Prehistory of Musical Robots

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This article presents a review of musical automata from classical antiquity to the 19th century. It is intended to extend existing surveys of musical robots, and provide a long view of challenges and research approaches in the field. It is also intended to provide resources for the further study of these automata, and to clarify some commonly perpetuated misunderstandings; consequently it summarizes primary sources, providing as little historical narrativization as is necessary for readability.

Keywords: musical robots, history, automaton, android

1. Introduction

Interaction between musicians while playing is rich, subtle, and idiosyncratic; mimicking this behaviour with machines presents many novel challenges. In recent decades, musical robotics has emerged as a niche subfield within HRI aimed at studying these particular challenges. Overviews of some important approaches have been compiled (Kapur, 2005)(Solis & Takanishi, 2007). However, this is not a new subfield. On the contrary, the turn towards *interactivity* is only the most recent development in a tradition of making automated musical instruments which is thousands of years old. Nor has this line of thought been frivolous; this research has always had in important voice in the scientific conversation. The unique challenges associated with playing music has often lead to important developments in engineering. Consequently, early musical automata are often cited in histories of programmable machines; histories of humanoid and biomimetic robots; of certain types of actuators; and of the relationships between technology and society. An overview of the long history of musical automata helps contextualize current work in the field, and helps pinpoint those research approaches which could not have been explored before today.

2. Greek Antiquity and the Islamic Golden Age

The first attempt to mechanize a musical instrument is no doubt lost to history. By the 4th century BCE there already existed sophisticated mechanically wind-fed organs in advanced stages of development, and at that point the practice was probably centuries old (Farmer, 1931); the earliest ones probably operated by means of mechanical bellows. The ancient history of mechanical instruments is probably even older still, if we consider predecessors to the organ, such as the bagpipes or aeolian

Journal of Human-Robot Interaction, Vol. 1, No. 1, 2012, Pages 78-95. DOI 10.5898/JHRI.1.1.Tanaka

harp, to be 'mechanically' wind-fed. In the first few centuries BCE, the Greeks laid the foundations for the fields of Hydrostatics, Pneumatics, and Hydraulics, which together provided more sophisticated means of supplying energy to a wide variety mechanical devices, including musical automata. One very famous example from the 1st Century AD, is the altar organ in Section 77 of Hero's *Pneumatica* (of Alexandria, n.d.), which is fed air via a windmill-driven piston, although a human would then presumably finger the organ. In the middle of the 1st millennium AD, scholars in the Middle East (such as the Banu Musa in Bagdad) began importing and translating these and other scientific manuscripts from all over the world. In the following centuries, while the Dark Ages consumed Europe, the techniques of building all manner of mechanical device, including mechanical musical instruments, flourished in the Middle East. A complete history of the organ, or mechanical instruments generally, will be out of scope for the present paper. However, even in these very early times, there developed a tradition of building *humanoid* musical automata, which, although functionally identical to non-humanoid mechanical instruments, nonetheless betray a slightly different way of thinking about such devices. These humanoids are perhaps worthy of separate consideration, and shall form the bulk of the following discussion.

2.1 Archimedes

In the 3rd century BCE, Archimedes, the father of hydrostatics, invented the first known humanoid musical automaton. Although his original treatise does not survive, his ideas are preserved in later Arabic translations (Archimedes & Apollonius, n.d.)(Archimedes, 1976). This treatise describes a very large and elaborate clepsydra (water clock). The basic premise of a water clock is that water will drain from a tap in the bottom of a cistern at an even rate until the cistern is empty, and this can be used to mark the passage of time. In principle, time could be measured with a simple graduated cistern. In practice, however, the kinetic energy in the water falling from the cistern was used to power complex mechanical devices which show the passage of time. In Archimedes' clock the falling water drives a water-wheel which moves an figurine of an executioner with a sword slowly forward along a track, past figurines of several fettered prisoners with hinged heads. Every canonical hour, the executioner knocks the head off one of the prisoners, so the time may be read by counting the beheaded figurines. This clock contains many other elaborate devices including that shown in Figure 1(a). This is a humanoid figurine holding a Byzantine whistle, which is connected via a pipe to a large vessel with two chambers. The upper chamber is connected to the lower chamber via a cylindrical syphon. After water falls through the other mechanisms in the clock, it is collected in the top chamber of the cistern. Once the water in that chamber has reached the top of the siphon, which will take 12 canonical hours, the water will be syphoned into the lower chamber. As that happens, the air in the lower chamber is expelled out through the tube and, subsequently, the whistle. This results in a loud whistling sound that, according to the author, can be heard from a 'considerable distance'. The whistle signals that the clock's main water reservoir is empty, and must be manually refilled with the water which is now at the bottom of the flute cistern.

It is worth noting that this treatise also contains a description of a fake tree with mechanical birds that have Byzantine whistles hidden inside them, which operate on the same principle. Mechanical birds have their own history, which perhaps culminates in the Parisian music-boxes of the 19th century, although they will not be discussed further in the present history.

2.2 Hero of Alexandria

In the first Century AD, Hero of Alexandria wrote *Pneumatica*, in which he describes many wind and water powered devices (of Alexandria & Bennet, 1851). This treatise contains several automatic singing birds and musical devices, operating on similar principles as those described by Archimedes. One notable example is described in Section 49, depicted here in Figure 1(b). A figurine holding

(a) (b)

Figure 1. (a) Archimedes' flute-playing automaton, (b) Hero's flute-playing automaton.

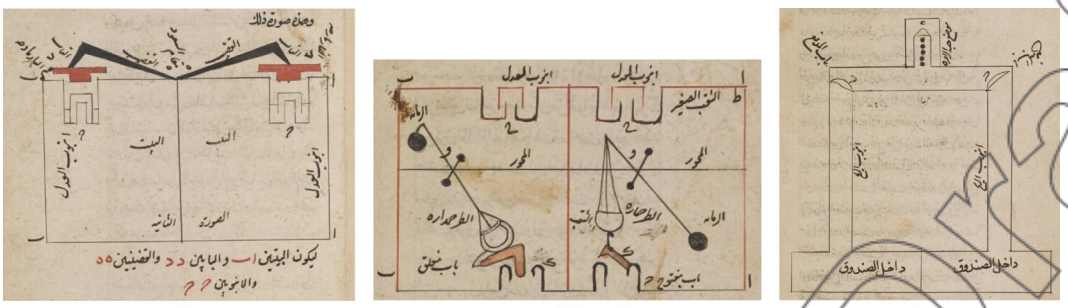
Source: (a) British Museum MS23391 f. 20 v. (Archimedes & Apollonius, n.d.), (b) (of Alexandria & Bennet, 1851) p. 71. Note that the figure in Woodcroft's source manuscript (of Alexandria, n.d.) f. 36 r. shows only the base and not the figure

a trumpet stands on top of a hemispherical chamber within a sealed pedestal. A pipe connects the trumpet to the interior of the hemisphere. The hemispherical chamber has many small holes in the bottom. The pedestal (and consequently the hemisphere) are filled partially with water. A person can expel the water from the hemisphere (into the pedestal) by blowing into the bell of the trumpet. When the person removes their breath, the water will flood back into the hemisphere through the holes in the bottom, thereby expelling air through the trumpet.

One problem with both of these models is that once all of the water has flowed from one chamber into the other, the water must be manually transferred back in order for the android to play again.

2.3 Apollonius

This latter problem was solved in the late 3rd Century BCE by Apollonius of Perga, in a treatise which survives in a copy in the same manuscript as Archimedes' (Archimedes & Apollonius, n.d.) which is explained in (Farmer, 1931). He again describes a mechanism for feeding air into a flute. It is driven by water falling from a cistern, which is from a stream so it is continually full. Below the cistern is a waterwheel driving a system of gears and levers, constituting a hydraulic *pump*. The levers open and close valves which causes water to flow alternately into two chambers below. While one chamber fills with water, its air is expelled out into the flute through a no-return valve; at the same time, the absence of water falling into the other chamber trips a lever which causes it to drain. Alternating the chambers in this way allows air to be fed continuously into the flute with no further human intervention. Part of his design is shown in Figure 2.



(a) (b) (c)

Figure 2. Part of Apollonius's mechanical flute player, demonstrating a hydraulic air pump. (a) Two stoppers (opened and closed via a spinning disc, not shown), allow water to flow alternately into two chambers. (b) The interior of the chambers; water flowing into a chamber lands on a cup mounted on a lever, which causes the bottom of the chamber to become plugged. This allows the chamber to fill, which causes the air in the chamber to be expelled through a pipe (not shown). When water stops flowing into a chamber, whatever water remains in the cup drains out a small hole in the bottom, which causes it to raise on account of a weight on the other side of the lever, allowing the water in the chamber to drain out the bottom. (c) Air-pipes emanating from the tops of the two chambers are connected to the flute via no-return valves.

Source: British Museum MS23391 (Archimedes & Apollonius, n.d.) (a)f.22 v (b)f.23 r (c)f.24 v

2.4 Banu (Sons of) Musa

The instruments discussed in the previous sections feed air into the flute but do not finger it. An obscure work entitled "The Instrument which Plays by Itself" by the famous 9th century scientists Muhammad, Ahmad, and al-Hasan, sons of Musa, describes a machine that does this, and a translation is given (Farmer, 1931)[1]. Air is continuously fed into the flute using a mechanism similar to that of Apollonius, but which also contains a means of regulating air pressure by expelling water from whichever chamber is currently filling when the pressure becomes too great (i.e. when all of the flute's finger-holes are closed). The finger-holes of the flute are covered with little hinged flaps which plug the holes, but which can be raised by levers. The levers are connected to a notched barrel, similar in construction to those found in barrel organs or modern music boxes. The barrel spins on account of sharing an axle with a water-wheel, and when a raised notch on the barrel comes into contact with a lever, it causes the flap on the corresponding finger-hole to be opened. The authors suggest making the barrel of large enough diameter to contain several repetitions of one melody in a half rotation, and several repetitions of another melody on the other half. They also suggest that the barrel can be twice as long as needed to provide a second set of melodies. An auxiliary mechanism controls the flow of water onto the water-wheel such that the tempo of the music continually speeds up and slows down to provide musical interest. The entire machine, which is roughly 150 cm (5 feet) tall, is hidden within the body of a humanoid figurine. The authors also suggest that a lute or psaltery player can be made in the same way. It is unclear whether they built this, but they do provide some details about how it would be tuned and how it could be made to play in unison with the flute. As an interesting side note, the authors also describe a method of recording the movement of the android's fingers by engraving into a large wax-coated cylinder, which then can then be used

[1]The whereabouts of the 12th century copy from which the translation was made is somewhat vague. He says it is in the 'Three Moons College of the Orthodox Greek Church in Bairut Syria', a location unknown to Google. The contents of the manuscript are so surprising that I would almost doubt it ever existed, except that al-Jazari, in the first of his chapters on perpetual flutes, references this work. Interestingly, he says he saw only the figures, without the text, whereas the surviving manuscript has only text and the figures are missing).

to make new melody barrels (through an unclear process). This is an interesting predecessor to early 20th century audio recording techniques.

The Banu Musa automaton is often cited (e.g. on the internet) as being the first programmable machine. This appears to be made on the misunderstanding that the barrel which drives the fingers is fitted with movable pegs. In the text, the authors describe the barrel as being smooth and having notched rings (one for each finger) fitted over it. My reading of the text is that the rings and barrel are permanently affixed to the device, and the authors make no mention of them being manipulated after construction. On the other hand, this does appear to be the first recorded use of a pegged cylinder, which subsequently becomes the standard controlling mechanism in musical automata. This also appears to be the first automata that is capable of playing complete pieces of music, as opposed to single tones. It should also be noted that another book by the Banu Musa called 'The Book of Ingenious Devices' (Ibn Shakir, Ibn Shakir, & ibn Musá ibn Shakir, 1979) contains no mention of musical automata (aside from a whistle that sounds when its base is dunked in water), although it seems to be commonly confused with the similarly-named book by al-Jazari, to be discussed presently.

2.5 Ismail ibn al-Razzaz al-Jazari

In The Book of Knowledge of Ingenious Mechanical Devices (al-Jazari, 1974), al-Jazari describes several musical automata, including what seem to be the earliest descriptions of mechanical percussionists. Of particular interest are a number of percussion androids. Chapter 2 of Category I (the Water Clock of the Drummers) describes a large and elaborate clepsydra (clock) which contains, amongst other things, two cymbalists, two drummers with generic drums slung over their shoulders and played with curved sticks, and one seated drummer with two kettle-drums and curved sticks. The main illustration is shown in Figure 3(a).

On every hour, 'the musicians perform with a clamorous sound which is heard from afar'. The two generic drummers and two cymbalists are wooden, and each have one hinged arm, a hollow body, and one hollow leg. A copper cable is attached to the moveable part of the arm, and is threaded through the interior of the body and leg into a hidden chamber below. Pulling on the cable causes the arm to raise, and releasing it causes it to fall and strike the drum, or the cymbals to clash. The kettle-drummer is similar except that both arms are moveable. Within the hidden chamber below, the copper cables are tied to levers. A water-wheel spins an axle that has pegs protruding from it, which press down upon and subsequently release the levers, causing the drummers to play. The construction of the drummers is shown in Figure 3(b). The pegs are arranged in a pattern that is used in all of this author's percussion instruments – "Since two of the three ends of the pegs are close together, the fall of the drumsticks on the drum is varied – [first] two raps then one rap – and likewise with the cymbal". Every hour, a sufficient quantity of water has drained out of the main cistern to cause a bucket to tip over (via a Rubegoldbergian contraption involving a falcon and a marble), which spills its water onto the water-wheel that drives the musicians.

This clock also has two figurines holding trumpets. However, the trumpets are props which do not produce sound, and the figurines share a single sound-producing mechanism which is hidden underfoot. The mechanism is essentially an ad-hoc, copper, jar-shaped whistle (with no ball) whose construction is described in detail in Chapter 1 of Category 1. Air is supplied to it using the same principle used by Archimedes, as is depicted in Figure 3(b). This artifice is used in all of al-Jazari's 'flute' and 'trumpet' automata.

Chapter 1 of Category I describes an even more elaborate water clock that has, amongst other things, a cymbalist, generic-drummer, kettle-drummer, and two trumpeters with similar construction and operation as above. Chapter 3 of Category II describes an amusement device for drinking parties that serves wine and plays music every 20 minutes. It has a flutist, tambourine player, lutenist,

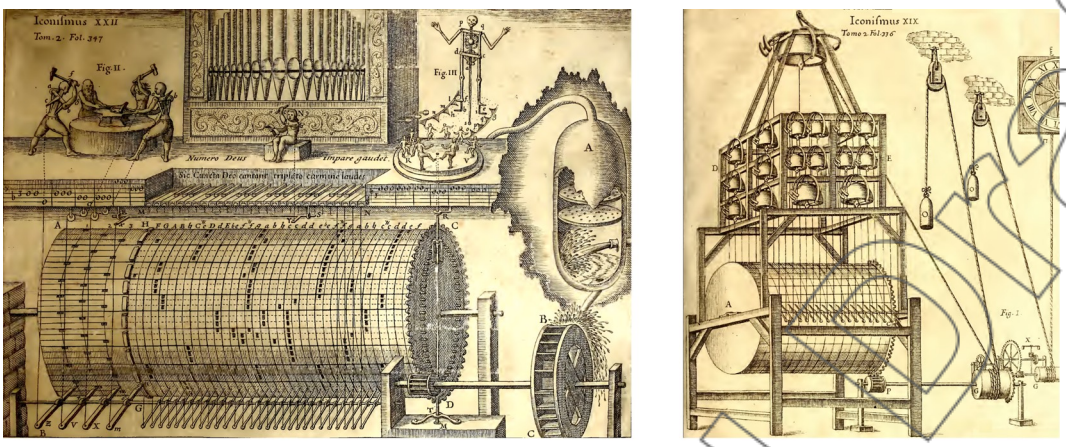
(a) (b)

Figure 3. (a) Al-Jazari's Water Clock of the Drummers showing 7 musical automata (2 trumpeters, two generic-drummers, a kettle-drummer, and two cymbal players). (b) Detail of a generic-drummer. The drummer's arm is controlled by a wire connected to a horizontal lever, which is impinged upon by a peg on an axle driven by a water-wheel. This diagram also shows a 'jar' whistle in the lower right, which make the sound attributed to the trumpeters; water from the water-wheel is collected and funneled into a chamber. As the chamber fills the air is expelled out through the top of the chamber, into the whistle. Once the chamber is full of water, a syphon drains it.

Source: (a) (al-Jazari, 1315) This image is from a Turkish manuscript whose folios have been sold individually to private collectors. (b) `https://commons.wikimedia.org/wiki/File:Arabic_machine_manuscript_-_Anonym_-_Ms._or._fol._3306_i.jpg`

and drummer (playing an odd two-sided drum held in the lap). These are made of jointed copper. Their operation is similar as above, with the following exceptions: The tambourine player's arm has two joints, and is connected somewhat differently; The interior of the flute player's arm contains a whistle with a ball, of slightly different construction than elsewhere, and the entire contraption is run on wine instead of water (those were good times)! The lute player has a moveable arm, but it is unclear whether it ever actually makes contact with the lute, or if it just moves the arm for show. The following chapter (Chapter 2 of Category 4) is a boat which contains two tambourine players, a flautist, and a harpist. It is said of the harpist "Both her hands are constructed so as to move, with their fingers over the strings but not touching them", indicating that this device was decorative but did not make sound.

This last device (Chapter 2 of Category 4 – a mechanical boat with four musical automata for a drinking party) is particularly famous on the internet, and many wild and false claims have been made about it. For instance, at the time of writing, Wikipedia states *s.v.* 'automata' "His automaton was a boat with four musicians that floated on a lake... His mechanism had a programmable drum machine with pegs... The drummer could be made to play different rhythms and patterns if the



(a) (b)

Figure 4. (a) Kircher's hydraulic organ; (b) Kircher's mechanical carillon

Source: (Kircher, 1650)

pegs were moved around". The original text does not support the claim that the drummer was programmable, as it reads "To the axle a short peg is fitted... A single peg on the axle is not sufficient, so two pegs are fitted close to each other opposite this peg, so that the movement of the hand gives two beats and one beat." Nowhere does the author state that the pegs are configurable. Wikipedia continues "...the automata were a 'robot band' which performed 'more than fifty facial and body actions during each musical selection' ". This is patently untrue on all counts. Al-Jazari's text is clear and technically precise and comprehensive, and does not mention facial movements, or any body actions in the musicians beyond the simple movement of the arms. Unfortunately, claims of this nature have been repeated and amplified *ad nauseam*, and many articles that cite primary sources have clearly copied false claims from Wikipedia and other blogs.

The Book of Knowledge of Ingenious Mechanical Devices also contains several chapters on perpetual flutes, in the manner of Apollonius, whom al-Jazari cites by name. They provide several alternative mechanisms for causing water to alternately fill and drain from two chambers, all driving air through a 'jar' whistle of a single pitch.

3. 17th to 19th Century Europe

This period saw an inflorescence of automated musical instruments and mechanical organs; a detailed overview is given in (Ord-Hume, 1978). This history perhaps begins with Althanasius Kirchers's eccentric 1650 treatise MVSVRGIAE VNIVERSALIS (Kircher, 1650), which contains a chapter (in Liber IX, Pars V, pp. 308 ff.) on the construction of *Omnis Generis Instrumentis Musicis Automatis*. This includes a novel hydraulic barrel-organ, which is somewhat backwards-looking for its use of falling water to supply energy and its similarities to the Banu Musa flautist, and forward-looking in its use of a pegged barrel to control a keyboard. The same chapter also includes an automated carillon made by similar means but driven by weights suspended on ropes and pulleys; and a variety of other things. These devices are shown in Figure 4. Around this time, horologists in the Black Forest began to incorporate similar mechanisms into increasingly elaborate clocks, which began to attract the attention of composers such as Haydn, who adapted 32 of his previous works explicitly for flute-clock (H.XIX 1 – 32). By the very end of the 18th Century (ex-

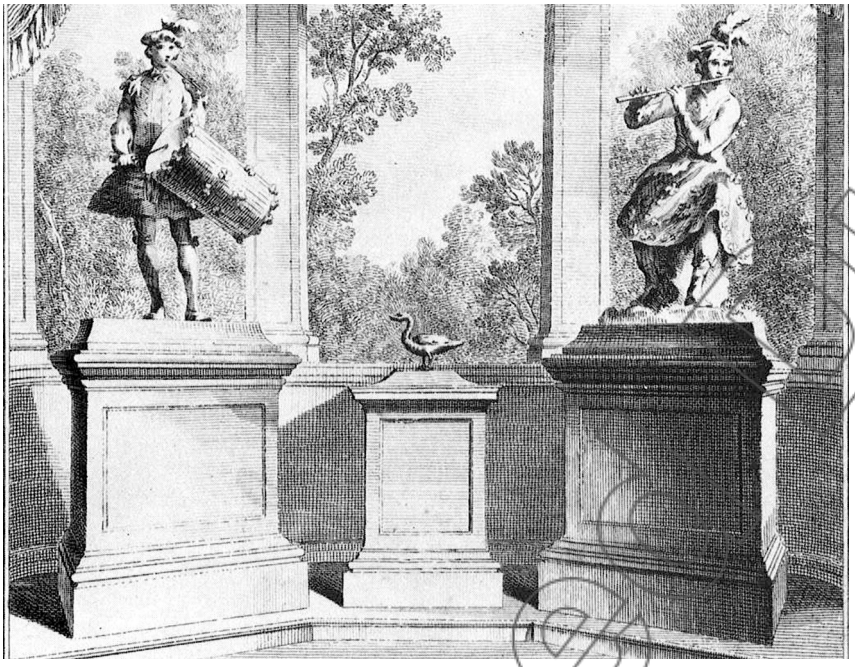


Figure 5. Vaucanson's automata
Source: by Hubert-François Bourguignon (a.k.a Gravelot), published in (Vaucanson, 1742)

tending into the 19th), such devices started becoming very elaborate and attempted to recreate entire wind orchestras. Notable are the so-called Panharmonicons, made first by Maelzel (premiered in Paris in 1807) (Anon, Samedi 25 Mai, 1846) and immediately copied by others such as Gurk (premiered in Germany in 1810) (Ord-Hume, 1973). Maelzel's contained 7 ranks of pipes imitating woodwind and brass instruments, and several percussion instruments. In 1812, Beethoven wrote a 'Battle' symphony for the Panharmonicon (the subsequently orchestrated version is his Opus 91) in exchange for some hearing devices made by Maelzel (Schindler, 1966). This appears to be the first piece composed specifically for a machine, although it subsequently became the subject of a legal battle between Beethoven and Maelzel. Although Maelzel built three Panharmonicons, they evidently failed to attract much attention and were eventually destroyed. During this period, a number of remarkable humanoid musical androids were also built, to be discussed anon.

3.1 Vaucanson

In the 1730s, Jacques de Vaucanson, who invented an important predecessor to the Jacquard Loom, and who is perhaps most famous for his shitting duck automaton, developed two highly sophisticated musical automata. These are shown in Figure 5. One plays a standard orchestral flute, and the other plays tabor and pipe (a small drum played with one hand and three-hole fife played with the other). He presented a technical description of the flute player to the Royal Academy of Sciences in 1738, and the tabor player in substantially less detail in a missive, both appearing in (Vaucanson, 1742), and each reprinted in (Diderot & d'Alembert, 1751) (s.v. 'Andriode' and 'Automate', respectively). The flute player appears to be the first automaton in history to play an actual musical instrument that was built to be played by a human. Thus, Vaucanson's description presents a thorough analysis of the mechanics of flute playing from an engineering perspective (although contemporary flautists dis-

agreed with the finer points of his analysis (Quantz, 1752), Chapter IV Section 14). The automaton itself was biologically-inspired, and informed by this analysis. The embouchure had four degrees of freedom plus a tongue for musical articulation; the fingers were covered in leather to imitate the softness of human skin.[2] The automaton had three sets of bellows, each driven by different weights to produce different strengths of breath, as necessary to produce notes in different registers and different dynamics. The mechanisms controlling the lips, fingers, and bellows's valves were connected via cables to levers that rested on a pegged cylinder, similar to that in the Banu Musa flautist or modern music boxes or barrel organs; the entire device was presumably wound up via a crank in the back of the plinth, and once set in motion it would play the play the music engraved on the cylinder. A good diagrammatic reconstruction of this mechanism can be found on page 81 in (Doyon & Liaigre, 1966). Less is known about the tabor and pipe player, but Vaucanson reports that a much greater range of air pressure is needed to produce the different pitches in the pipe. He also notes that in order to sound good, every note needs to articulated individually by the tongue, which human players do not achieve well in fast passages. He reports that his automaton outperforms humans in this task, and this appears to be the first instance in history of a machine with the ability to produce music that would be too difficult for a human to produce. It can strike the drum with a variety of velocities, and play a variety of strokes and rolls, but no further information is provided on how this worked.

3.2 Keyboard Automata

In the 1760s and '70s, the Swiss clockmaker Pierre Jacquet-Droz built several remarkable and very famous automata, amongst which is a figurine which plays a small reed organ; the organ is functionally separate from the figurine, and the force of the figurine's hands depresses the keys. In 1784, Peter Kintzing and David Roentgen built a similar automaton that plays hammer dulcimer, which they subsequently presented to Queen Marie Antoinette. Both automata still exist and function, and videos of them are widely available[3] [4]. In roughly the 1820s, another Swiss clockmaker, Henri Maillardet created several automata which were strongly inspired by those of Jacquet-Droz. Amongst them was an organist automata, which is described in (Brewster, 1832) s.v. 'Androides' (vol II p. 61) and an exhibition advertisement reprinted in (Ord-Hume, 1973).

3.3 Miscellaneous

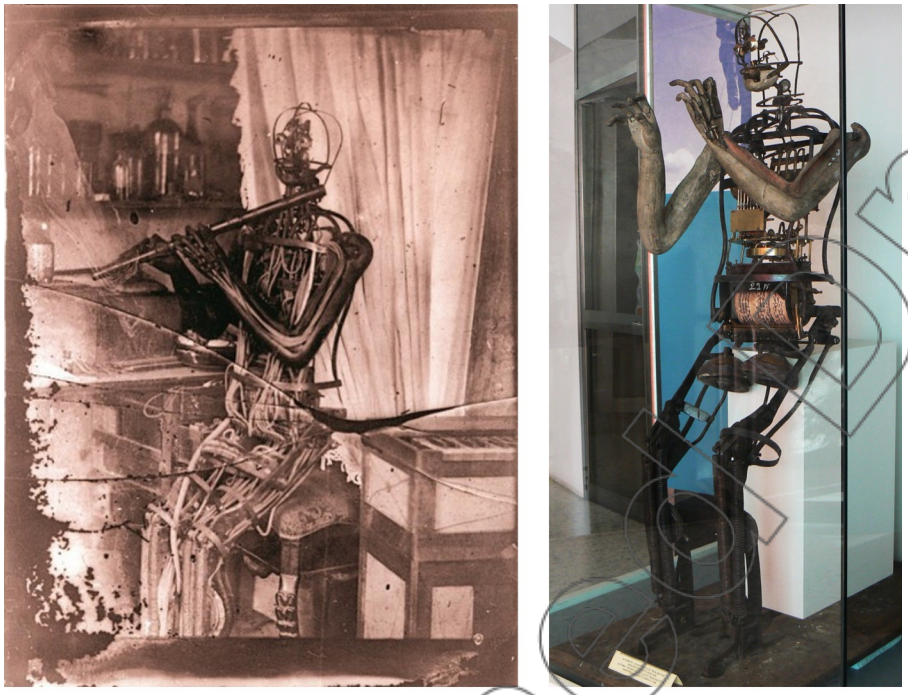
3.3.1 Marreppe's Violinist In 1837, an account of a remarkable violinist automaton appeared in (Anon, December 9, 1837). The life-size automaton, built by one Mr. Marreppe, was evidently exhibited at the Royal Conservatory in Paris. It played virtuosic music that was compared to that of Paganini and Ole Bull, owing to a range of extended techniques, very fast playing, and large dynamic variation. It played both solo and with an orchestra, and as such it seems to have been the first automaton to, in a limited sense, *interact* with human musicians. It was also reported that the automaton started playing on the conductor's cue, and could 'obey the direction of the conductor'. Unfortunately, all further information about this automaton seems to be lost.

3.3.2 Friedrich Kaufmann In 1810, the German and eventual orchestrion manufacturer Friedrich Kaufmann built a musical automaton which holds a trumpet. Within the automaton is a 12-note reed organ, the air from which exits through the trumpet, creating a trumpet-like sound. An article in the

[2] Gaby Wood (Wood, 2003) highlights Vauconson's obsession with biological realism by half-jokingly pointing out that, in French, Vaucanson actually says the fingers are covered with *'peau'*, which could in fact refer not to leather but to human skin.

[3] http://www.mahn.ch/expo-automates

[4] http://www.arts-et-metiers.net/musee/automate-joueuse-de-tympanon



(a) (b)

Figure 6. (a) Manzetti's flute automaton (b) As it appears today in the Saint-Bénin exposition center in Aosta

Source: (a) `http://www.manzetti.eu/s/cc_images/cache_17300898.jpg` (b) `https://upload.wikimedia.org/wikipedia/commons/2/2e/Automa_Manzetti_1840.JPG`

August 1950 edition of *Mechanix Illustrated* erroneously stated that this was built in 1910 and that it was the first robot in history. This automaton still exists [5].

3.4 Manzetti

It is unfortunate that Innocenzo Manzetti is not better known in the English-speaking world. As an inventor, he is the unrecognized inventor of the telephone and steam-powered automobile, amongst other things. In the 1840s, he began building the flute-playing automaton pictured in Figure 6 (Tibaldi, 1897)(Krzyzaniak, 2016). By 1949 a prototype was complete; it worked like a barrel-organ, and it had a metal cylinder with raised bumps hidden in its abdomen. The mechanism was wound-up like a clock, and as the barrel rotated, the bumps impinged on levers attached to cables which made the fingers, lips, tongue, and eyes move. It presumably had a mechanical bellows hidden in the chair on which it was seated, and could provide four gradiations of air pressure. It could play about 20 pieces by this method. As such, it was structurally similar to Vaucanson's automata. However, in the following decades, Manzetti made a number of important and novel improvements. First, he wanted it to be capable of playing arbitrary melodies. Therefore, during the 1850s, he replaced the metal linkages with rubber-like pneumatic tubes which he built (Caniggia Nicolotti & Poggianti, 2015). He also built a special harmonium (pump reed-organ), which he connected to the automaton via pneumatic tubes. Thus, whatever notes a keyboardist depressed on the keyboard would be sounded

[5] `http://www.deutsches-museum.de/en/exhibitions/communication/computers/automata/`

by the flute automaton. This was probably the first pneumatically actuated automaton, as well as the first distinct use of a musical *controller*. These improvements also remove the flautist from a strict definition of 'automaton'; although it still carries out complex actions automatically (e.g. fingering and tonguing), it does so only in response to a human's actions. This represents a marked departure from previous musical androids, as it puts the focus on the interaction between the human and machine. An account from 1865 (Quétànd, Mercredi 22 Novembre, 1865) reports that assistants operated the bellows, although in 1866 Manzetti built a battery-powered air pump, perhaps the first of its kind, making this the first known electrically-powered automaton. The flautist was also designed such that when the bellows were started, the tubes in its knees and arms would inflate, causing it to rise from its chair and bring the instrument to its lips, and its porcelain eyes would rove around. Manzetti also expanded the idea of the musical controller. The same 1865 account reports that he ran a tube from his harmonium in his studio (on Giocondo St. in Aosta), out the window and into the Aosta Cathedral across the street, and devised a mechanism whereby he could use his harmonium to control the organ in the cathedral. This may be the first example of *telematic* musical performance.

4. Conclusion

Many current trends in musical robotics have had long histories. These histories often provide remarkably succinct solutions to tricky problems in the design of new musical robots. The history has explored actuation strategies, materials selection, the mechanics of musical instrument playing, the beginnings of human-robot interaction, and other pertinent topics. Current work in robotic musicianship, machine learning of music, more sophisticated types of interaction and musical exchange, improvisation, and the mechanics of the subtler aspects of music continue to expand this work.

Acknowledgements

Thanks to Grisha Coleman for all of her help and feedback, and to ASU library staff for their incredible persistence and patience.

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