings [86]. Thanks to the institute of Arabian scientific heritage- *Ḥalb* University in Syria for microfilming this precious manuscript[87], and indexing it as **Nº**. 1739[88].

2. A Copy Dated back to 715 AH/ 1315 AD

This was once thought to be an incomplete copy; however, it was realized later that two-thirds of the original copy had been sold in an auction in London in 1978 AD. This copy was documented to be transcribed in *Ramadan* 715 AH/ December 1315 AD by the scribe *Farkh ibn ʿ Abd el-Latīf*. Due to its date, this may be the 2nd or the 3rd in order from oldest to most recent copies. Despite being incomplete and having comprised some incorrectly spelled words; it is designated as one of the best copies; with a good script and fine paintings[89].

3. *Hagia Sophia «Ayasofya»* Manuscript Nº. 3606

This is one of the oldest copies of « *kitāb al-ḥiyal*». It had been transcribed in 755 AH/ 1354 AD. Historians of Islamic arts have considered it the best. Unfortunately, several paintings had been lost, and sold separately all-over diverse museums of arts. Furthermore, the transcript in no less than 17 parts is lost either. Nonetheless, it is still believed to be one of the best copies.

4. *Top Kapi Sarai* Istanbul, Manuscript Bookcase Nº. 414

This copy had raised a great conflict in dating it. Several suggestions refer to 602 AH/1206 AD, but still doubtful, however, others dated it back to 672 AH/1273 AD. This copy was described to be composed of 175 folios. It is recently known to researchers, who classified it among the best outstanding copies, though about 10 to 12 sheets had been lost, while others had been shredded[90].

5. Bodleian Oxford, Graves manuscript Nº. 27

This is almost a complete copy in a good script and fine paintings, dated back to 891 AH/ 1486 AD. It is of recent date than previously mentioned copies, though, it is distinguished by the alphabetical letters used on numbering paintings, unlike previous copies where paintings had unclear symbols.

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[86] ALǦAZARĪ & AL-ḤASSAN (ED.)1979: 39- 45.
[87] AL-ǦAZARĪ 1206:1–365.
[88] ʿŪMAR 1986:72.
[89] ALǦAZARĪ & AL-ḤASSAN (ED.)1979: 40, 41.
[90] AL-ǦAZARĪ 1273: 1–175.

This copy had been used by two German physicists and historians of sciences, Eilhard Wiedemann and Fredrich Hauser, who had translated some chapters to Dutch in the 1st quarter of the 20th century AD. In addition, Donald Hill; the English engineer and historian of sciences and Technology had, as well, depended on this copy to produce the first complete and most famous translation of this valued manuscript of *al-Ğazarī* in the last quarter of the 20th century AD.

6. Paris National Library, Arabian manuscript Nº. 2477

This copy is dated back to 890 AH/ 1485 AD. It includes one chapter of *al-Ğazarī*'s book dealing with drinking sessions, besides, a part of the 6th type, though, unfortunately with no paintings. This copy is of a good script; however, its paintings are of moderate quality and had no symbols[91].

Artistic Analyses for the Publication of «*kitāb al-Hiyal*»

Painting is one of the main branches of Islamic Art. It has gained great fame and popularity due to its significance in depicting the social, economic, and cultural environment through consequent Islamic epochs, and in the vast regions of the Muslim Caliphate. Such paintings had been applied on walls, besides multiple types of manuscripts[92]. Paintings included in these manuscripts are known as «miniatures». These could be categorized into two types; one of them refers to the finely elaborated miniatures, employed to adorn literary books. The other type was the miniatures employed to explain the text in scientific books, these almost disregarded the artistic features, and thus came of lesser quality. The manuscript of «*kitāb al-ḥiyal*» for *al-Ğazarī* is one of the valuable scientific books with miniatures[93]. More specifically, this manuscript is of a type known as «automata miniatures», representing mechanical devices. Some art historians had attributed this type to the end of the 6th century AH/ 12th century AD. Though, others had assigned them to the mid of the 8th century AH/ 14th century AD accurately (752 - 755 AH/ 1351-1355 AD), and supposed them to be of Egyptian provenance[94]. Nevertheless, a 20th century scholar called Coomaraswamy managed to prove that the manuscript of «*kitāb al-ḥiyal*» for *al-Ğazarī* from the beginning of the 7th century AH/ 13th century AD is the initial sample for «automata miniatures»[95].

The original copy which had been granted to the *Artuqid* sultan in *Diyarbakir* was lost.

[91] ALĞAZARĪ & AL-ḤASSAN (ED.)1979: 41-45.
[92] BAHNASĪ 1986: 23.
[93] AL-BĀSHĀ1959: 92-4.
[94] RIEFSTAHL 1929: 206–15
[95] COOMARASWAMY 1924:1–21.

However, there are two indications that it was embellished with miniatures; the first is that later known copies were accompanied by miniatures, among which was a human figure accompanied by the name of *Sultan Nūr el-Dīn Mūḥammad* (1174- 1185). The second indication is the identity of the style of miniatures in all copies although they had been transcribed in different regions and through several epochs. This is probably due to the accuracy and honesty in transcribing [96].

Throughout the long history of the Islamic civilization; painting, like all other types of Islamic art, had passed through several stages. These can be divided into four technical schools; Arabian, Persian, Indian Mongolian, and Turkish, each with special features and diverse centers[97]. The manuscript of «*kitāb al-ḥiyal*» for *al-Ğazarī* is attributed to the Abbasid technical school in Iraq which is one of the main centers of the Arabian school of painting[98].

Paintings of the Arabian technical school are distinguished by several features; generally, the tendency towards unreal representations; neglecting the illustration of landscapes, disregarding the embodiment of varied depth, and giving great concern to human figures, which are presented modified. Additionally, Arabian paintings were simple, and frameless, with straight line-shaped ground and plain, almost gilded, backgrounds. Besides, multiple lustrous colors are employed in the numerous elements of the diverse paintings[99]. Human figures were characterized by Arabian facial features influenced by Byzantine and Syrian Christian features. Once the scene had a master figure; the Arabian artist used to draw attention to this figure by depicting it on a larger scale than others, and by lavishly adorning his costumes and all his equipment. In addition, Arabian paintings had been characterized by drawing halos around human heads, without any symbolism, but to strike the sight. Such haloes were sometimes applied around the heads of birds and variant vegetal ornaments as well[100]. Costumes were usually loose with broad sleeves adorned on upper arms with bands of calligraphy or diverse ornaments. Likewise, Costumes usually had folds applied in simple lines, in geometrical drawings, or in diverse shapes of vegetal ornaments, animals, spheres, crescents, or foliated Arabian decoration known as «*arabesque*».[101]

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[96] ḤASSAN 1955: 16-19.

[97] FARGHALĪ 1991:12.

[98] The Arabian school of painting is the earliest Islamic technical school of manuscripts with miniatures. It had been spread all over the Islamic world. Iraq was the pioneer center for manuscripts with miniatures according to artistic features of the Arabian technical school, these were produced in *Baghdad, Diyarbakir, and al-Mosul*. Other centers were Egypt and Syria during the Mamluk epoch. A later center was Iran during the *Seljukian* and *Mongol* epochs. Nevertheless, Baghdad was the best and the most important. It is worth mentioning that the earliest manuscripts bearing features of this Arabian technical school had been dated back to the end of the 6th century A.H/ 12th century A.D.
AL-BĀSHĀ 1959:125.

[99] AL-BĀSHĀ 1959: 128.

[100] ḤASSAN 1955: 16.

[101] Arabesque is an Islamic form of conventionalized vegetal ornaments composed of spiral or stylized waves and abstract elements. KHAZÂIE 2005: 27-50.

Other forms of costumes' folds were more complicated; in the shape of lines flowing from a central point, wavy lines, or gathering worms[102].

Despite being a technical treatise, miniatures of the book of *al Ğazarī* are of great artistic value. All illustrations had been superbly colored, and had great artistic virtue[103]. Though the multiplicity of copies and the distinction in quality between them; the researcher's attached plates have mainly relied on four copies; *Top Kapi* in Istanbul (*Aḥmad III* Nº. 3472) dated back to 602 AH/ 1206 AD **[FIGURES 5, 9, 11]**, the Copy dated back to 715 AH/ 1315 AD [**FIGURES 4, 8, 10**], *Hagia Sophia «Ayasofya»* manuscript Nº. 3606 dated back to 755 AH/ 1354 AD [**FIGURE 7**] and Paris National library (Arabian manuscript, Nº. 2477) dated back to 890 AH/ 1485AD [**FIGURE 6**].

Confining our analysis to bring forward the characteristics of the Arabian technical school of painting that are applied to the miniatures of «*kitāb al-Ḥiyal*», these are:

- Human figures in miniatures of «*kitāb al-Ḥiyal*» enclose Byzantine and Christian Syrian impacts which were widely known in *Diyarbakir* due to its historical and geographical circumstances [**FIGURERS 4, 7, 8, 10**].
- Costumes are loose, with wide sleeves adorned on the upper arm with plain bands [**FIGURE 4**], and others with diverse ornamented bands [**FIGURE 7**].
- Human heads are surrounded by haloes [**FIGURES 4, 7, 8, 10**].
- The paintings' background is plain [**FIGURES 4, 7, 8, 10**].
- Abstract vegetal ornaments «*Arabesque*» are applied in several locations; on the domed platform [**FIGURE 4**], on costumes [**FIGURE 7**], and on the domed castle of the stage [**FIGURE 10**].
- The master human figures in [**FIGURES 7, 10**] are depicted on a large scale thanother elements with lavishly adorned costumes.
- Costumes' folds are applied in a more real form; in the shape of lines flowing from acentral point [**FIGURE 10**].
- Water is depicted in a wavy form or gathering worms **[FIGURES 4, 5, 8, 9, 10, 11].**
- Miniatures are applied in lustrous multiple colors **[FIGURES 4, 7, 8, 10**].

Although several copies of «*kitāb al-Ḥiyal*» had not been transcribed in *Diyarbakir;* their miniatures are almost alike. In addition, all the copies are in strong relation with *Diyarbakir* features, which had been influenced by Byzantine and Christian Syrian features once spread in the North of *al- Ğazīrah* and Northern Syria[104]. In addition, the «automata miniatures» had a unique significance in their broad decorative conception, which qualified them to be among the most valuable remaining miniatures.

[102] AL-BĀSHĀ 1959: 127-9.
[103] ROMDHANE & ZEGHLOUL 2010: 1-22.
[104] COOMARASWAMY 1924: 1–21.

Generally, these miniatures' perfection reflects how supremacy was in the Islamic civilization at the end of the 6th century AH/ 12th century AD [105].

VI. CONCISE SCIENTIFIC ANALYSIS FOR THE CHOSEN AUTOMATA MECHANISMS

As mentioned before, this research paper's chief aim is to illuminate how the Muslims were so advanced in mechanical engineering since the medieval ages; known as the golden age for Islamic Civilization, and on the contrary, the Dark ones in Europe. No doubt, Muslim engineers had built most of their knowledge upon their predecessors, though; they were seniors in practical applications.

This paper focuses on four samples of automata' «self-moving» mechanisms, to demonstrate a link between these primary samples and their modern counterparts, taking into consideration, the difference according to the long distance of time. Furthermore, this point is intended to concisely reveal how these primary samples of automata mechanisms had produced innovative techniques, still employed – in a more advanced way- in several modern industries. Besides, these automata mechanisms presented numerous mechanical components of diverse duties that are still in use in modern industries.

Nevertheless, due to the complexity of the field of mechanical engineering to the non -specialists; the researcher had contented with a concise scientific survey on the mechanical techniques employed in automata mechanisms of *al- Ǧazarī,* as follows;

- In the device of the musical robotic band **[FIGURES 4, 5, 6]** *al- Ǧazarī* used hydraulic switching power, which is a system based on power transmission forces of liquids either static or dynamic. This became the base for modern hydraulic systems widely employed in modern industrial applications to transmit power from the prime mover to operate machine parts or vehicles. This system is widely employed in ship lock gates, movable bridges, agricultural equipment, etc [106].

- In his automated drinking device (a pitcher for wine), *al- Ǧazarī* used humanoid automata. This device's main mechanism is **[FIGURE 7]** a slave girl acting as a waitress, applied in a hollow human-shaped mobile robot, with a complex mechanical design for moving the arms with axles and bars attached to control their moving up and down. Recently, composing human-shaped robots have been developed and widely spread in all fields of modern industries.

[105] RIEFSTAHL 1929: 206–15.
[106] THEISSEN & MURRENHOFF 2014: 31-77.

Of these, science fiction and mass media finely exploited humanoid robots in advertisements. In addition, humanoid robots are used for research into the mechanics of walking and human-machine interaction[107].

- The peacock basin for washing hands **[FIGURES 8, 9]** had been working by the hydropower mechanism. This converts the power of falling water into mechanical energy. What is interesting here is that hydropower, which is also known as hydroelectric power, was introduced by *al- Ǧazarī* in the 7th century AH/ 13th century AD, became the most widely utilized form of renewable and clean energy later in areas with heavy rainfall and with mountainous regions in the 21st century[108].
- In the hand-washing automaton device used to perform the ritual ablution, *al- Ǧazarī* had presented another form of the humanoid automata, which had been mentioned before. In addition, *al- Ǧazarī* had invented a new superb technique, known as the« flush mechanism». It is worth mentioning that this technique is the core stone for modern flush toilets first known in the 10th century AH/ 16th century AD by the British Sir John Harington[109].

[107] WINFIELD 2012:112-130, BEN-ARI &MONDADA 2018:3-6.
[108] ALLERHAND 2020: 76–87.
[109] MCCLURE (ED.)1930: 1-58.

VII. CONCLUSION

This research paper adopted the assumption that automata mechanisms are not an invention of the West, undertaking the mission to prove that they are an outcome of the Islamic civilization. The main method was through the Arabic treatise of *Ibn al- Razzāz al- Ǧazarī* dated back to the 7th century AH/ 13th century AD in mechanical engineering, known briefly as «*kitāb al-Ḥiyal*». Although the Muslim scientists had been influenced by their predecessors; they had a head start in practical application, which was missing in robotic sciences before.

The treatise of *Ibn al-Razzāz al- Ǧazarī* included fifty devices; distributed into six categories. This research paper focused on only four automata mechanisms, recently simulated in diverse types and categories of industry, these are;

- A musical robotic band on a boat during drinking parties, which was an inspiration for a musical robot live-coding system bearing *al- Ǧazarī's* name.
- A pitcher for wine, recently simulated by automated mechanisms for drinks.
- A peacock basin for washing hands, simulated by recent and contemporary robotic mechanisms for washing hands.
- A hand-washing automaton with a flush mechanism to perform the ritual ablution. This had been recently the core stone for modern flush toilets.

Devices of *al- Ǧazarī,* his detailed description of how they work, and the attached illustrations testify that the automaton was not an innovation from the Western civilization. They are with no doubt a considerable achievement of Muslim civilization. Thus, the work of *al- Ǧazarī* deserves to be described as the senior real study in systematic machinery design. In addition, he owed the title of 'the father of robotics.

Conclusively, by the Muslim engineer *al- Ǧazarī* modern technology had superbly improved. Robotics became a key technology employed in assembling cars, moving goods, washing machines, etc. Furthermore, robotics became of a higher value when, recently, employed in health care in case of infectious diseases as what happened in China to face the Coronavirus pandemic widely known as Covid-19.

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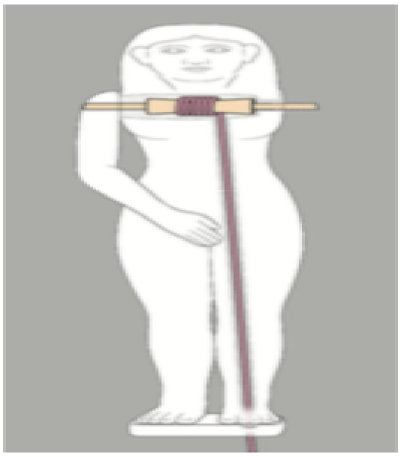
FIGURES

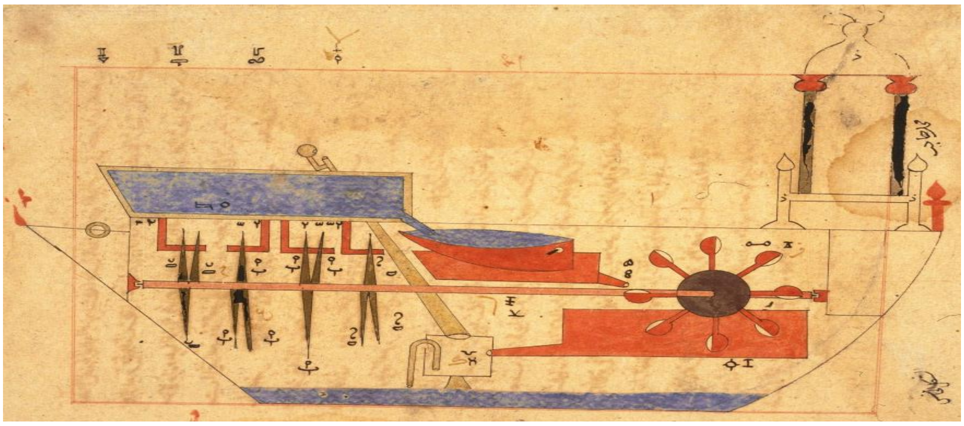
[FIGURE 1]: Female figure with internal mechanism. Egyptian, ca. 945–664 BC. Wood, The Metropolitan Museum of Art,
REEVES 2015: [FIGURE 1]

[FIGURE 2]: Female figure's right arm and the axle attached
REEVES 2015: [FIGURE 4]

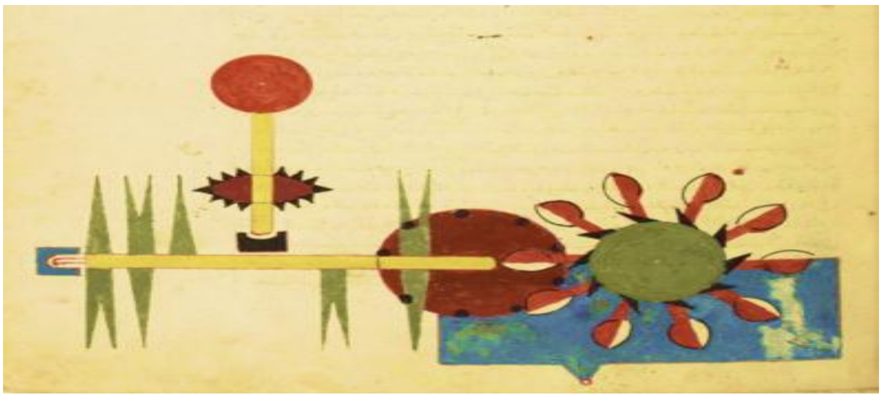


[FIGURE 3]: Diagram of figure1, Showing the operating mechanism (axle in beige, string in pink)
REEVES 2015: [FIGURE 6]

[FIGURE 4]: A wooden decked over boat. With a platform for the automated musical band
AL- ĞAZARĪ 1315: folio. [n.k] *Verso*
Smithsonian Gallery, Freer Gallery of Art and Arthur M. Sackler Gallery
Https://www.si.edu/object/folio-kitāb-fi-maarifat-al-hiyal-al-handisaya-book-knowledge-ingenious-mechanical-devices-automata%3Afsg_F1930.73 Accessed 21- 10- 2020



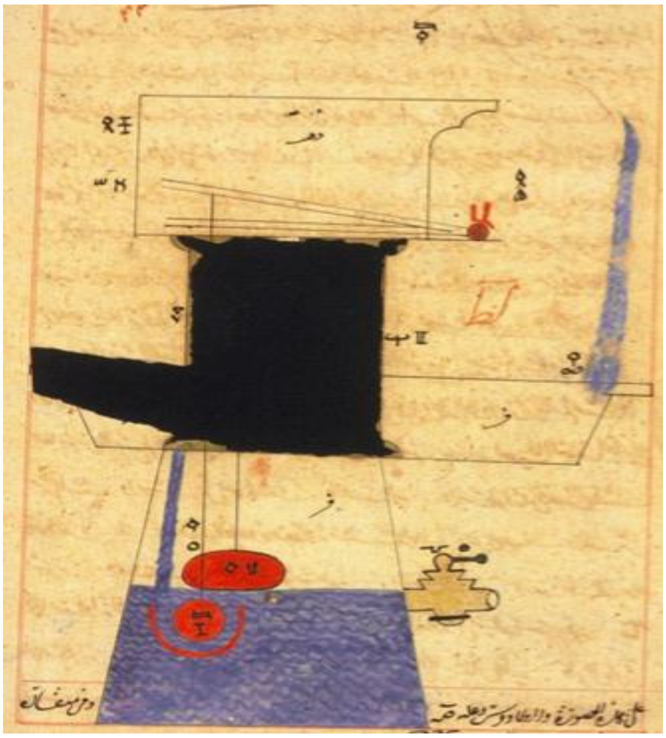
[FIGURE 5]: The automated musical band's boat; only displaying the boat and its mechanical functioning
AL- ĞAZARĪ 1206: Folio. 71. *Verso*



[FIGURE 6]: The cam mechanism
AL- ĞAZARĪ 1485: *Folio*. 14

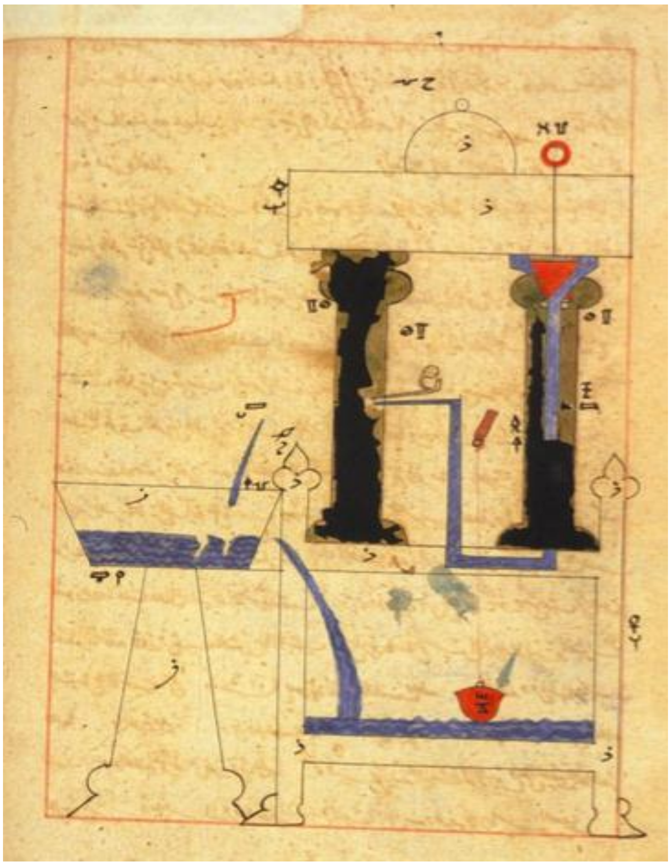
[FIGURE 7]: Illustration for A pitcher of wine
AL- ĞAZARĪ 1354: ***Folio [n.k] recto***
Harvard Art Museums/Arthur M. Sackler Museum, Bequest of Hervey E. Wetzel object
number.1919.138 Https://hvrd.art/o/216544 Accessed 17-10- 2020

[FIGURE 8]: A peacock basin for washing hands
AL- ĞAZARĪ 1315: Folio [n.k] ***recto***
https://www.clevelandart.org/art/1945.383 Accessed 20-10- 2020



[FIGURE 9]: A miniature for the peacock basin showing the float, the side tap, and the whole mechanism of the basin
AL- ĞAZARĪ 1206: Folio 99 *Verso*

[FIGURE 10]: A miniature for the mechanism of the hand washing automaton
AL- ĞAZARĪ 1315: *Folio [n.k] recto*
Smithsonian Gallery, Freer Gallery of Art and Arthur M. Sackler Gallery
https://www.si.edu/object/folio-kitāb-fi-ma-arifat-al-hiyal-al-handisaya-book-knowledge-ingenious-mechanical-devices-automata%3Afsg_F1930.75 Accessed 21- 10- 2020



[FIGURE 11]: **A miniature for the mechanism of the hand washing automaton**
AL- ĞAZARĪ 1206: ***Folio 101 Verso***

اسهامات الهندسة الميكانيكية الإسلامية في تطوير الآلات ذاتية الحركة
(في ضوء كتاب الحيل للجزري)
دراسة وصفية تحليلية

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الملخص

هل كان للعرب المسلمين قديما باع في علم الهندسة الميكانيكية؟ وهل كان لهم السبق على الغرب فى هذا المجال؟ من الملاحظ حاليا أن العرب والمسلمين فى شتى دول العالم –تقريباً– أصبحوا مجرد مستهلكون لما ينتجه الغرب فى شتى المجالات، نتيجة لما وصل اليه الغرب من تقدم وتطور تكنولوجى مستمر ومتنامى بسرعة فائقة. وهنا كان لابد لنا ان نتساءل هل كان العرب المسلمين على هذا الحال قديما؟ يقوم هذا البحث على اثبات فرضية أن العلماء المسلمين قد حققوا تقدماً كبيرا فى مجال الهندسة الميكانيكية، واستطاعوا ابتكار آلات ذاتية الحركة، والمعروفة حديثاً بـ «الأتمته». ووفقاً لذلك، كان الهدف الأساسي لهذا البحث هو إثبات صحة هذه الفرضية. يتناول هذا البحث بعض نماذج من الآلات ذاتية الحركة؛ وذلك من خلال كتاب «الجامع بين العلم والعمل النافع في معرفة الحيل الهندسية» لمؤلفه العالم المسلم الجزري. تضمن الكتاب – في الأصل مخطوط – وصف تفصيلي لهذه الآلات الميكانيكية ذاتية الحركة، وكيفية تنفيذها مشفوعا بالتصاوير الملونة المعروفة اصطلاحاً بـ «المنمنمات». تتكون خطة البحث من تمهيد يتناول التعريف بما يصطلح عليه التكنولوجيا الدقيقة والأتمته «الآلات ذاتية الحركة»، ويلى ذلك تاريخ الأتمته بدءا من العصور القديمة وحتى العصور الوسطى. كما سيتناول البحث إسهامات علماء المسلمين فى مجال الهندسة الميكانيكية بشكل عام، وفى مجال انتاج الآلات ذاتية الحركة بشكل خاص، مدعوما باستعراض نماذج للآلات ذاتية الحركة تم شرحها ضمن «كتاب الحيل». ويلى ذلك السيرة الذاتية للعالم المسلم اسماعيل بن الرزاز الملقب بـ «الجزري» ، بالإضافة إلى تحليل تاريخي وفني موجز عن المخطوط محل الدراسة. وفى النهاية سيتم عمل دراسة تحليلية للنماذج المختارة من الآلات ذاتية الحركة وعلاقتهم بالآلات الحديثة والصناعات التكنولوجية المتطورة. وفي المجمل واستنادا على «كتاب الحيل»، والذى يعود تاريخه للقرن ٧هـ/ ١٣م تمكن هذا البحث من التدليل على أن الآلات ذاتية الحركة ليست اختراعاً غربياً؛ بل هى نتاج الحضارة الإسلامية، ودليل ملموس على مدى تفوقهم فى مجال الهندسة الميكانيكية منذ العصور الوسطى.

الكلمات الدالة: الهندسة الميكانيكية، الأتمته، المنمنمات، مخطوط، الحضارة الإسلامية، الجزرى، كتاب الحيل.