

WATER FOUNTAINS BLEND ART AND ENGINEERING: A RESOURCE FOR ENGINEERING EDUCATION

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Abstract

Because water fountains have a rich history and are multidisciplinary entities, there is a great potential for enhancing engineering education by incorporating fountain-related activities in the curricula. To assist educators in this endeavor, this paper provides a review of innovative fountains developed throughout history, then suggests ways to use the subject of fountains for course enhancement.

1. Introduction

Water fountains have been used for thousands of years for climatic control, beautification, entertainment, and as a means for relaxation. Among the most popular fountains have been those that incorporate elements of surprise and/or special effects. These fountains elegantly combine engineering and artistic features. Due to the inherent multidisciplinary nature of fountains and their appeal to the general public, there exists a great potential for enhancing engineering education by incorporating fountain-related activities in the curricula.

To assist educators in this endeavor, the paper first presents a review of innovative fountains developed throughout the history, and then, it suggests ways to use the subject of fountains for course enhancement. The suggestions could be implemented in a number of courses such as introduction to engineering, fluid mechanics, engineering design, and mechatronics, depending on the scope and desired technical details.

The review section provides brief descriptions of ingenious fountains designed in the 1st, 12th, 16th, 17th, and 20th centuries, including about sixteen US patents. In addition, the paper presents a resource guide for fountain materials (pumps, basins, controllers, etc.), information on design firms specializing in fountains, and the web sites of artists whose medium of artistic expression is water (i.e., water sculptors).

The suggested class activities include reviewing and summarizing relevant patents, reproducing historic fountains with special effects, design of water features, development of interactive fountain displays, and participation in the Rube Goldberg-type fountain competition.

It is hoped that the subject of fountains and the related activities would motivate and inspire students to design future innovative fountains and exercise their creativity in general.

2. Review of Fountains

The earliest record of fountains dates back to 4000 BC in Iran¹. For thousands of years fountains were gravity fed - either directly from a running source of water such as a river that was located at a higher elevation², or from a holding tank built just behind the fountain³. Simple devices were used in ingenious setups to provide special effects such as creating sound and motion to surprise onlookers.

Around the 20th century the availability of electric pumps and later on the advancement of control technology brought even more ingenuity to the design of fountains with special effects. Today, with state-of-the-art computer controlled technology, we witness monumental fountain installations such as “Fountains of Bellagio,” shown in Figure 1. Requiring 7.5 MW of power, this fountain utilizes more than 1200 nozzles that shoot out water jets to heights reaching 240 feet in the air. And 300 of those jets (nozzles) move back and forth to dance in synch with music for the enjoyment of visitors⁴. From the earliest fountains to today’s sophisticated versions, one thing has remained the same – that successful fountains blend in elements of engineering and art in elegant ways.



Figure 1 – Aerial view of “Fountains of Bellagio” in Las Vegas. Designed by WET Design in 1998. Photo by Ira Kahn.

In the following sub-sections examples of devices, mechanisms, and setups that have been used to create special effects in fountains will be presented. Special effects include, but are not limited to, creation of sound, motion, interaction with people, unusual forms of water jets, synchronization of water flow with lighting and music, and combining water with fire.

2.1. Alternating Fountains

Hero of Alexandria (1st century) was perhaps the first designer of fountains with special effects⁵. Siphons (U-shaped or concentric) served as the main part responsible for creation of special effects in his fountains. One of Hero's designs is schematically shown in Figure 2. In this fountain, after the water level rises and covers the siphon inlet, its continued flow into an otherwise airtight vessel pushes the existing air out through a whistle within a bird's statue. The whistling sound appears to be coming from the bird and thus surprises the onlookers. The siphon starts discharging the water as soon as the water level in the vessel reaches the top of the siphon. Then the bird is silenced as air is sucked into the vessel due to partial vacuum created by discharging the water through the siphon. This continues until the water level in the vessel reaches below the siphon. Air is let in and the siphoning is terminated. The whistling period starts again shortly thereafter. In other words, the siphon is responsible for the whistling-silence cycle. In more elaborate setups, Hero masterfully used several siphons in conjunction with other mechanical devices such as floats, cables and pulleys to create sound and motion. Siphons are still used today for the creation of special effects in fountains; e.g., see US patent # 5,381,956, where a U-shaped siphon is used in a self-activating falling water display.

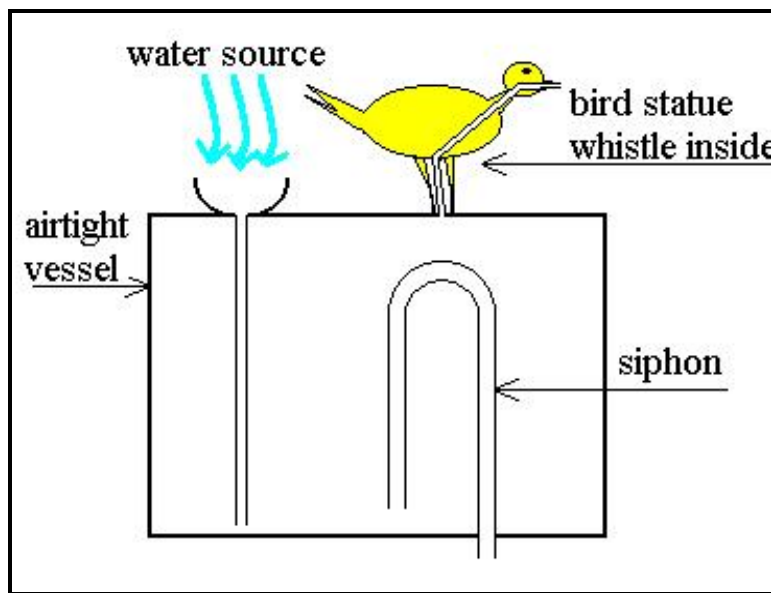


Figure 2 – Hero's singing bird fountain (1st century), redrawn based on a figure in reference 5.

Another alternating device extensively used in fountains is the tipping bucket designed by the Banu Mussa brothers (9th century) and perfected by Al-Jazari (12th century)⁶. An application of the tipping bucket is depicted in Figure 3. This fountain alternates between a single vertical jet (A'') and several curved jets (B''). The tipping buckets (T and T') cause the alternation. Once filled with water coming from a small orifice (O), the tipping bucket (T) tips about its pivot, and its small protrusion pushes the main pipe in a CCW direction about its central fulcrum. The main pipe is then tilted to the other side. This action is reversed once the tipping bucket T' becomes full and is tipped.

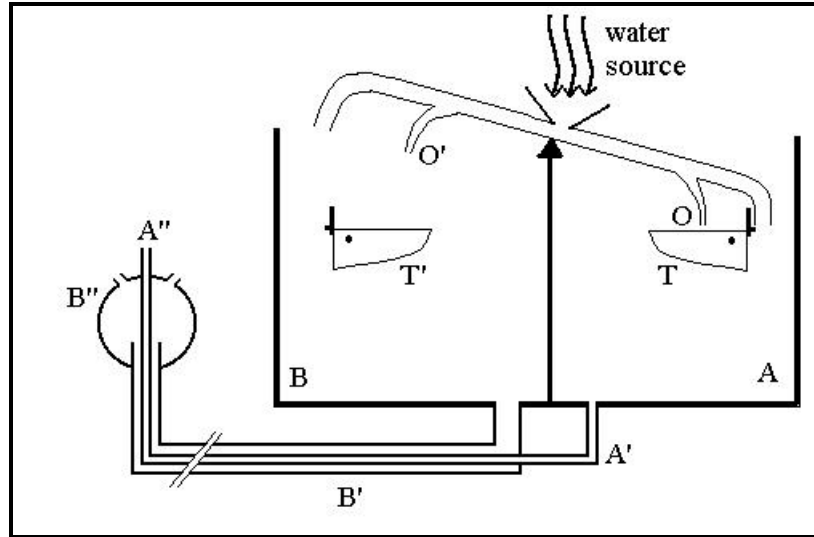


Figure 3 – Al-Jazari alternating fountain (12th century), redrawn based on a figure in reference 6.

The tipping bucket idea was used in the “Big-Mouth” water display in the Hellbrunn Palace, which was designed by architect Solari (17th century)⁷. Many other water features with special effects are still working in Hellbrunn Palace today. The “Big-Mouth” mechanism is shown in Figure 4. Note that the lower jaw is a tipping bucket. And when full of water, it tips over, grabbing a bent rod that actuates the tongue and the eyelids. Once emptied, the lower jaw returns to its closed position and the above cycle is repeated as long as there is water flow to the mechanism. The use of the tipping bucket is recurring even in modern-day patents. An example can be seen in US patent # 5,367,805, where the action of a hidden tipping bucket actuates the handle of an old-fashioned pump, creating a motion whose cause is non-obvious to onlookers.

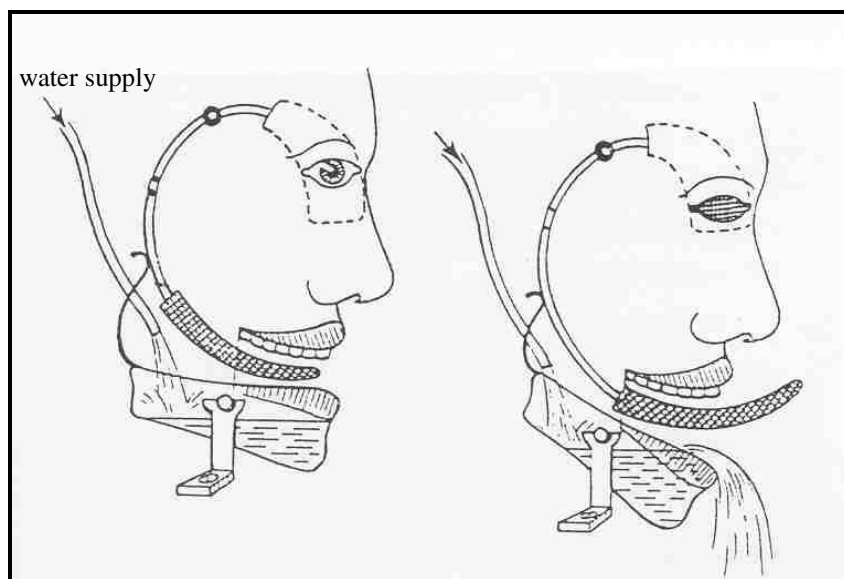


Figure 4 – “Big-Mouth” mechanism in Hellbrunn Palace, Salzburg, Austria (17th century), scanned from reference 7.

2.2. Air and Steam Assisted Fountains

Figure 5 is taken from US patent # 151,003 that describes an air-assisted fountain for indoor use⁸. A hand pump was used to pressurize air in the water reservoir (part A), which allowed for a steady jet of water from the nozzle (part D). Steam has also been used to drive water jets in small fountains for indoor use⁹.

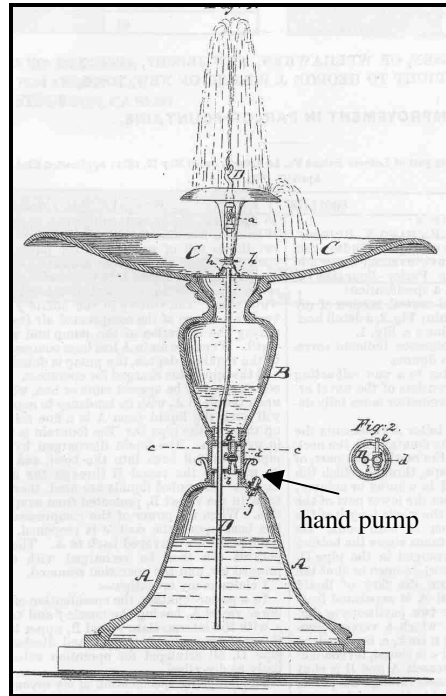


Figure 5 – Air-powered fountain, scanned from US patent # 151,003.

Fuller and Robinson invented a modern version of air-powered water display¹⁰. As shown in Figure 6, taken from US patent # 4,852,801, water is allowed to fill in the nozzle body (part # 50) and then a blast of compressed air (coming from part 34) shoots most of the water out of the nozzle to great heights. This effect could be produced by pressurized water as well but it would cost much more to pressurize water than use compressed air. Fuller and his co-inventor made improvements to their air-powered fountains^{11, 12}; for example, by using computer controlled proportional valves, water jets with varying heights could be obtained.

2.3. Interactive Fountains

Interactive fountains are those in which the water flow (shown) is initiated by some action of a user. The earliest interactive fountain, designed by Hero of Alexandria, was a water dispenser. A user would drop a coin into a slot at the top of the dispenser. The coin would fall on a lever arm actuating a valve momentarily to let out water. Another interactive fountain was the “Organ Fountain” in Villa d’Este (16th century). A water wheel was used to operate bellows to pump air for the organ. The organ would start playing as visitors stepped on certain pavement stone blocks near the fountain. A mechanism was hidden below those blocks that activated the organ keys when stepped on.

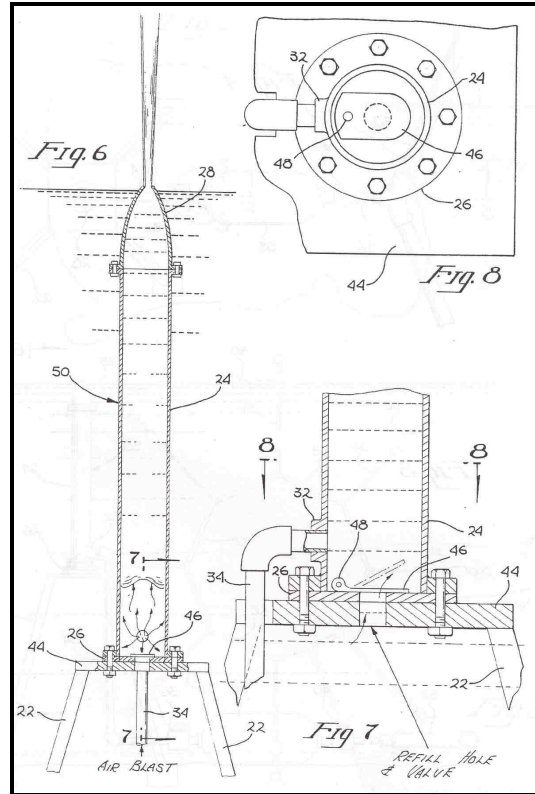


Figure 6 – Air-powered fountain, scanned from US patent # 4,852,801.

Fuller and Robinson disclosed a user-activated fountain, where sound sensors are installed on the bottom of a fountain pool¹³. The fountain is normally off. Figure 7, taken from patent 4,817,312, shows the general layout of the nozzles (parts 22) and sensors (parts 11A & B). After a coin is tossed into the pool, the sensors pick up the sound waves generated by the coin. By gating (triangulation of) the sensor outputs, the area of the pool in which the coin was tossed can be identified. The nozzle action can then be directed to that area of the pool. After a predetermined time the fountain is turned off and then it would be ready for the next coin.

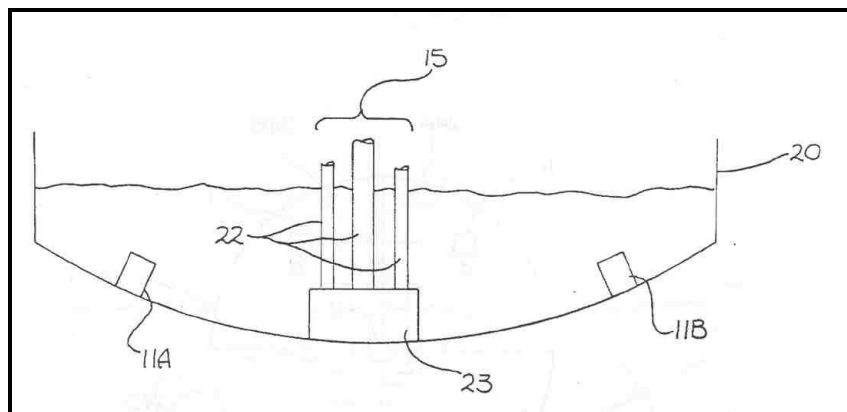


Figure 7 – User-activated fountain, scanned from US patent # 4,817,312.

2.4. Variable Spray or Dancing Fountains

Przystawik invented a mechanical arrangement to rock (move back and forth) multi nozzles for water shows synchronized with music and perhaps lighting. This mechanism is shown in Figure 8, taken from US patent # 3,907,204¹⁴.

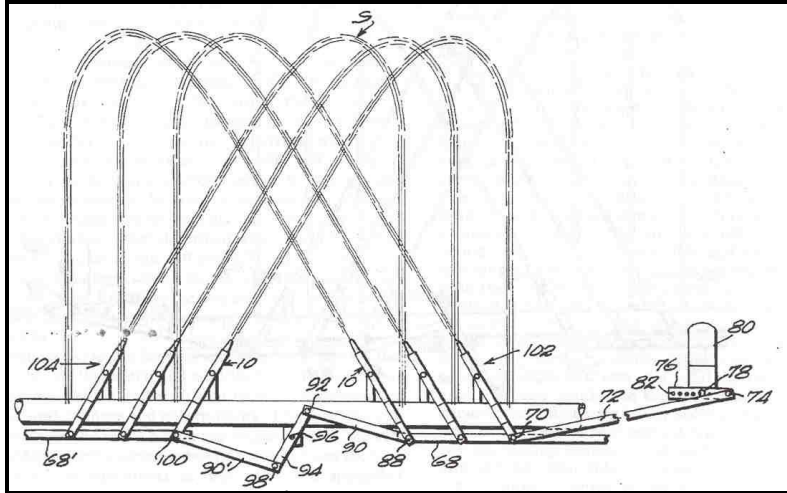


Figure 8 – Movable Nozzles, scanned from US patent # 3,907,204.

Opposing streams were used in an invention by Simmons to produce pleasing water displays¹⁵. As shown in Figure 9, taken from US patent # 5,524,822, two separate streams (flowing through parts 92 and 93) enter conduits (part 91) from opposite ends. The two streams combine and produce jets coming out from the openings as shown. According to the inventor, one can control the jets' direction and flow rate by varying the pressures and/or flow rates of the streams.

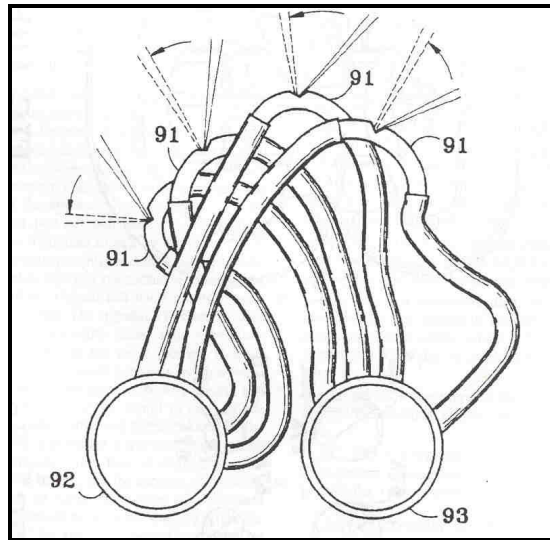


Figure 9 – Variable-play fountain, scanned from US patent # 5,524,822.

Jacobsen et al. invented a two-degree freedom apparatus capable of rocking nozzles along perpendicular directions¹⁶. Figure 10, taken from US patent # 6,053,423, shows their invention. There are two motors involved and the whole apparatus is placed on a platform (not shown) that could be moved in and out of the water as desired during a water show. Dynamic shows can be produced with computerized control of the motors in synch with accompanied music/lighting.

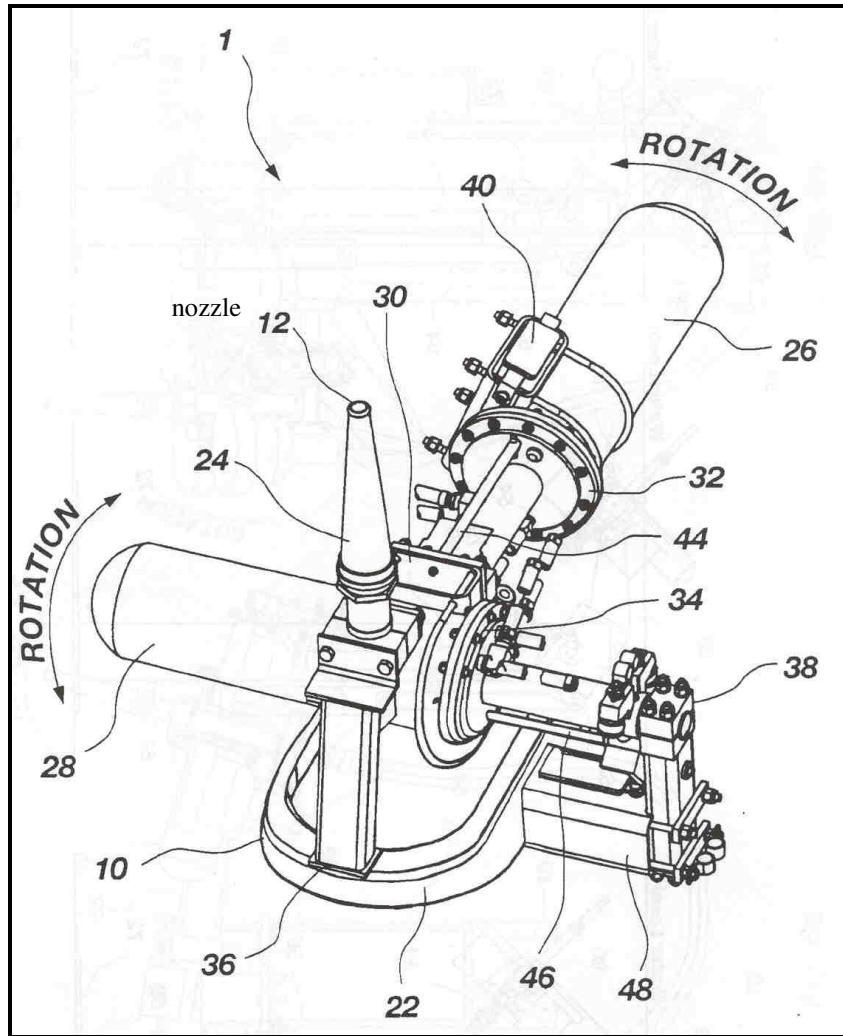


Figure 10 – Two-degree freedom nozzle apparatus, scanned from US patent # 6,053,423.

2.5. Fire on Fountains

Integrating fire into fountains is an intriguing task. Designers of fountains have been able to produce such integration. Both gas and liquid fuels have been used. Pejack and Eubanks designed a small-scale decorative fountain with eight water jets surrounding a propane (fuel) jet¹⁷. Figure 11 displays two photographs of their fountain. Slight wind in the proximity of the fountain causes interesting fluctuation and separation in the flame. Flow rates of propane and water are adjustable via appropriate valves.



Figure 11 – Water and fire designed by Pejack and Eubanks, 2003. Note the separated flame in the photo on the left. Photos by Ed Pejack.

Robinson and Fuller invented a fountain system capable of illuminating water jets with colored flames¹⁸. Figure 12, taken from US patent # 4,858,826, shows the details of their colored flame apparatus. The flame colors are produced by solutions of various metallic salts injected (from parts 34) into the main burner (part 22). Note the water nozzles are numbered 20 in the figure. Various sensors are used for safety; for example, the fuel is shut when the flame is extinguished by whatever reason.

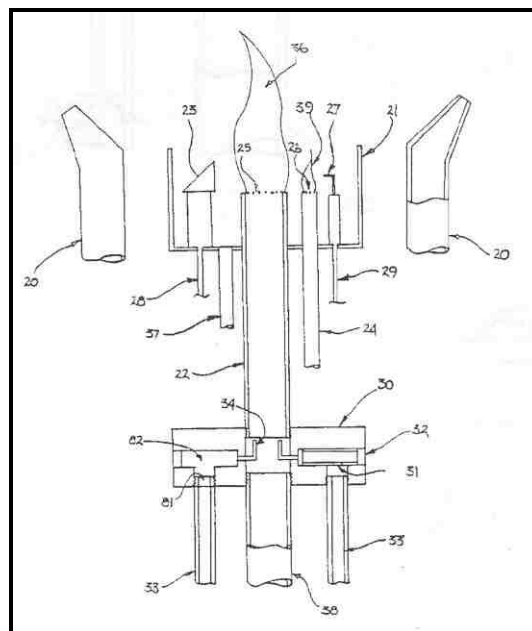


Figure 12 – Colored flame fountain apparatus, scanned from US patent # 4,858,826.

In U.S. Patent # 5,961,042, Doyle describes a system of water nozzles fitted with a gas line for producing flames¹⁹. The schematic of his invention is shown in Figure 13. Sensors are used for safety. The inverted U-shaped section of the gas line (part 54) reaches sufficiently above the surface of the pool to assure that the gas line does not fill with water when the gas is turned off. Placing several of these nozzles in a row in a pool can create dramatic water shows. Safety features include sensor (part 68).

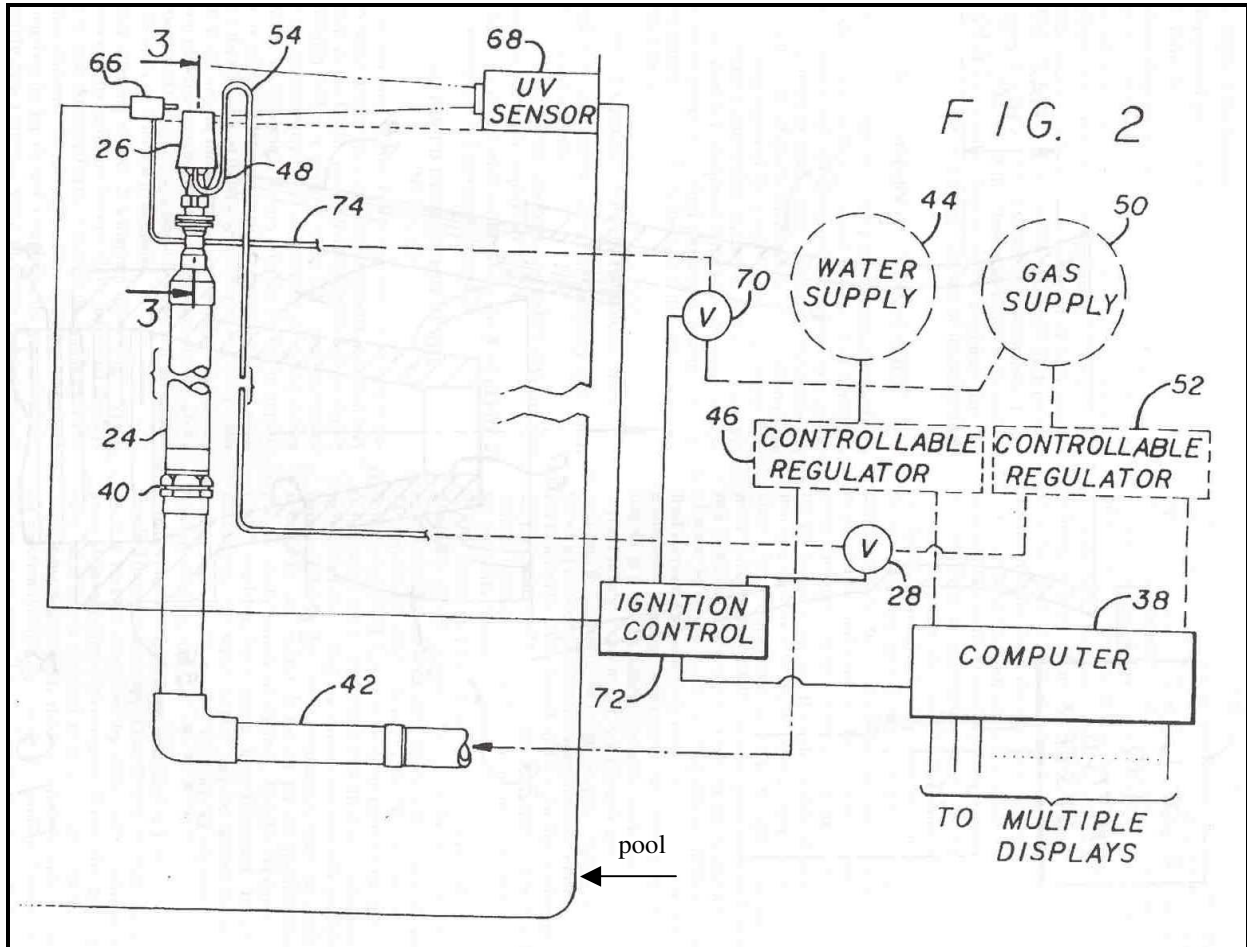


Figure 13 – Water on fire appearing water display, scanned from US patent # 5,961,042.

2.6. Laminar Stream Fountains

A popular fountain, the laminar stream nozzle, has been installed in theme parks and shopping centers since the 1980s. Fuller received a patent for this nozzle²⁰. Figure 14, taken from US patent # 4,795,092, shows a cutout view of the laminar nozzle. It is made of a cylinder with a tangential inlet and a knife-edge orifice outlet (part 12). The screens (parts 19 and 22) and honeycomb or drinking straws (part 21) significantly reduce the turbulence and cause the exiting stream to be laminar.

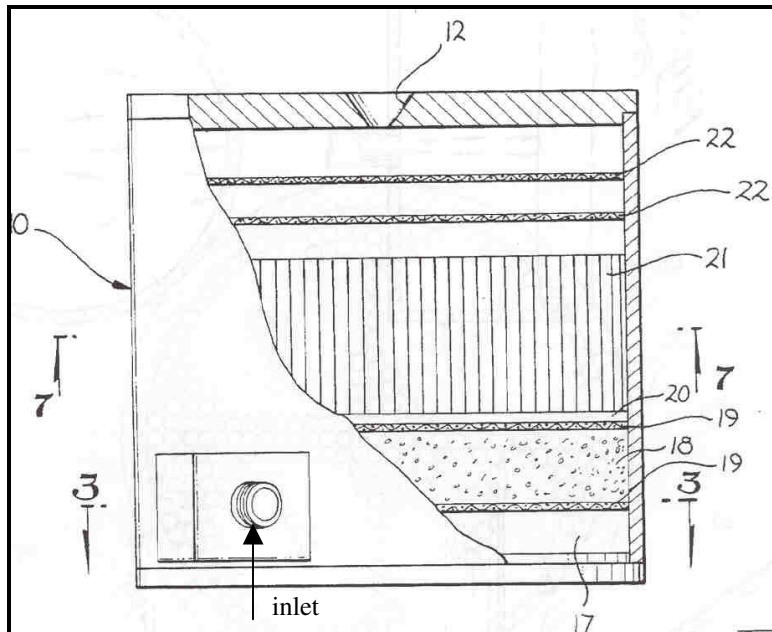


Figure 14 – Laminar stream nozzle, scanned from US patent # 4,795,092.

In a follow up invention, Fuller and Robinson devised a quick diversion method by which the laminar stream could be controllably terminated to give the effect of slicing the stream perpendicularly to its longitudinal axis²¹. Further improvement to the original laminar nozzle included adding a mounting assembly for the laminar nozzle²²⁻²⁴. The assembly is used for changing the angle and repositioning of the nozzle so that the laminar stream appears to emanate from a fixed location at different angles, which allows varying the characteristics of the arch-like laminar stream in dynamic displays.

2.7. Other Artistic Fountains

Calder was commissioned to design a symbolic statue for the Spanish Pavilion at the 1937 World Fair in Paris, France. Responding to this commission, he designed the famous “Mercury Fountain” - mercury being an important export of Spain and the subject of mineworkers’ unrest at the time²⁵. The visitors would toss coins into the fountain pool, and to their amazement, the coins would float on the mercury! This fountain was later relocated, and is now enclosed in a glass housing in a museum in Madrid. To see pictures of the fountain on the web, refer to references 26 and 27.

Lin designed “Timetable” for Stanford University in 2000, see Figure 15. This fountain-clock sculpture is made of a 10-ton granite, which moves in an elliptical rotation, 360 degrees in one year to indicate the months. A clock mechanism is situated in a cavity in the middle of the granite, see Figure 15. Water flows out of this cavity and smoothly spreads in a uniform film over the perfectly leveled granite. The clock hands have a special clutch to allow for slippage and prevent damage from occurring when curious onlookers grasp and stop the hands from moving. According to the clock’s designer, it is the first clock mechanism completely immersed in water. The sculpture cost \$500,000²⁸.



Figure 15 – (left) “Timetable” designed by Maya Lin, (right) close up of clock hands. Photos by Mahnaz Saremi and the author.

Pye has designed water features and fountains for corporate and private clients²⁹. Water is the medium of artistic expression for him. His works have appeared in large building projects such as the British Pavilion at the 1992 World Fair in Seville, Spain and Mercury House in London, UK³⁰. His recent projects have incorporated large-scale vortex motion.

Shakerin designed a small-scale, decorative fountain that can produce letters of the alphabet and simple geometrical shapes with water jets. Figure 16 shows the three letters of UOP (acronym of the author’s university) generated in sequence by this fountain. A complete description of the fountain is available^{31, 32}. Briefly, it is made of nine outlets arranged in three rows with three outlets per row. Each outlet is connected to a small submersible pump. A programmable microcontroller (BasicStamp 2) is used to turn the pumps on and off as instructed. The programming is done in PBASIC language via a serial connection to a personal computer.



Figure 16 – Viewed from the top, three letters of UOP generated by water jets of microcontrolled fountain. Jets are spaced 2 inches apart. Photos by the author.

3. Course Activities

In the previous section, we reviewed different kinds of fountains to exhibit human ingenuity that has gone into their development. It should now be obvious that the subject of fountains is rich in both art and engineering. There is a great potential for educational enhancement by bringing in

the subject of design/development of fountains into engineering curricula. Specifically, three kinds of course activities are suggested here. These could be assigned in various courses depending on the scope and required technical details of the assignments.

A resource guide that lists useful books and Internet sites is provided in the appendix to assist those interested to further their studies of fountains.

3.1. Study Patents on Fountains

In general, studying patents is not a routine practice in engineering curricula even though patents offer a rich source of design knowledge. The following relevant anecdote is quoted from *Real-World Engineering* authored by L. J. Kamm³³. "...After WWII the US sent a group of scientists to Europe in Operation Paper Clip to round up German scientists and engineers, particularly those responsible for the V-1 and V-2 guided-missile programs. (The Russians, of course, ran a matching program.) We netted Wernher von Braun and most of the engineers and scientists who had worked with him. When Americans asked von Braun how he had developed the V-2 rocket in such a short time compared with the little progress which had been made in the US, he answered, with surprise, "Why, we studied the patents of your great Dr. Goddard, of course."..."

The suggested activity is for students to search the patent database (e.g., www.uspto.gov) for inventions related to various types of fountains, study the patents, and write short summaries. A 5-minute class presentation could also be included as part of the assignment. The references cited in this paper are representative of what is available in the patent database. Patents can and should be used as an educational resource. This activity is suitable for a variety of courses regardless of the level.

3.2. Reproduce Historical Fountains

Students are asked to study historical fountains (such as those designed by Hero and Al-Jazari) and reproduce them with modern materials. They not only have to search the literature to find out as much details about these fountains as possible, but also design the parts and fabricate them. This activity is more suitable for introductory level courses such as introduction to engineering. Another relevant activity is to design and construct a water clock using siphons and tipping buckets, among other devices used in early fountains.

3.3. Design Fountains with Special Effects

Students could be asked to take the microcontrolled fountain, mentioned above, and modify it to include programmed lighting (e.g., using laser pointers) to enhance the visual aspect of the fountain. Or, they could be asked to develop an interactive fountain – one that could be installed in the hallway of their classroom building. Another project is to design a fountain in which jets respond to, and are in synch with, the notes played by an accompanied piece of music. There are many other possibilities for student projects. By using a microcontroller, students can incorporate sophisticated control schemes in their fountain designs. This activity is suited for courses that have design component such as engineering design and mechatronics.

Another creative activity is to challenge students to design and build a fountain in the spirit of Rube Goldberg inventions³⁴. That is, performing a simple daily task through complicated multi-steps using siphons, tipping buckets, floats, pumps, and other devices used in fountains. Regional and national student design competitions based on this challenge could be envisioned.

A Word on Safety: As construction of fountains involves water and electricity, one must be extra careful in following safety rules and procedures, in general, and relevant electrical codes, in particular. Furthermore, fountains that include flames must be equipped with fire safety devices, e.g., automatic shut-off valve in the fuel line in case flames go out.

4. Implementation at UOP

During the past several years mechanical engineering students carried out three senior design projects and one independent study in fountains at UOP. For example, one of the senior projects was to design a fountain apparatus that could shoot up blobs of water at random times. This work was presented at an ASME Regional Student Conference and won the second place award. Another project incorporated several parabolic water jets placed around a pool with a water bell at the center. Propane gas was also supplied to the fountain for fire addition and display enhancement. The independent study resulted in a fountain that integrated eight water jets surrounding a flame; photographs of this fountain were presented in Figure 11. Overall, students were enthusiastic about fountain projects and enjoyed working on them. More fountain projects will be assigned in the future, hopefully to teams of engineering and art majors.

5. Summary

The paper provided a fairly comprehensive review of water fountains that exhibit special effects. The main purpose was to excite the reader about educational potentials that lie in the subject of fountains, and to encourage engineering educators to include relevant work in their courses for students' benefit. Three kinds of class activities were suggested to assist educators in this endeavor. It is hoped that by consulting the cited references, the reader will be inspired to come up with his/her own fountain design ideas to pursue.

The author would appreciate hearing about any project that results from the suggestions made in this paper.

6. Acknowledgements

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Appendix – Resource Guide to Fountains

Examples of books with "how to" instructions for fountains.

Adkins, D., 1999, "Simple Fountains for Indoors and Outdoors – 20 Step-By-Step Projects," Storey Books.

Aurand, C. D., 1986, "Fountains and Pools – Construction Guidelines and Specifications," PDA Publishers Corporation, Meza, Arizona.

Binsacca, R., 1991, "Garden Pools, Fountains and Water Courses," Creative Publishing International, Inc.

Rees, Y., 2002, "Indoor Water Garden Design – 20 Eye Catching Designs to Bring the Outdoors Into Your Home," Barron Educational Series, Inc.

Examples of companies specializing in fountains.

www.wetdesign.com

<http://www.georgia-fountain.com>

www.atlanticfountains.com

Examples of artists who work with water.

www.williampye.com

www.nayerkazemi.com

www.christophercurtis.com

<http://www.broquard.com>

<http://www.jamesdesigns.co.uk>

Examples of manufacturers/distributors of pumps, microcontroller, small parts, etc.

www.eponds.com small submersible pumps, underwater lights, pond accessories.

www.opto22.com relays and control electronics.

www.parallaxinc.com microcontrollers and some electronic parts.

www.smallparts.com small hardware, tools, etc.

Biography

SAID SHAKERIN is professor of Mechanical Engineering at University of the Pacific, where he has been since earning his Ph.D. from Colorado State University in 1986. He is a registered professional engineer in California, and served as department chairman from 1995 to 1998 but stepped down due to medical reason. His teaching encompassed thermal/fluid sciences, instrumentation, and engineering design. Current scholarly activities include design of special effect fountains and educational materials. He is a recipient of a DOE-AWU sabbatical fellowship and DOW-ASEE Outstanding Educator Award.