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DEVELOPMENT OF EXPERIMENTAL SELF-CHOREOGRAPHED DANCING FOUNTAIN

Master's thesis

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Dipl. Eng.

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TALLINNA TEHNIKAÜLIKOOL
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EKSPERIMENTAALSE ISESEADISTAVA TANTSUGA PURSKKAEVU ARENDAMINE

Magistritöö

Juhendaja: Eero Haldre
Dipl. Ins.

Tallinn 2019

Author’s declaration of originality

I hereby certify that I am the sole author of this thesis. All the used materials, references to the literature and the work of others have been referred to. This thesis has not been presented for examination anywhere else.

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Abstract

Art always was considered as an important part of humanity. One form of art is represented by combination of music, light and water movements. It is known as dancing or musical fountain.

Major part of fountain control systems is sending the pre-defined by artist control signals to hydraulic units in certain moment of time, which means that the entire show program has to be pre-programmed. The need was to prototype self-choreographed dancing fountain system, which is reacting on real-time audio signal and automatically synchronizes water movements with music to achieve the artistic effect.

Several iterations were required to move from simple frequency based concept to the complex system prototype. Initial approach to set low, mid and high pass filters to operate different water jets did not give the required artistic effect and demanded to re-consider the overall concept.

Taking into consideration all the potential requirements from artist point of view helped to combine required functionality into one system and define the technology to be used per each module. Some parts of the system are be developed by engineer and some parts re-use existing on the market solutions.

The result of this study is in detail planned self-choreographed dancing fountain concept with audio pattern recognition and hydraulics control pattern modules. The system is in the initial stage and requires further development.

This thesis is written in English and is 71 pages long, including 6 chapters, 39 figures and 4 tables.

Annotatsioon

Eksperimentaalse iseseadistava tantsuga purskkaevu arendamine

Kunsti on alati loetud inimkonna tähtsaks osaks. Üks kunsti vorm on esindatud muusika, valgustuse ja vee koreograafia kombinatsiooni poolt. Seda tuntakse kui tantsiva või muusikalise purskkaevuna.

Põhiline osa purskkaevu juhtsüsteemist saadab kindlatel ajahetkedel kunstniku poolt eelmääratud juhtsignaale hüdraulika moodulitesse, mis tähendab, et kogu vaatemäng peab olema eelprogrammeeritud. Vajadus oli prototüüpida iseseadistava tantsuga purskkaevu süsteem, mis reageeriks reaalajas helisignaalile ja sünkroniseeriks automaatselt vee liikumise selle järgi, et saavutada kunstilist efekti.

Vaja läks mitu iteratsiooni, et liikuda lihtsa helisageduste põhise kontseptsiooni pealt keerulisema prototüüp süsteemi peale. Algne lähenemine seada madal-, kesk- ja kõrgheli filtrid juhtima erinevaid veejugasid ei andnud nõutud kunstilist efekti ja vajas üldise kontseptsiooni ümber mõtlemist.

Kõikide võimalike nõudmiste ja kunstniku vaatenurga arvesse võtmine aitas kombineerida vajaliku funktsionaalsuse ühe süsteemi ja defineerida tehnoloogiad mida kasutada erinevate moodulite jaoks. Mõned süsteemiosad arendatakse välja inseneri poolt ja mõnede puhul taaskasutatakse juba turul olemasolevaid lahendusi.

Selle uurimuse tulemuseks on iseseadistava tantsuga purskkaevu kontseptsioon koos helimustri tuvastus ja hüdraulikamustri juhtmoodulitega. Süsteem on algfaasis ja vajab edasist arendamist.

Lõputöö on kirjutatud inglise keeles ning sisaldab teksti 71 leheküljel, 6 peatükki, 39 joonist, 4 tabelit.

List of abbreviations and terms

API	*Application Programming Interface*
COM Port	*Communication Port*
CPU	*Central Processing Unit*
DC	*Direct Current*
DMX	*Digital MultipleX*
DSPs	*Digial Signal Processors*
DTMF	*Dual tone multi frequency*
FFT	*Fast Fourier Transform*
FIR	*Finite impulse response*
IIR	*Infinite impulse response*
IR	*Infra-Red*
LED	*Light emitting diode*
MVP	*Minimum Viable Product*
PC	*Personal Computer*
PLC	*Programmable Logic Controller*
PWM	*Pulse-width modulation*
RGB	*Red, Green and Blue*
rpm	*Revolution per minute*
US	*United States*
WASAPI	*Windows Audio Session API*

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1 Introduction

Cambridge dictionary says:

Fountain - a stream of water that is forced up into the air through a small hole, especially for decorative effect, or the structure in a lake or pool from which this flows. [1]

Fountains always were considered as Art objects and it was inevitable that someone took this one art object and combined it with another one – the Music.

First musical fountain was created in 19th century and was operated by hydraulic means. Small bells were playing the music while the river was rotating the watermill.

Since that time the technology has evolved a lot and gave us the opportunity to create more and more technologically advanced systems. Fountains are not an exception. Musical fountains were replaced by dancing fountains.

Dancing fountain (also known as Musical fountain) is a type of animated fountains for entertainment purposes. The movements of water jets are synchronized with music to achieve the artistic effect.

Early dancing fountains required an operator to control the jets, lightning and music, which means, that the person was listening the music and at the same time pressing the buttons to control all the equipment.

Step by step human interface was replaced by electronic circuits, but the main progress in dancing fountain automation was achieved in early 80th with help of Programmable Logic Controllers. PLCs were able to pre-program all the required signals to control the hydraulics part.

The programming of PLCs were easy and cheap comparing to creation of specific electronic circuit for different songs. Many fountains over the world were re-designed to be able to use automatic controllers.

These days we have a huge variety of dancing fountains. Installation could be whether really big, like 36000 square meters of Bellagio fountains, or small enough to fit into the backyard. Cost of installation also depends on its complexity and can go up to 100 million euros.

Almost all modern fountains are fully automated and running the pre-programmed shows many times a day.

The key point of the previous sentence is “pre-programmed”, which means that all the control signals are pre-defined by human.

There are also some developments in the market for “self-choreographed" real-time fountains, what can react to random musical input. Such a fountains and especially the control algorithm is the main focus of this Master’s thesis.

1.1 Fountains Progress timeline

Figure 1: Fountain history timeline

- 1820-1822 - First musical fountain. Built by Peter Bodor in the Transylvanian town of Marosvásárhely (now Târgu Mureş, Romania) Operated by hydraulic means.

- 1891 - Křižík's fountain. Built by František Křižík in 1891 on the occasion of the World Exhibition. The bottom of the fountain plate is equipped with 1300 multicolored reflectors and water circuits composed of more than 2 kilometers of pipes with almost 3000 nozzles.

- 1909 - Prismatic Fountain, Denver, Colorado. Eleven columns of brightly colored light stream through the dramatic changing patterns of water. F.W.

Darlington was a pioneer in electrical fountain control as well as water design. Fountain required an operator to change the water effects and lighting

- 1929 - The Magic Fountain of Montjuïc, Barcelona. In the 1980s, an element of music was incorporated to the fountain's light show, which now appears to perform to the rhythm of song
- 1980 – The revolution has started mainly in US. Fully automated Dancing fountains started to appear.
- 1998 - Fountains of Bellagio. Largest at that time. More than 1,200 nozzles that make it possible to stage fountain displays coordinated with more than 4,500 lights. It is estimated that the fountains cost $40 million to build.
- 2009 - The Dubai Fountain. Largest fountain in the world. USD $218 million
- 2012 - India's most spectacular musical fountain – the CESC Fountain of Joy – was inaugurated in Kolkata.

Quite many musical fountains, what we can observe now, were created in mid or early ages of 20th century. Most of them were lacking musical or lightning part in the beginning and were redesigned already at the end of 20th century.

1.2 Current situation on the Market

Almost all dancing fountains in the world, and especially the most famous ones, are using pre-programmed style of choreography for dancing fountains.

There are many dancing fountain control systems in the market, but most of them are proprietary development. There is no common standard on the market.

1.2.1 Most common installation

Even if there is no common standard in the Dancing fountain market, the components of the system are more or less the same from one system to another.

Most common installation for dancing fountains includes:

Pump

Pump can be submersible or external.

Submersible pumps are used when the whole assembly is submerged into the fluid (water in our case) to be pumped. They push fluid to the surface. Such pumps are usually used when dancing fountain is a temporary construction and has to be built inside the pool or pound. Floating dancing fountains are also using submersible pumps.

External of jet pump is assembled outside of the fluid source and pulling fluids through the pipes. External pumps are usually used in the permanent setups and require more complex piping network.

The choice of the pump varies from one application to another.

Different Pump motor drivers are in use to control the motor speed, which allows controlling the water jet height.

Nozzles

Nozzles are connected to the pipes and can modify the jet qualities, such as shape thickness. They can make foamy water or split it into mane small jets.

These days technology allows creating Digital Nozzles with 2 or 3 dimensional rotating possibilities. Digital nozzles allow controlling the direction of each individual water jet and increasing the water dancing effect.

Digital Nozzles is an interesting topic for research, but it is out of scope in this Master's thesis.

Electronic Valves

The main role of the valve is to block water flow in each individual nozzle or the whole pipe. Electronic valves can be controlled by the electric signal, which allows pre-programming their behavior.

Controllers

Controllers are used to send the re-defined signals in time to control all the equipment: pumps (via motor drivers), Digital nozzles, Electronic valves, Light etc.

PLCs were the most common application during the long time, but now it is more and more replaced by DMX controllers.

DMX technology (actually the name is DMX512, but usually it is shortened) is an electronic protocol used in lighting technologies to control shows lighting, allowing communication between the lights control equipment and light sources. [10]

DMX is usually used in more complex projects with a lot of components used independently and PLC is still used in projects with a physical grouping of common elements.

Computer with Fountain control software

It is the main point of interest in frames of this Master's thesis. Usually the controllers are programmed with specific software. Almost every major company in Dancing Fountain market is using their proprietary systems.

Specific software allows for Artist to define the fountain movement in time domain to synchronize them with the specific song. This software transforms the Artist's vision into the signals required to control every part of the system and saves this "program" to the Controller.

In some cases signals are not saved on the controllers but information is send to Controller from the computer in real-time and Controller forward this signals to the relevant component.

Lights

Also Video or Laser projector, RGB LEDs or movable head Lamps can be used to increase the artistic effect.

Here is the example for the usual Dancing fountain setup from Paai Company:

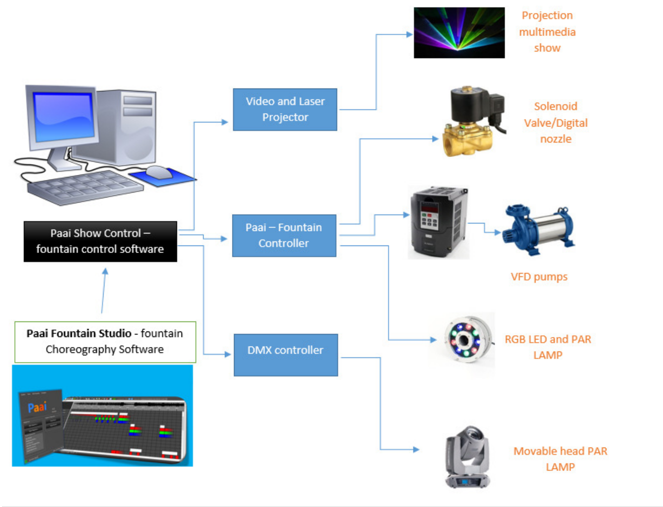


Figure 2: Example. Paai company components chart [7]

Our days almost all musical fountains have similar components and even if technology is different, the approach is more or less the same.

- Almost 100% of dancing fountains are pre-choreographed, which means that all control signals are pre-defined. Not real-time.

- Almost 100% of dancing fountains are big or even huge, so they are not applicable for in-house use in small rooms or in apartments.

Only few companies are developing self-choreographed dancing fountain systems these days. Most successful is H2OArts (www.h20arts.com). They have couple of commercial implementations already, but, of course, we are talking about really small fountains comparing to the leaders on the market.

1.3 What is the need?

It is true, that more and more cities, casinos, shopping malls are interesting in installing different versions of dancing fountains on their premises to attract more people. At the same time ordinary people are also interested in decoration their back yards and dancing fountains could be a good option to impress guests.

What about small restaurants or even apartments? We can have dancing fountains there as well, but the specifications for such a fountains are already different than the other ones.

It has to be:

- Standalone product, which is easy to deploy.
- Size is not bigger than 1 m^2.
- The cost is also matters and it can be reduced by using less powerful and cheaper components: pumps, motor drives and electronics controllers.

The main thing, this Dancing fountain has to be able adjusting the "Show program" in real-time. There is no option that someone will pre-program every water jet for all the songs playing out of the loudspeakers. So, it would be reasonable to implement the technology to avoid human interaction in pre-programming.

It is necessary to design the control system for musical fountain which meets the following requirements:

- Able to read the signal (Musical signal in my use case, but it can be any other signal) from external environment. Use of microphone.
- Analyze this signal in real-time.
- Send control signals to motor drives and electronic valves.

Other words, the Dancing fountain control system has to be self-choreographed.

The ultimate goal is to build the full system with the criteria described above, but the main focus of this Master's thesis is the research and tests of the best appropriate algorithm to be used in self-choreographed dancing fountain.

Also, for now the exact control signals to all the components will be based on pre-defined hydraulics part, but they are not final, because hydraulics part most probably will be changed in final application. What is more important is to understand how to analyze the incoming sound signal and what water behavior has to follow after this analysis.

2 Pre-requirements / Preparations

Despite the fact that I am focusing on research and analysis of best possible algorithm required to build the self-choreographed dancing fountain, it is necessary to define the hydraulics and electronics parts and perform some tests first.

I have to define the hydraulics parts to know what signals I have to send to control them. Even if the component brands or models will be changed in future, the common approach will stay the same or similar to current one.

Combination of Hydraulics and Electronics parts is the toolbox and the environment for testing the self-choreographed algorithms.

It doesn’t necessarily mean that same hydraulics or electronics parts will stay in final product. For now it just represents the minimum requirements to start the control algorithm development and testing.

Even if the main goal of this Master’s thesis not to build the fully operational system, the initial idea is not simply to define the components, but also purchase them for testing purposes. There are too many uncertainties with this project and real life testing will help to eliminate or minimize these uncertainties.

Please also note that the choice of fountain parts is not final and contains a lot of compromises in respect of price/quality combination.

Selection of proper components for production system is a topic for another case study.

2.1 Hydraulics parts

Submersible pump: JT-500-12V

Water pump to be used to pump the water and create the water jet. One pump is used per one set of Nozzles. It can be just one or plenty of nozzles (holes) controlled by one Water pump.

Specifications:

- Size:105mm(height)*38mm(diameter)
- Water Outlet Outer Diameter:12mm
- Water Outlet Inner Diameter:9.7mm
- Rated Voltage: 12V
- Working Voltage: 6-12V (Maximum 15V)
- Rated Current: 1.2A
- Maximum Lift: 5M
- Maximum Flow Rate: 60 0L/Hour
- Cable: Three core
- Cable Length: 1.5m

Wire Connection:

1. Brown cable connects the Positive Pole "+"
2. Blue cable connects Negative Pole "-"
3. Yellow cable is GND, don't need to connect.

Important Information:

The temperature of the water cannot be over 40 degree.

Seller has indicated one important point about this pump: “This is the brush pump, so it cannot be used continuously, or the lifespan of the pump will be short. Suggest relaxing 1 hour after using 2 hours to extend the lifespan of the pump.”

This information clearly states that this pump can’t be used in dancing fountain system, but quite Ok for testing purposes.

G1/2" Plastic electronic valve

Blocks the output of water for the pipe or for the individual nozzle until the proper signal is send. Electronic valve is closed until the voltage is applied.

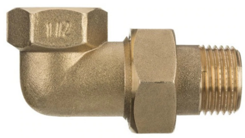
Specifications:

- Use fluid: Water
- Type: Normally closed
- Voltage: AC220V DC12V DC24V
- Size: G1/2"
- Pressure range: 0.02 ~ 0.6mpa
- Temperature range: 0 ~ 80 °

Pipes and Pipe Joints

Pipes and pipe joints will be used in hydraulics part of test model. This is something what is not related to electronics or control system part, but you can't ignore it while working on any of Dancing fountain subsystems.

Specifications:



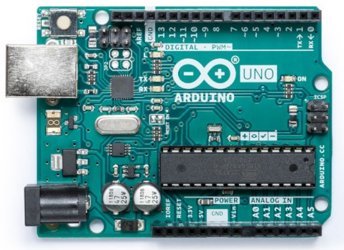
- Pipe size: D12/16 mm
- Joint size: 16mm

2.2 Electronics Parts

Arduino Uno

Arduino's main role is to control the Hydraulics part with PWM signal. Level of Signal processing logic on the microcontroller was changing during the research process.

Specifications:



- Microcontroller: ATmega328P
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limit): 6-20V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- PWM Digital I/O Pins: 6
- Analog Input Pins: 6
- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 32 KB (ATmega328P) of which 0.5 KB used by bootloader
- SRAM: 2 KB (ATmega328P)
- EEPROM: 1 KB (ATmega328P)
- Clock Speed: 16 MHz
- LED_BUILTIN: 13
- Length: 68.6 mm
- Width: 53.4 mm
- Weight: 25 g

Important Information:

Arduino Uno Board was chosen as test environment for 2 reasons:

1. Big variety of libraries. Way easier to get the working prototype than with other Launchpad's.
2. I already had it in my "Electronics box".

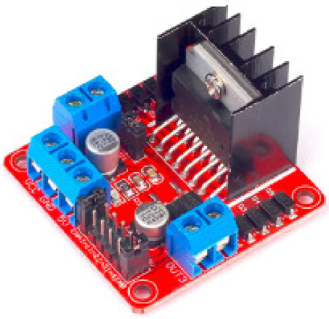
It will be replaced in production environment. Not powerful enough for Signal processing

Motor driver with L298N chip, H-Bridge, PWM

Motor driver controls the speed of DC motor in the Water pump, which follows with changes of the water jet height.

Specifications:

- Work mode: H bridge drive (double)
- Main control chip: L298N
- Logical voltage: 5V
- Drive voltage: 5v-35v
- Logical current: 0mA-36mA
- Driving current: 2A (MAX single bridge)
- Storage temperature: - 20 ℃ to + 135 ℃
- Maximum power: 25W
- Weight: 30 g
- Peripheral dimensions : 43*43*27m



Important Information:

1. When driving voltage is less than 12V, on-board 5V power supply can be used to power the Microcontroller or other board.

2. When the driving voltage is higher than 12V, 5V power supply can't be used.

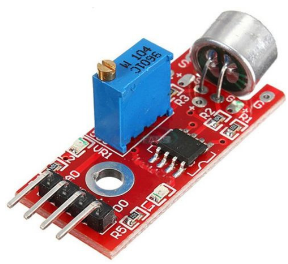
Use board jumper to control these modes.

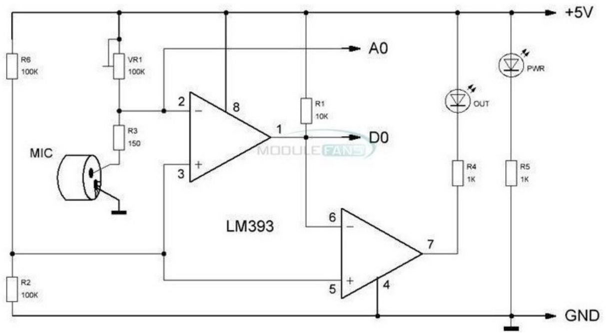
Arduino Microphone Module

Electret microphone with amplifier on-board. To be used for sound detection.

Specifications:

- Voltage : 3.3v to 5v
- Differential Comparator : LM393
- Microphone : Electret condenser
- Size : 45mm x 17mm x 10mm (length x width x height)





Connection to Arduino

1. Pin + to Arduino 5+
2. Pin - to Arduino -
3. Pin A0 to Arduino A0 (for analog program)
4. Pin D0 to Arduino 13 (for digital program)

Important Information:

This module has configurable sound level.

- The sound level setpoint is adjusted via an on-board potentiometer clockwise more sensitive and counter clockwise less sensitive.
- When the sound level exceeds the set point, LED on the module is illuminated and the output is sent low.

Arduino IR Remote module

Remote to be used in testing purposes to send control signals to Arduino.

Specifications:

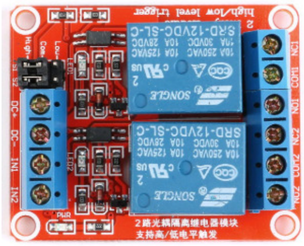
- Battery: CR2025
- Transmission Distance: up to 8m
- Effective Angle: 60°
- Static Current: 3~5uA,
- Dynamic Current: 3~5mA

Relay

Power electronics can't be controlled directly from low voltage Arduino pins. This relay will be connected to Electronic Valve and to be controlled by Arduino. When control signal is applied and relay is on – the Electronic Valve will get the power signal then.

Specifications:

- Max Voltage: 12V
- Control signal: 3-5V
- Channels: 2



2.3 Hydraulics Test Model

As I have mentioned before, building the real life model of dancing fountain is out of scope for this Master's thesis, but before starting the algorithm development it was necessary to define hydraulics and electronics parts and also run couple tests understand the water behavior and eliminate the uncertainties.

The following model of fountain hydraulics part was created:

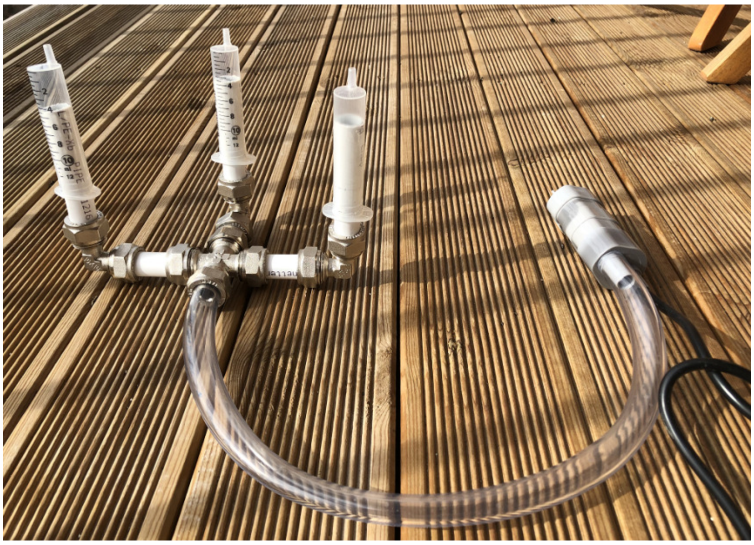


Figure 3: Hydraulics test model

Even if this model has 3 nozzles (syringes in my case), all of them are connected to one water pump. So, it was done more for artistic than for practical purpose.

2.4 Preparation tests

I had some vision in my mind, how water jets should response the certain signal, but I was not sure, will the situation be the same in reality or not. Previously, in my life I had no experience working with water pumps and especially with water pumps in fountain applications. Some tests had to be done.

In addition to getting the overall idea how water pumps work I also wanted to test 2 aspects of dancing fountain system:

1. Water jet delay
2. Water behavior with Electronic valves

2.4.1 Water jet delay

If we think about electricity or light quite often there is no point to worry about the signal delay, but the situation is different with fluids.

Frankly speaking I had no idea what could be the delay of water jet after PWM signal is sent to Motor Driver. The main question for the test is it possible at all to create real-time responsive system because of water delay or not.

If the delay will be more that 2 seconds, it would be necessary to consider the alternative approach.

One of the ideas is to send musical signal to the control environment a little in advance (delay time) and only then play it through the loudspeakers. This approach would solve the problem, but will definitely add complexity to the system and decrease the system flexibility.

Already existing hydraulics test model will be used for water jet delay testing. Knowledge and information achieved during the first test will help in the whole project in future.

The Electronics (control) part presented below:

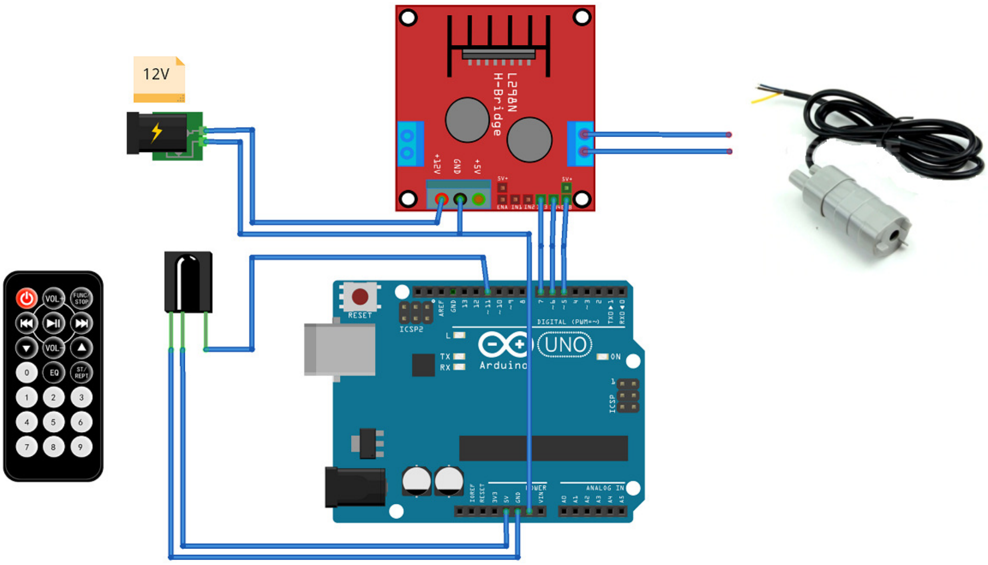


Figure 4: Water jet test control part

The control part of my test environment contains:

1. Arduino Uno as a central unis. It processes the received signals and sends signals to control the hydraulics part

2. Motor driver controls the speed of water pump motor. Controlled by PWM signal from Arduino.

3. IR transmitter/receiver combination is programmed to control the PWM signal from Arduino.

4. 12V Power supply is used to power the water pump motor and motor driver

5. Submersible Water pump pushes the water

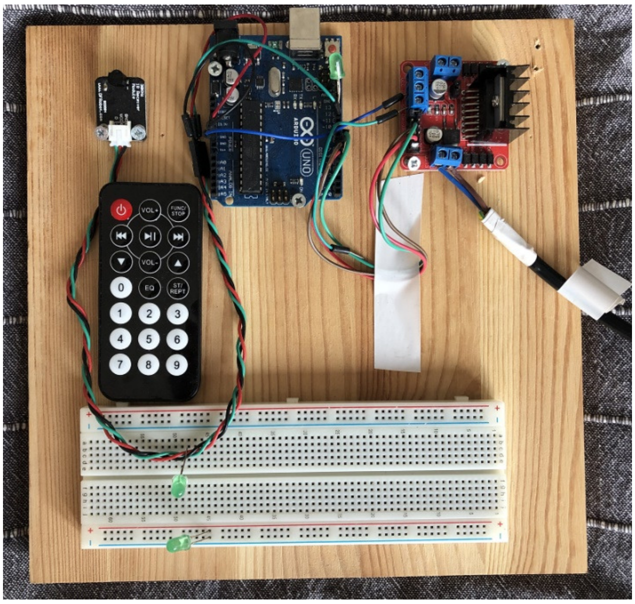


Figure 5: Real life model of Control part

Arduino Uno can write an analog value (PWM wave) to a pin. Supported pins: 3, 5, 6, 9, 10, and 11.

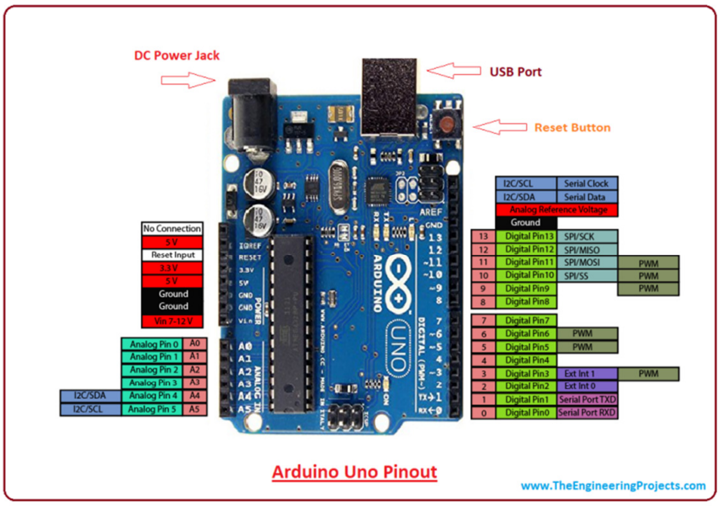


Figure 6: Arduino Uno pinout

PWM signal can be used to light a LED with different brightness or drive a motor with different speed. After a call to analogWrite(), the pin will generate a steady square wave of the specified duty cycle until the next call to analogWrite().

Syntax: analogWrite(pin, value)

Parameters: pin: the pin to write to. Allowed data types: int. value: the duty cycle: between 0 (always off) and 255 (always on). Allowed data types: int [12]

From the documentation we can see that the range of analogWrite() value is from 0 to 255.

I've programmed the IR remote buttons 1, 2 and 3 to change Arduino Uno PWM signal on pin 5 to 100, 150 and 200 accordingly.

```
int speed;
…
     //Speed control
     if (results.value == 16599223)     speed = 100;  // Button 3
     if (results.value == 16591063)     speed = 150;  // Button 4
     if (results.value == 16623703)     speed = 200;  // Button 5
…
analogWrite(EnB, speed);
```

Also I've added the Motor turn on and turn off logic as described on the table below:

Table 1: L298N Motor Driver control logic

Input 1	**Input 2**	**Result**
LOW	HIGH	Move Forward
HIGH	LOW	Move Backward
LOW	LOW	Motor Stop
HIGH	HIGH	Motor Stop

```
 // Turn ON motor
if (results.value == 16593103) { // Button 0
   digitalWrite(In3, LOW);
   digitalWrite(In4, HIGH);
   speed = 100;
}
```

Please see the full code in Appendix 1.

After all the installation was done and Program code was loaded into Arduino I was able successfully run the test.

Test Outcome:

Water jet delay was really small. Less than half a second. It was not visible for human eye. The height of the water jet was changing right after clicking the button on the remote. The result is good and allows moving on with the initial idea: system will read and analyze the sound signal real-time.

2.4.2 Electronic / Solenoid Valve

To perform this test it was necessary to modify the hydraulics part of my test environment. Electronic valve was added to the circuit. Expected behavior is to have the water shoots out of the nozzle when valve is open for one second or less.

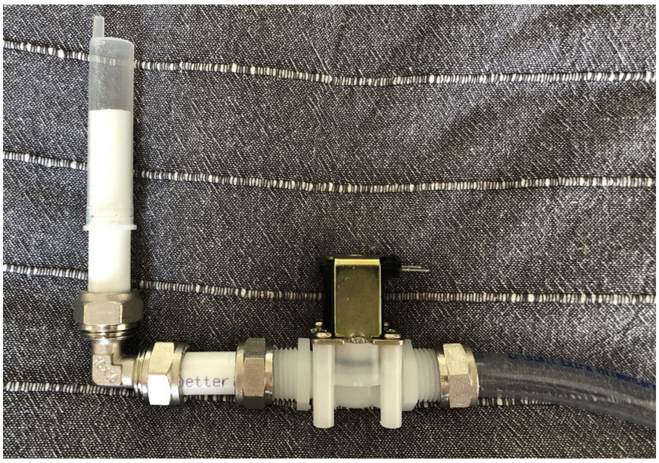


Figure 7: Electronic valve test

I've decided not to create the complex systems, but just to connect 12V DC power to Electronic Valve with ON/OFF switch. After starting the water pump, I've just played with the switch and observer the result.

Test Outcome:

The test has failed: For some reason the water jet height was too low. Almost no jet, just slowly flowing water.

I don't think that the problem is with electronic valve, because I heard the 'Clicks' when 12V voltage was applied and water started to flow. Most probably the pump is not powerful enough to push the water through the Valve.

Anyway, I decided not to spend a lot of time to solve this problem, but just to eliminate the Electronic valve from my fountain system for now. Such valves with the expected water behavior will definitely add the artistic value to the system, but hydraulics part is not the main goal for this Master's thesis. Secondly, when the control logic is defined, it is planned to extend the hydraulics part not only with electronic valves but with electronic nozzles as well.

2.5 Preparation results

For now we have:

- Suitable for our application water delay after sending the control PWM signal.
- Physical test model to perform the tests of water jet behavior
- Knowledge acquired during the preparation tests is a good starting point.

After all the preparations and tests are done, it is possible to move on with the main topic – self-choreographed dancing fountain control logic.

3 Light Organ approach

The idea is to use Light organ approach in dancing fountain application.

Light organ is a device which separates the musical spectrum into frequency bands (called channels) and blinks the lamps in time with the music. Usually music is separated into low, mid, and high frequency bands (sometimes even more) and one or many colored lamps are driven from each channel – usually red for the high frequencies, yellow for mid, and blue for low. [14]

Figure 8: Light organ example [13]

In Dancing fountain application the plan is also to use 3 frequency bands. Each band will be attached to one (or many) pumps with motor drivers. Each motor driver reacts to the filtered musical signal and sends PWM signal to the pump if related frequency exists in the filtered signal.

Also, volume (also known as loudness) should be considered in the algorithm. Loudness should play the reference role for the highest and lowest water jet (biggest and smallest PWM signal).

The initial plan is to use FIR [16] filters to split audio signal into three bands. [15]

The concept looks like this:

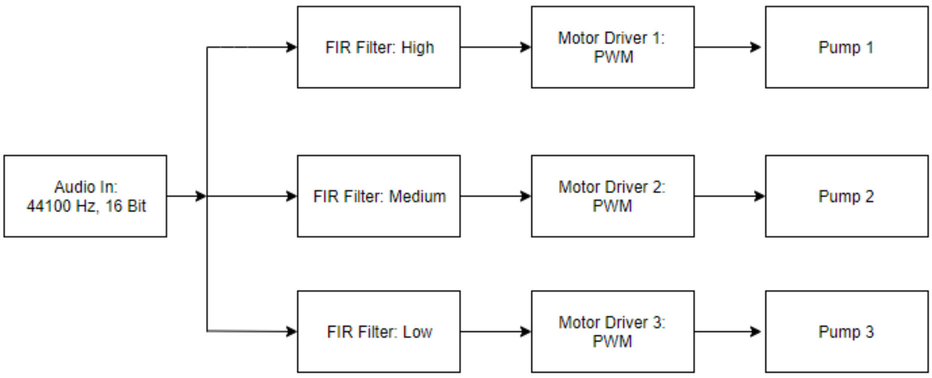


Figure 9: FIR filter to Dancing fountain concept

3.1 Microphone & Arduino: Volume application

Before FIR filters implementation it is necessary to connect the microphone module to my test environment and check, is real-time sound analyzing work at all. I've decided not to start with sound signal filtering right away, but decrease the complexity first and make water jet reacting to loudness.

IR transmitter/receiver was eliminated from the system and microphone module was connected to Arduino board. This module has built-in amplifier which makes things easier. Module is connected to power and to Arduino's analog input A0 [17].

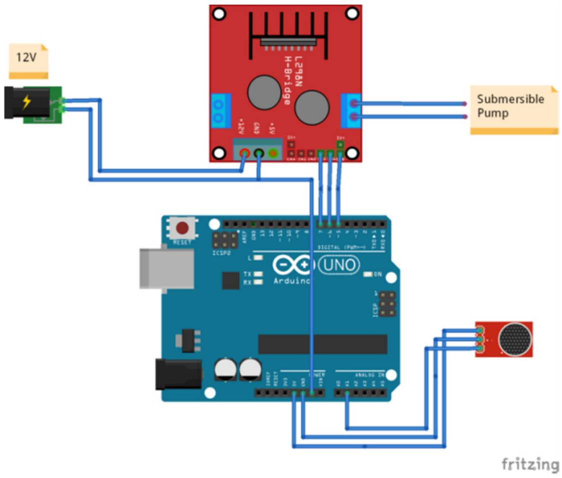


Figure 10: Microphone module connected

3.1.1 Program and Simulation

I've configured the Microphone module's potentiometer to have the baseline at around 700 and decided to implement the following logic:

- Analog signal value 700 equal to PWM value 100
- Difference (more or less) is added to PWM value
- If PWM value higher than 250 – it is equal to 250

Please see the full programming code in Appendix 1.

Here is the plotted signal for PWM values (speed variable)

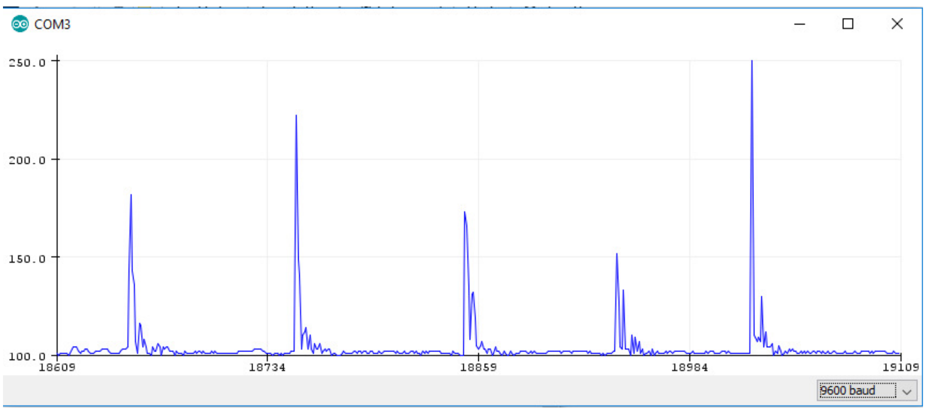


Figure 11: PWM signal for Hand clapping

3.1.2 Real-model tests

When program code was ready, I've connected the Electronics part to hydraulics part to perform the test. It was also necessary slightly modify the program logic, because clapping hands gave much higher values than music (probably, the influence of air flow from the hands).

```
speed = (abs(sensorValue - 700))*9 + 100; // analog value to PWM value
```

I've multiplied the change in music loudness by 9 and the amplitude became more reasonable.

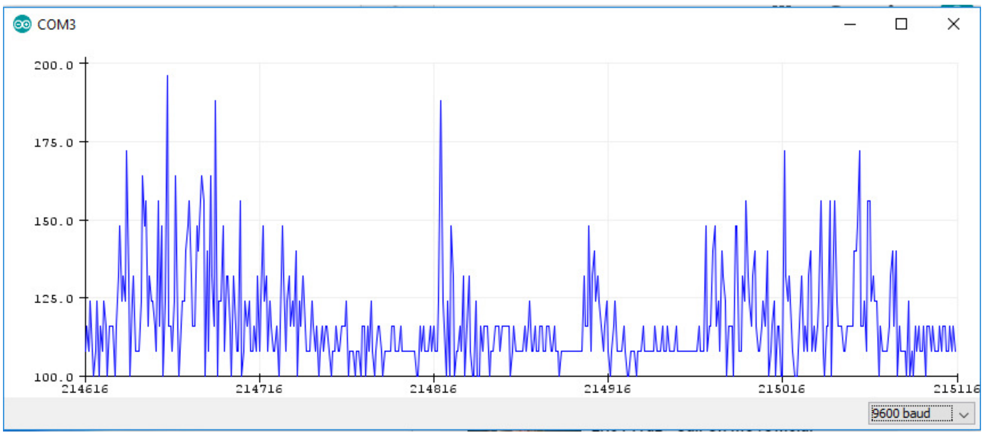


Figure 12: Multiplied Musical signal

With such an approach the changes in water jet height became more reasonable. They have also reflected the changes in music loudness quite well.

Test Outcome:

The loudness test is successful. Water behavior is as predicted. I can move on with filtering the signal. In this test the loudness variable was applied to the original signal, but when high pass, band (middle) pass and low pass filter will be implemented, the Loudness variable will be applied for each band separately.

3.2 Matlab & Arduino: Filters

After successful testing of controlling the water jet with sound loudness, next step would be to implement the light organ logic on Arduino Uno with three FIR filters.

Despite the fact that Arduino can read signal voltages from the analog pins and it is good as one stop shop for all the tests – after reading Arduino specification in more details I've realized that it is not fast enough to read and filter audio signals in real time.

I had nothing to do than find an alternative way for filtering my sound signals. I've considered Texas Instrument DSP Starting kit (development board) and Raspberry Pi as an alternative, but as final solution I've decided to use the MatLab and Arduino combination.

The idea is to move all the resource intensive processes out of Arduino to PC.

The final system was separated into:

1. Matlab on PC: Read the real-time sound signal, analyze it and send the PWM values to Arduino via USB

2. Arduino: Receive the PWM values from MatLab and send control PWM signals to Motor Driver. No microphone needed.

Such an approach would fit my needs as I am not producing the final product and not selecting the spare parts for final product now, but making research about the most appropriate controlling algorithm.

3.2.1 Matlab: real-time audio

At first it is necessary to read the real-time audio from computer microphone in Matlab. There are plenty of options how to implement this and after investigation, I've decided that the easiest way is to use Matlab built-in "Audiorecorder" object. [18]

Please see Appendix 2 for Matlab codes.

It is possible to put the Matlab code into the loop and it will sample the audio every 0.5 seconds using signal from PC microphone (default device).

As MATLAB Audiorecorder records not audio data only, but the variety of other properties as well. To be able to analyze and filter data we have to convert it into the numerical array

If sampling rate is 8000 in one second and I am sampling 0.5 seconds. Each sample will contain 4000 values in array.

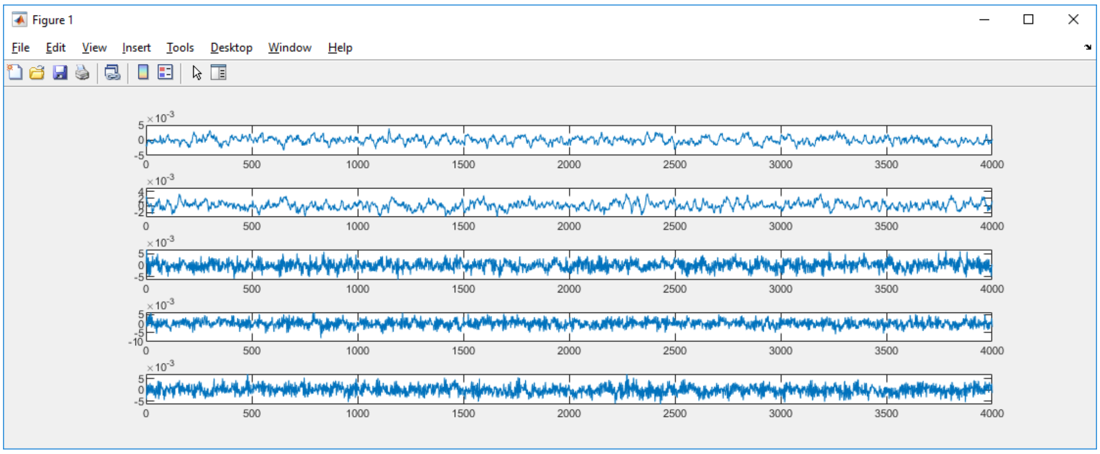


Figure 13: Real-time audio signal / 0.6 seconds samples

3.2.2 Matlab: Filters

Matlab has a good filter designer. Even if the outcome of this designer is just a line of code, it is still easier (for me) to use it. Please note that Signal Processing Toolbox has to be installed in Matlab.

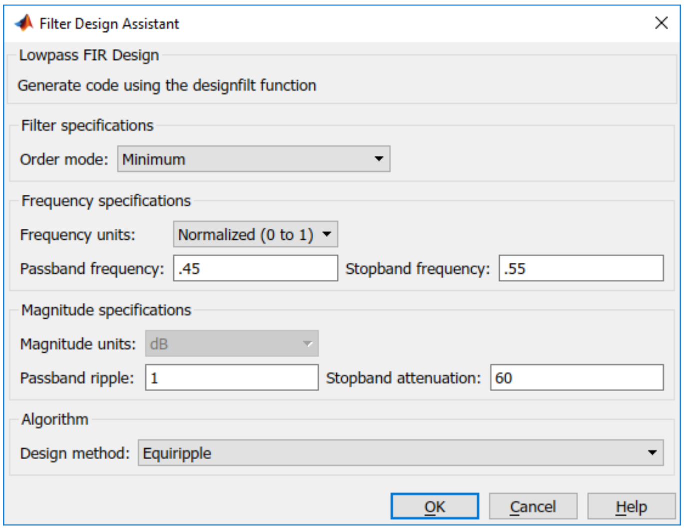


Figure 14: Lowpass FIR Filter design window

Frequency bands were chosen based on a traditional color organ design as follows: Low Channel 60-150 Hz, Mid channel 200-600 Hz, and High channel 800-2200 Hz. [14]

I've used the following parameters in my Low-pass filter:

```
filtlp = designfilt('lowpassfir', 'PassbandFrequency', .13,
'StopbandFrequency', .15, 'PassbandRipple', 1,
'StopbandAttenuation', 60);
```

Band (mid channel) filter parameters:

```
filtbp = designfilt('bandpassfir', 'StopbandFrequency1', .2,
'PassbandFrequency1', .22, 'PassbandFrequency2', .58,
'StopbandFrequency2', .6, 'StopbandAttenuation1', 60,
'PassbandRipple', 1, 'StopbandAttenuation2', 60);
```

Parameters for High-Pass filter:

```
filthp = designfilt('highpassfir', 'StopbandFrequency', .78,
'PassbandFrequency', .8, 'StopbandAttenuation', 60,
'PassbandRipple', 1);
```

After running the code many times and analyzing the results, I've decided:

1. Change from FIR to IIR filters, because accuracy is not as important in my application as speed. In Matlab it was just necessary to change parameter 'lowpassfir' to 'lowpassiir'.

2. Increase sampling rate from 8000 to 16000. Probably I will decrease it back again, but with such a rate, filter graphs looks more accurate.

3. Decrease the sampling time to 0.3 seconds. Not sure yet about this variable, because when I will send information to Arduino to control the Pump motor, how many times should I do that in one second? Filter is applied only after sample is taken, so I have to decide, will I send data to Arduino 2 or more times per second.

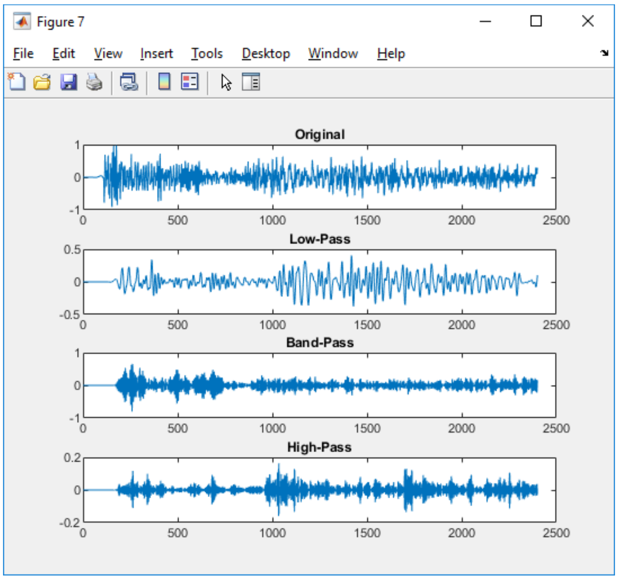


Figure 15: Individual sample of the signal

As we can see from the images above, the signal is filtered quite well. The amplitude of every band is different per sample, which means that the behavior of water jet attached to each frequency band will be different and will change from one sample to another.

The other question is: Even if water delay is small, I can't send all the 8000 values per 0.5 seconds (if sampling rate is 16000).

Every signal or filtered signal is represented as array. In our case (0.3 second sample) original signal and each filtered signal has 2400 values in one array.

Instead of using absolutely all values I've decided to take the maximum value from each sample for every band. The results are the following:

```
Real 0.81635;Low-Pass 0.41573;Band-Pass 0.4035;High-Pass 0.15339;
Real 0.97629;Low-Pass 0.4057;Band-Pass 0.65763;High-Pass 0.16412;
Real 0.99997;Low-Pass 0.84957;Band-Pass 0.57048;High-Pass 0.10366;
Real 0.87512;Low-Pass 0.5446;Band-Pass 0.59478;High-Pass 0.07632;
Real 0.64154;Low-Pass 0.51937;Band-Pass 0.35554;High-Pass 0.12107;
```

It is possible to use these values to send to Arduino Uno via Serial port, represent them as PWM signal and send them to Motor Driver.

Full Matlab and Arduino codes can be found in Appendix 1 and 2.

I've tested the real-life model with Low pass filter signal and the success of my tests and the light organ approach in total is under a big question mark.

3.3 Light Organ approach outcome

If we will start to analyze the Master's thesis topic, then the goal is accomplished. I got the working real-time self-choreographed dancing fountain. Water jet movements are synchronized with the real-time musical signal and they are changing in time using the parameters from this signal.

It works and from technical point of view it looks fine, but from artistic point of view it is a total disaster. What I got as an outcome is not the Dancing fountain but just a jumping water. It can't be used as a real-life application. I don't really want to have it in my apartments.

Anyway, all these actions were not waste of time. Many things were achieved and some lessons learned.

1. New technology tested, such as Matlab & Arduino combination.
2. Light organ approach can be used for standby/idle mode as a background. “Show mode” of real-time dancing fountain has to be developed different way.
3. Difficult to test without the real-time model. Almost at every stage the first assumption after real-life testing was disproved and approach was changed. Real-life model or simulation software required.

Master’s thesis work is not finished yet. I’ve decided to move on with further research of possible solution.

4 Experimental Self-Choreographed Dancing Fountain Concept

After making the live model of a dancing fountain with Light organ approach, it was clear that this solution “technically” works but has no much artistic value.

Checking the other music visualization technology available on the Market did not give much more information as well.

There are quite many companies in the world which are dealing with music visualization algorithms. I am talking not about water visualization, but about so called light music on Computer music players, such as iTunes, Windows Media player and, of course, old fashioned Winamp.

All of these visualization effects look really different and it makes sense, because it is possible to use a lot of different colors, shapes and figures. Literally, the amount of variations is unlimited. But the logic behind all these music visualization algorithms [19] is more or less the same.

It is necessary take a certain amount of the audio data (short time slices, usually less than 20 milliseconds) and run a frequency analysis over it. The obvious way to do the frequency analysis is with an FFT. [20] So, the visualizer does a Fourier transform on each slice, extracting the frequency component and uses that data to modify some graphic that's being displayed over and over.

How the visual display is updated in response to the frequency info is up to the programmer to decide. Same like I had in the light organ approach, the graphics methods have to be extremely fast and lightweight in order to update the visuals in time with the music. But in my use case water is changing not so fast, so the sampling rate has to be way slower.

Other words, to visualize the music it is necessary to move from time to frequency domain, get frequencies of a musical signal at certain period of time and add some logic on top of that.

This is more or less the same what I already did in previous chapter, which means that I need not just to change the technology but fully re-consider the development approach.

4.1 Artist's point of view

As it was necessary to change the way of thinking, I've decided to see the problem not from the Engineer, but from the Artist point of view. Let's name it Top – Down approach.

After all the previous tests it became clear that implementing only one algorithm (FIR filter, FFT with extra logic etc.) is not enough. The self-choreographed dancing fountain system has to be configured by someone. In my case it should be the Artist. To make it simple, the Artist has to be able to configure two things:

1. Define the musical pattern, when the fountain has to perform something specific
2. Define the movements of the fountain per each musical pattern.

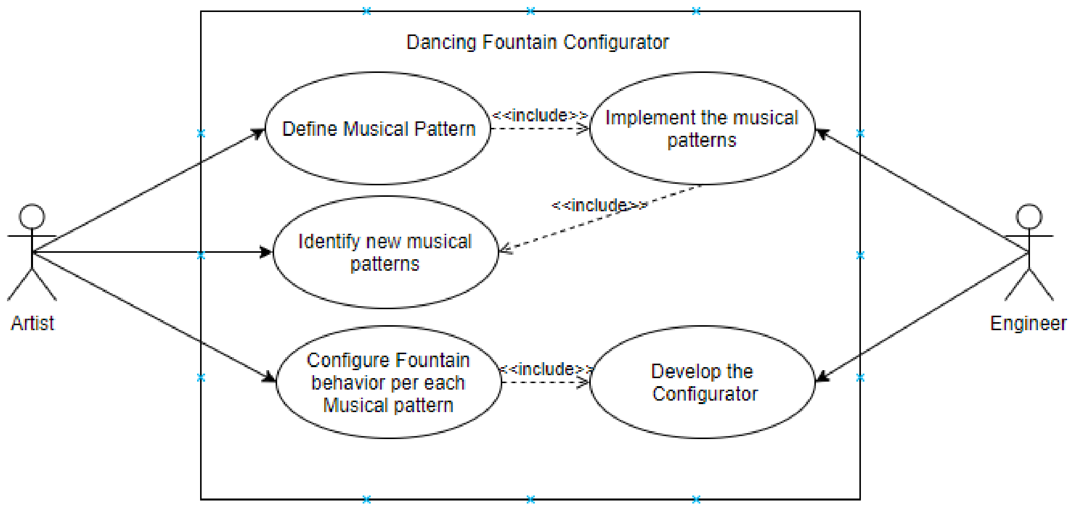


Figure 16: Fountain Configurator Use case

This means from Artist point of view that he or she has to choose the appropriate audio signal pattern from the library, which means that it has to be added to the library by Engineer, which means that it has to be defined by Artist first.

The musical patterns can be different, for example:

- Specific musical instrument: drums (bass, splash cymbal etc.), violin
- Specific piano note
- Specific moment of the song
- Specific behavior of the sound wave: quick jump from quiet to loud music

I have to consider that the Artist is not a programmer and not the technical expert. When the artist hears the specific sound he or she just wants the water jets to move this or that way. So, it is necessary to give the artist a tool to configure the dancing fountain behavior.

4.2 Fountain Behavior Configurator

To make the system work, as we have defined above, Artist has to:

1. Select the appropriate audio signal pattern
2. Define the appropriate control pattern for the fountain

The high level overview of the system looks like this:

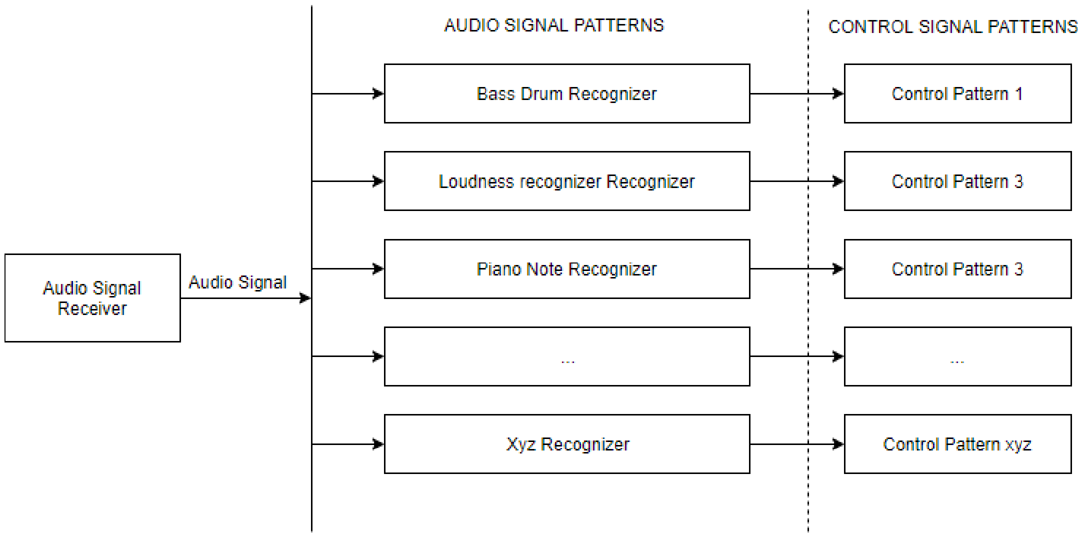


Figure 17: Overall concept overview

4.2.1 Audio Signal Patterns

So, the first step for control system would be to analyze the incoming signal. Acoustical pattern recognition is quite actual topic these days and there are quite many ways to analyze the audio signal and find the patterns inside the signals. In my prototype of self-choreographed dancing fountain system I will consider three types of pattern recognition:

1. Algorithmic functions
2. Fingerprinting
3. Machine learning

4.2.1.1 Algorithmic functions

It is the most known technology in audio pattern recognition fully based on Mathematical calculations.

Such an approach can be used to detect the loudness pattern detection or in single, “pure” tones detection.

For example the pure tone detection is in use in DTMF technology. It is the signal to the phone company that you generate when you press an ordinary telephone's touch keys. Such a tone inside the signal can be detected by FFT or by Goertzel Algorithm [28]. The second one is faster and requires less CPU power.

As with the FFT, Goertzel algorithm works with blocks of samples. However, that doesn't mean it is necessary to process the data in blocks. The numerical processing is short enough to be done in the very short interrupt service routine that is gathering the samples.

In case of dancing fountain patterns there are no many specific algorithms required. As an example, please see the activity diagram for change in Loudness detection.

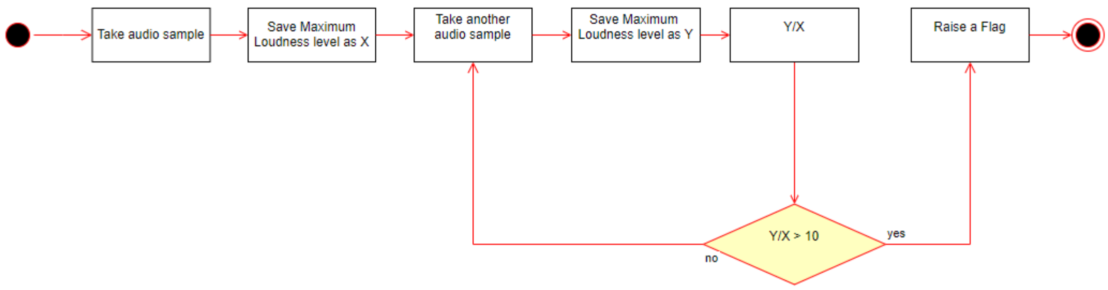


Figure 18: Loudness change detection

This can be used, for example, if Artist wants to "shoot" from all the nozzles if there really huge change in loudness in a short moment of time.

If we are talking about music sample, voice or sound effects recognition then algorithmic approach is not the option.

4.2.1.2 Fingerprinting

Second type of audio pattern recognition is known as fingerprinting [26].

Fingerprinting approach is good if it is required to compare the sample of audio signal to another audio signal in order to see if they both are coming from the same song or audio source.

For example, if artist has the certain song in playlist and he or she would like the fountain to behave specific way at the certain moment of the song, there are 2 options for this scenario:

1. Use timer and start specific Control pattern at the certain moment of time.

2. Use Fingerprinting to find this specific moment of the song and run specific Control pattern at that moment.

Fingerprinting is recognizing the exact match, not the pattern. For example if we want to recognize the fire alarm in audio signal and we will create one fingerprint for specific fire alarm – only this fire alarm will be recognized and all the rest will be missed.

Audio fingerprint can be seen as a compressed summary of the corresponding audio object/audio sample. Mathematically speaking, a fingermark function F maps the audio object X consisting from a large number of bits to a fingerprint of only a limited number of bits. So, the entire mechanism of extraction of a fingerprint can be seen as a hash-function H, which maps an object X to a hash. The main advantage why hash functions are so widely used in the field of computer science is that they allow comparing two large objects X, Y, by just comparing their respective hash values. Such an approach requires less computing resources.

General schema of fingerprint creation

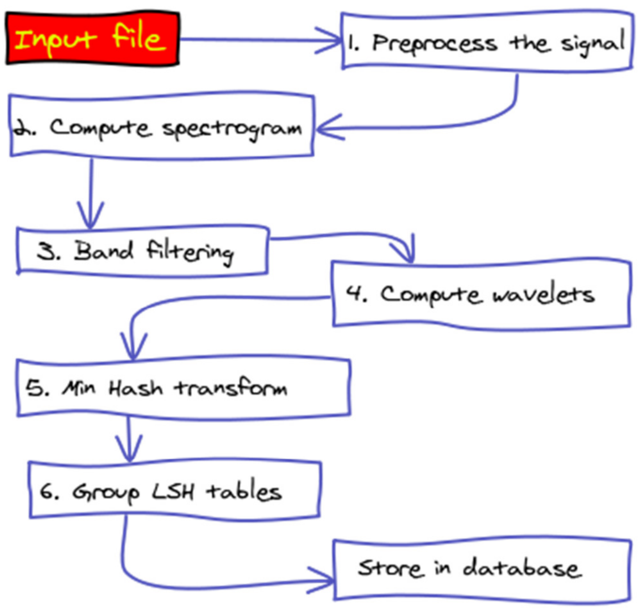


Figure 19: General schema of fingerprint creation [26]

There are quite many Audio fingerprinting frameworks [27] on the market and they can be used for the audio signal processing in self-choreographed dancing fountain control system.

The problem with the fingerprinting is that you can only recognize the perfect match, which is not so common if audio signal will come from the real environment. It is not possible fully avoid noise and extra sounds. But in my use case such an approach makes sense, because the real-time audio data will be taken directly from the computer's sound card, without any noise and extra sounds. Please see Prototyping chapter for more information.

4.2.1.3 Machine Learning

The state-of-art in computer vision, speech recognition, and audio pattern recognition is to use neural networks that do not require engineers to develop complicated algorithms. Instead, given a lot of training data, the neural network can learn to recognize the patterns on its own.

Machine learning is the idea that there are generic algorithms that can tell you something interesting about a set of data without you having to write any custom code specific to the problem. Instead of writing code, you feed data to the generic algorithm and it builds its own logic based on the data. [29]

Same generics algorithms can be used to be trained for different purposes, for example same kind of classification generic algorithm can be trained to recognize the handwriting letters and at the same time to classify if the email spam or not.

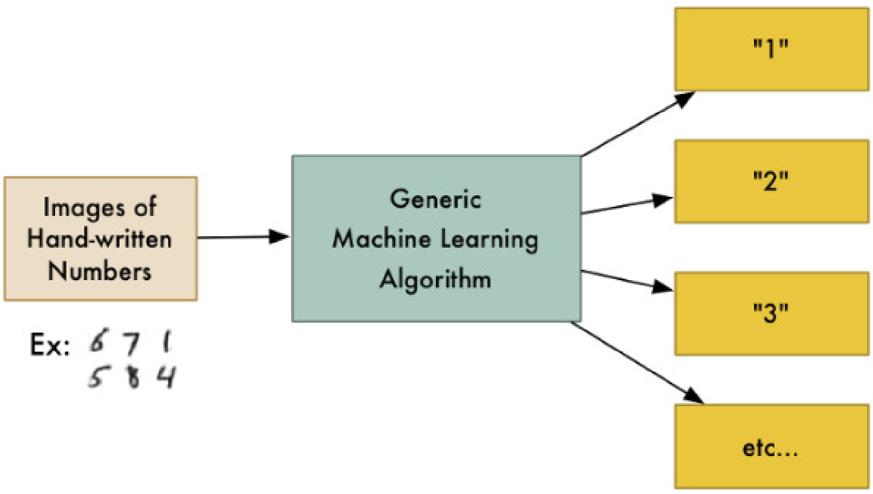


Figure 20: Machine learning / handwriting recognition [29]

There are a huge variety of different machine learning algorithms and the main goal is to choose the correct one to train for specific requirements.

Same approach can be used for sound classification.

Advantage of Machine learning approach that such a system can be trained to recognize:

- Individual note
- Individual musical instrument
- Specific musical pattern

Especially the Specific musical pattern point is interesting for dancing fountain approach. If artist find some specific musical pattern which he can hear from one song to another, it might be difficult or even impossible to describe it by mathematical function, but the machine learning algorithm can be trained to recognize these patterns.

The disadvantage of machine learning approach is the requirement of a huge amount of example data to feed the algorithm for training.

Also, with machine leaning it's important to remember that machine learning only works if the problem is actually solvable with the data that you have. If you don't' have certain amount of examples, you will not be able to train the algorithm and if a human expert couldn't use the data to solve the problem manually, a computer probably won't be able to either.

Please be informed that the Author of this Master's thesis is not the qualified expert in Machine/Deep learning and have the high level overview of this topic. In case of a real-life implementation the consultation with the expert is required.

There are quite many works already done in the field of sound classification and some of them can be re-used in my application [30], such as note or specific musical instrument detection. But if Artist would like to implement some specific musical pattern, then it will require a lot of input data. When it comes to deep learning, the data is the key. Larger the data, better the accuracy.

Despite the fact that machine learning requires quite a lot of training (and validation) data, this technology is the future and it can bring to life quite many solutions, which are not possible to achieve with other technology.

Machine learning will represent the major part of audio patterns in dancing fountain application.

4.2.1.4 Audio Signal Pattern parameters

Every audio pattern recognition technology listed above can use its own libraries or even its own framework, which means that every technology should be used as a separate audio analyzing block in Dancing fountain control system. Audio signal has to come to these blocks as an input in parallel.

Also, no matter what frameworks or programming languages to be used for audio pattern recognition, the input and output data has to be the same.

- Input: Audio signal
- Output: Number of audio pattern in pattern library

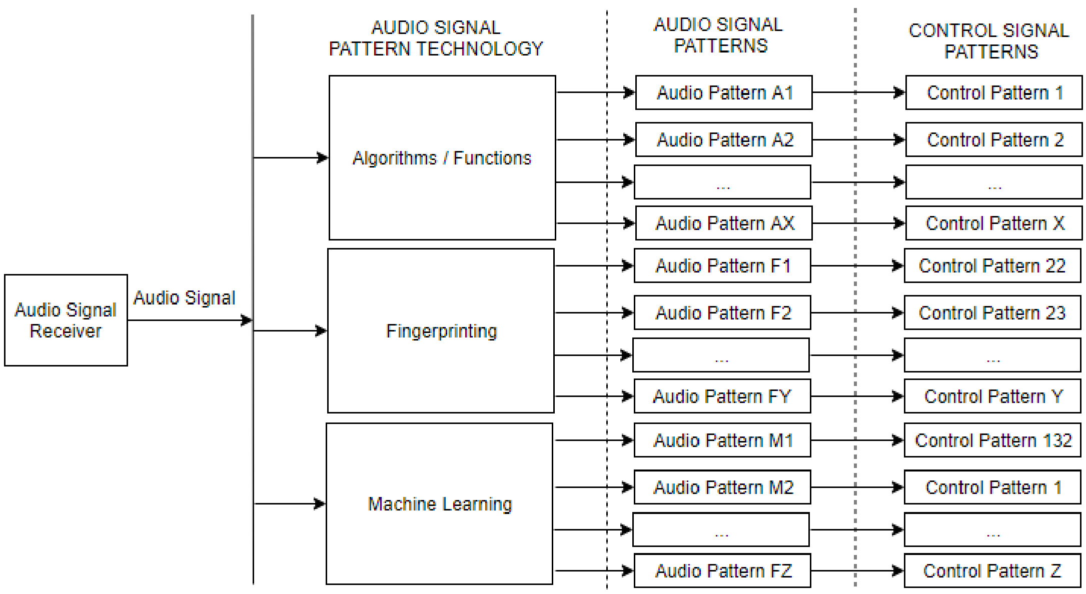


Figure 21: Audio Pattern recognition logic

As mentioned before, audio patterns have to be recognized by Artist and implemented by Engineer.

Each audio pattern added to the audio pattern library will have only one parameter (it might be extended in future): Priority

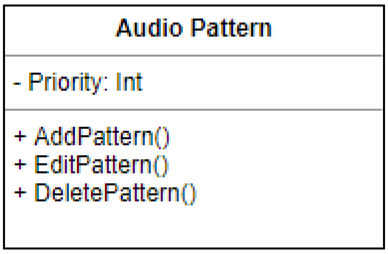


Figure 22: Audio Pattern class

“Priority parameter” is required to solve the conflicts if two or more patterns will be recognized at the same time. For example:

- If violin and drums are playing at the same time and both of these patterns are using the sprinkling Hydraulics unit,
- Or drums are playing repeatedly, but some defined by Artist pattern was recognized and it has higher priority

The pattern with higher priority will be prioritized. Priority parameter will work within one audio pattern recognition technology only, because the results from different sound recognition blocks may come in different time. See more information in Validation chapter.

4.2.2 Controls Signals patterns

At the same time it is necessary to create the control signal pattern per each recognized musical pattern.

Control signal pattern is an array of signals required to control the hydraulics unit.

Hydraulics unit is an every device in the Dancing fountain that able to receive the control signal. It can be:

- Motor Driver, which controls the water pump
- Electronic Valve
- Rotating Nozzles

- 3D nozzle

It also can be the LEDs or light bulbs or projector, but they are out of the scope now.

Each control pattern can include as much hydraulics units of the system as necessary. Even all of them. It has to be configured by the Artist. Every hydraulics unit is added and configured one by one and attached into the Control pattern array.

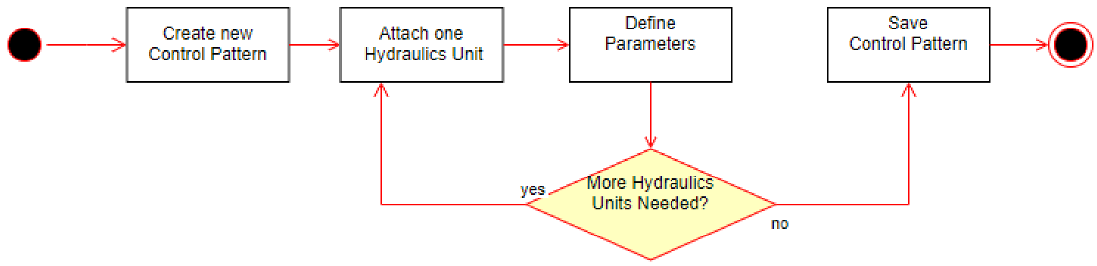


Figure 23: Create new control pattern Activity Diagram

Each patterns got its own reference number and all the parameters are saved into to Control pattern library

List of the Hydraulics Units above looks fine from engineering point of view, but if, for example, different nozzles will be attached to the same pipe, controlled by the same water pump, from Artist point of view it will be already different unit. Visually the water jet will also look differently and will have different parameters.

So, from technical point of view, engineer can define the technical hydraulics units and Artist can split the technical units to sub-units. Specific parameters can be defined for Control pattern and per each Hydraulics unit.

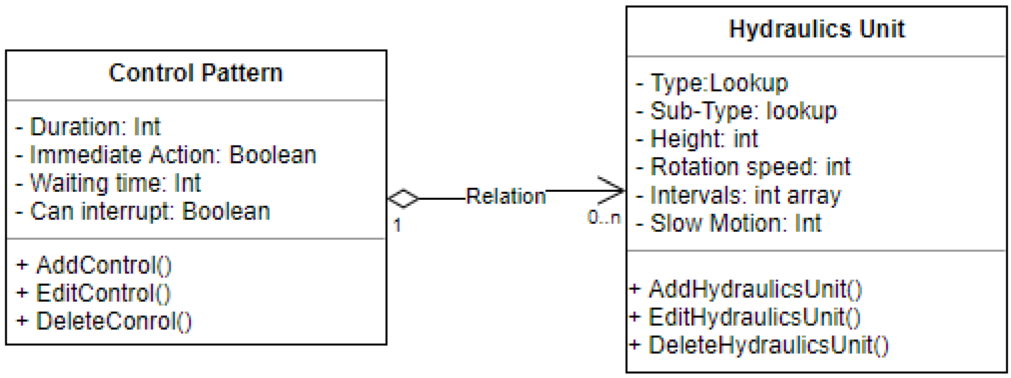


Figure 24: Control pattern class diagram

Table 2: Hydraulics Unit parameters

Unit Parameter	**Hydraulics Unit**	**Control method**	**Controlling device**	**Comments**
Height	Motor driver with Water pump	PWM Signal	Pump Motor Driver	Height of water jet in millimetres
Rotation speed	Rotation Nozzle	PWM Signal	Rotating nozzle motor drive	Rotation speed in rpm
Intervals	Electronic Valves	Control signal to Relay	Power relay	Int array for open and closed intervals in milliseconds
Slow Motion	Motor driver with Water pump	PWM Signal	Pump Motor Driver	Water jet fast Up but Slow down. Delay in Milliseconds.

Table 3: Control Pattern parameters

Pattern Parameter	**Comments**
Duration	Time to accomplish this pattern in Milliseconds
Immediate action	Wait until the execution of previous control pattern ends of act immediately
Waiting time	How long it is fine to wait to execute the current Control Pattern
Can interrupt	If value is FALSE, this pattern execution can't be interrupted, even if the other pattern has Immediate action Value = TRUE

4.2.3 Audio And Control patterns matching

When variety of Audio and Control patterns are added to the library Artist can make an Audio Pattern <> Control Pattern combination.

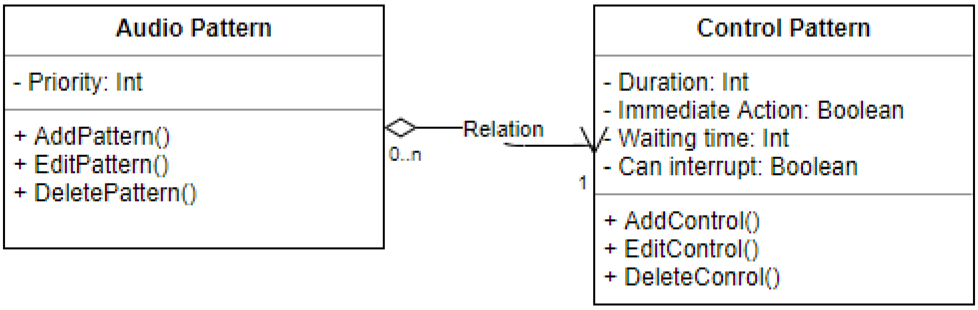


Figure 25: Audio to Control pattern combination

Every control pattern may have many audio patterns, but every Audio pattern may have only one control patterns. Other words, the behavior of the fountain may be the same for different Audio patterns.

4.3 Dancing Fountain Control system

I expect to get only the audio pattern ID from the audio pattern recognizer system block. Every Audio pattern should be connected to Control pattern so, the next step would be to request the relevant Control pattern with parameters from Control Pattern library.

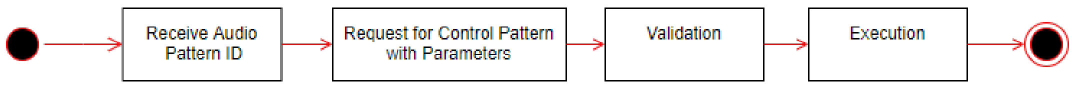


Figure 26: Dancing Fountain Control part

4.3.1 Validation block

Despite that we have the priority control in every audio pattern recognition block; there might be two scenarios when we can receive another Audio pattern ID at a time when the execution of previous one is not finished yet.

1. New Audio pattern ID will come from another Audio recognition block.

2. New Audio pattern ID will come from the same block, but control pattern execution time is different and if, for example, some pattern execution will last for 5 seconds, most probably many more audio patterns will be recognized during this time.

That's why every Control pattern needs the parameters described in "Control signal patterns" chapter.

In Validation block will be two controls:

1. Availability control: It will check that pumps, valves and nozzles, required for this control pattern execution are not busy at the moment.

2. Timing Control: If Availability control is failed, timing control will check is this Control pattern should be added to the queue or just dismissed from the execution.

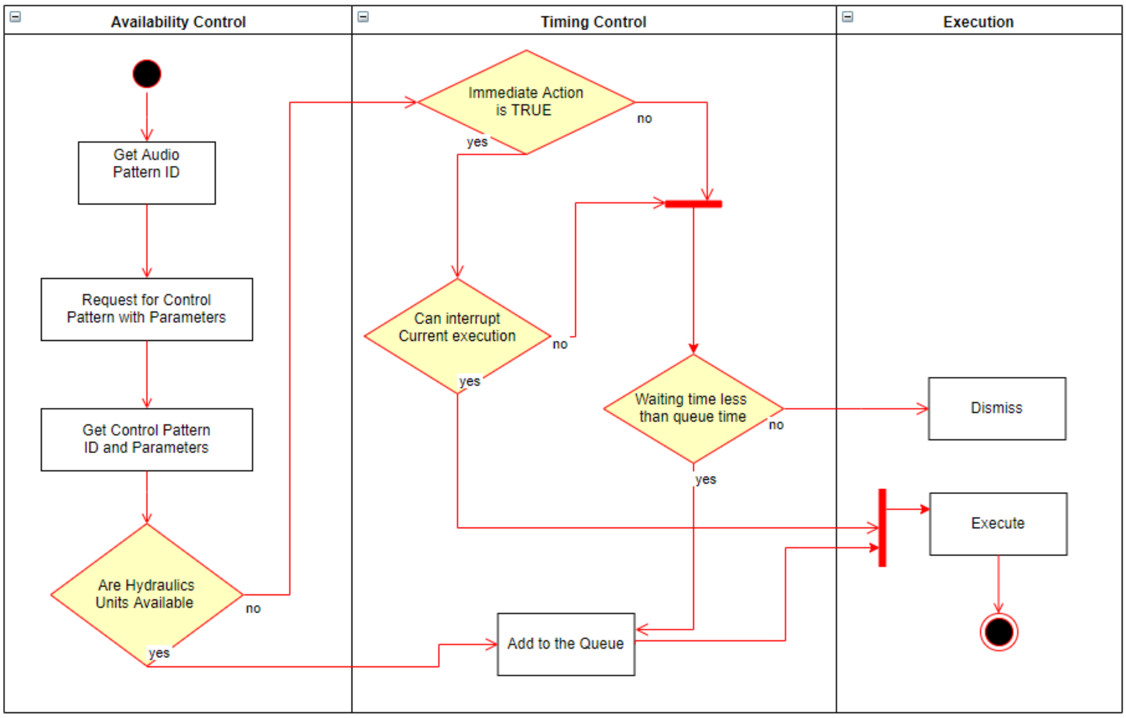


Figure 27: Validation Block

Timing control:

1. Immediate action: shows should all the currently executable patterns stop and execution of this pattern start or not.

2. Can interrupt the currently executed pattern also depend of the currently executable pattern parameter “Can Interrupt”. If it is true, then this control pattern execution can be interrupted.

3. Each Control pattern has “Waiting time” parameter. If waiting time is less than the total time in the queue, this control pattern can be added to the queue then. Otherwise it will be just dismissed.

4.3.2 Control Signals technology

Control signals to Hydraulic Units will come to the Executable block and will for the queue.

It is necessary to consider that every control pattern may include more than one Hydraulic unit. It can include even all of them, which means that the controller has to be able to send control signals to all the Hydraulic Units at the same time.

The DMX technology [10] already briefly explained in this Master's thesis can be used to control each element (or group of elements) in the dancing fountain system.

Controllers generate serial signals in DMX512 format. It is a master-slave system where the first controller acts as the master, and the second controller acts as a slave to the first controller but as a master controller to the next controllers that are attached.

This technology is mainly used in lightning, but can be also adjusted to control other dancing fountain units. Basically, it is possible to implement any other Bus technology, but as DMX already has quite many use cases to be used in Fountain industry – it makes sense to take it in my use case as well.

4.4 Outcome

As a final result now I have the structure of experimental Self-Choreographed Dancing Fountain with description of:

- System concept
- System blocks
- System processes
- System parameters

Based on this information it is possible to start building the real life system.

4.4.1 Dancing Fountain Control system concept

Top level overview of the Dancing fountain control system.

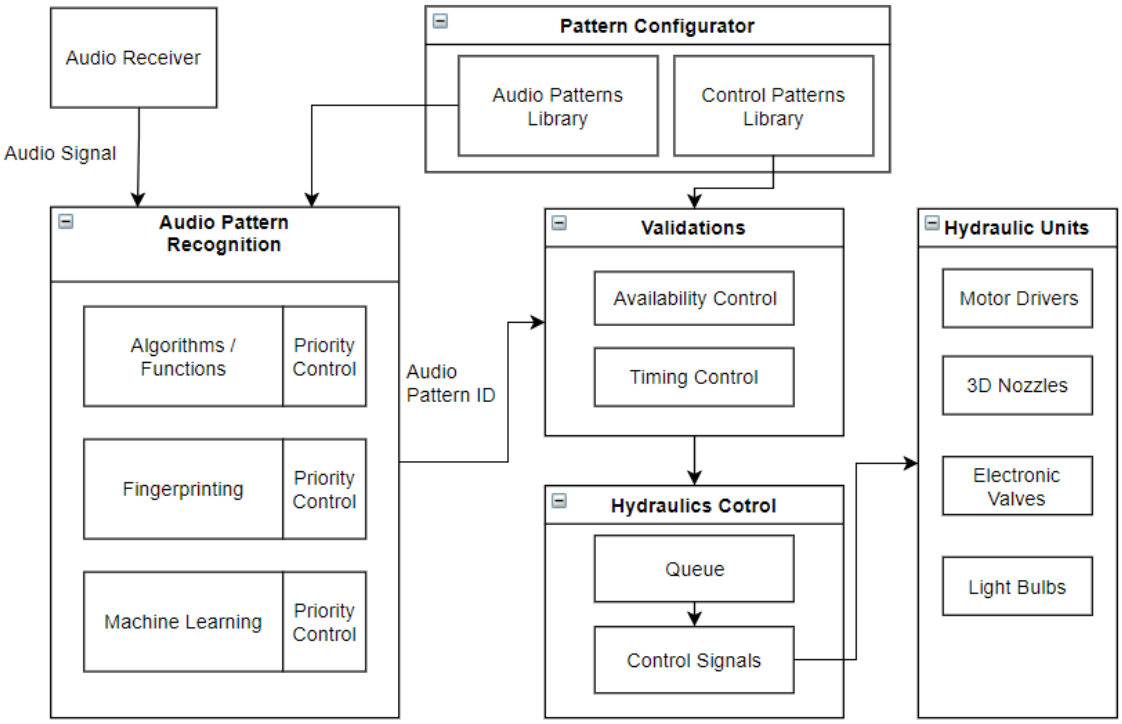


Figure 28: Self-Choreographed dancing fountain control system

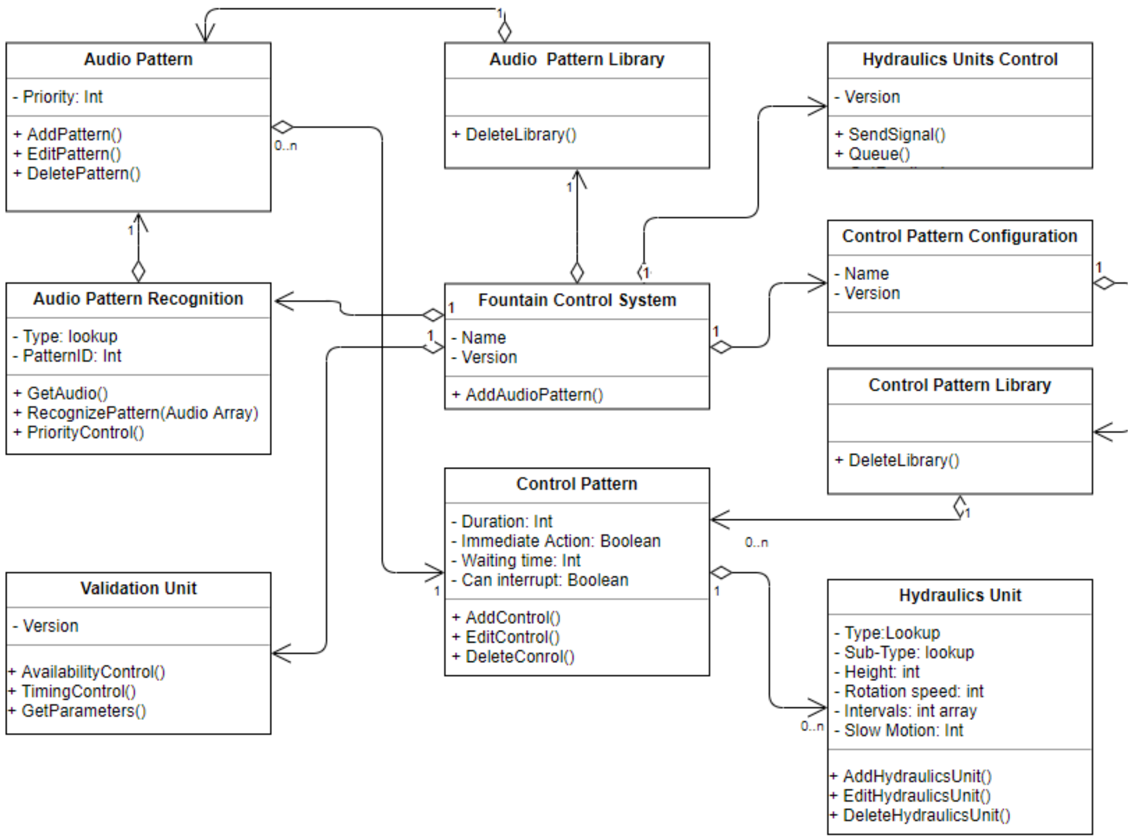


Figure 29: Self-Choreographed dancing fountain control system class diagram

5 Prototyping

Self-choreographed dancing fountain control system prototyping will be based on the structure described in the previous chapter.

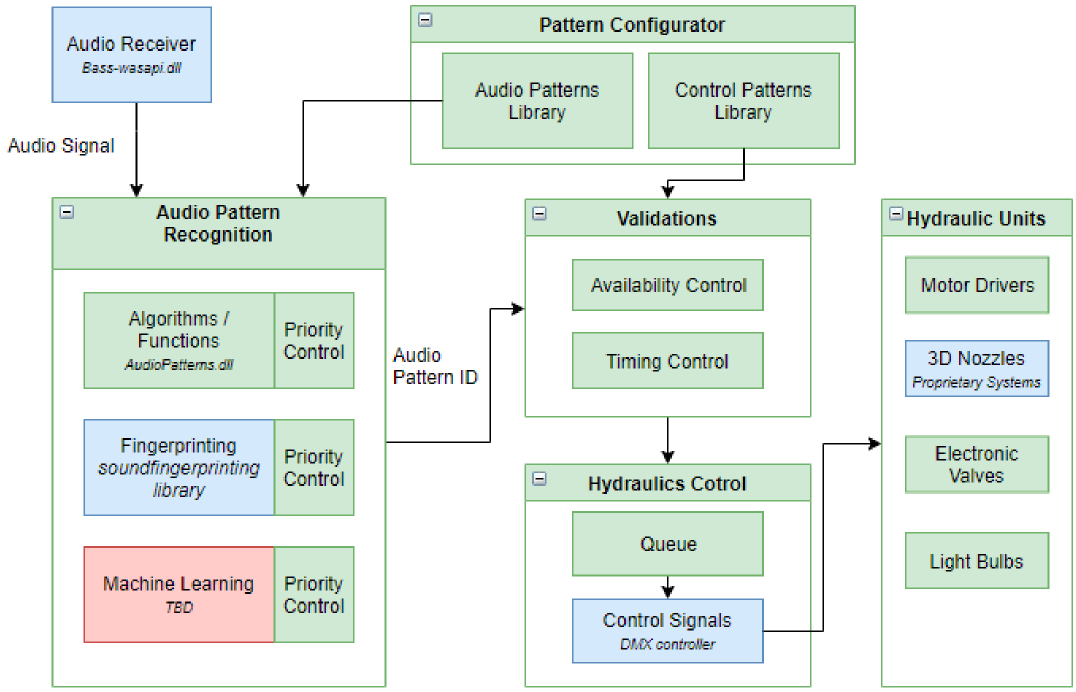


Figure 30: Self-Choreographed dancing fountain control system development

Control system interface will be developed in Microsoft Visual Studio, using C# language. This interface will play the role of the container for all the modules represented on the scheme above. Some modules will be developed by Engineer, but some modules will use already existing solutions on the market.

- Green: These modules to be developed in-house, specifically for this application.
- Blue: Modules, which will use the external libraries or other frameworks. This libraries or frameworks will work as separate units, but will have the interface/protocol (input/output parameters) to be integrated into the common container.
- Red: External expert assistance is required.

It is necessary to understand, that the Self-choreographed dancing fountain control system presented in prototyping chapter is only the early stage of the product development. It gives the understanding of the overall concept, but still lacking a lot of functionality. It has to be extended with required functionality step by step.

5.1 Audio receiver

There are two options, how to read the audio signal:

1. Using the microphone
2. Directly from the device

In first case we will get a lot of extra signals, such as noise, which will make audio pattern recognition more difficult and in case of Fingerprinting even not possible. So, the second option is more preferable. WASAPI can be used for these purposes.

The Windows Audio Session API (WASAPI) enables client applications to manage the flow of audio data between the application and an audio endpoint device. [23]

Basically, it provides a mixer API that talk directly to your sound card. No need of microphone to read the audio signal. It handles sample rate conversion, recording, audio effects and everything that's Audio related. This API is supported starting from Windows 7.

5.1.1 Bass.dll library

When looking for alternative to Matlab tools for audio simulation I came across with “bass.dll” audio library developed by “Un4seen Developments” company [21].

BASS is an audio library for use in software on several platforms. Its purpose is to provide developers with powerful and efficient sample, stream (MP3, MP2, MP1, OGG, WAV, AIFF, custom generated, and more via OS codecs and add-ons), MOD music (XM, IT, S3M, MOD, MTM, UMX), MO3 music (MP3/OGG compressed MODs), and recording functions. All in a compact DLL that won't bloat your distribution. [21]

Other words, this library gives the powerful set of tools to create own music player or sound recorder or online radio client etc.

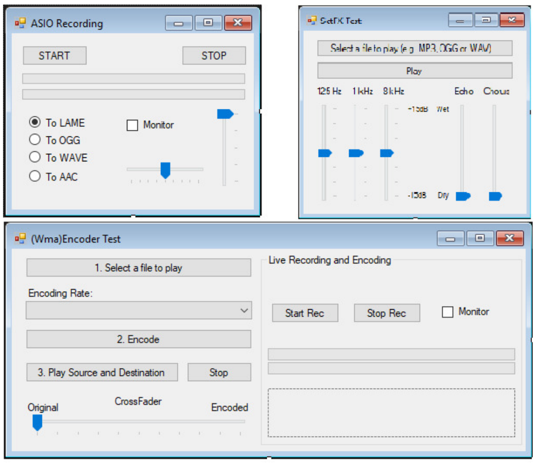


Figure 31: Bass.dll application examples [24]

Bass.dll is built over the Direct Sound API, but it has an add-on called bass-wasapi.dll, that makes it possible to use WASAPI with bass.dll.

The point that, if it is possible to read the musical signal, then it is possible not only build my own music player, but analyze this signal as well.

And actually I don't need Bass.dll library itself, but bass-wasapi.dll add-on to read the signal from sound card. Reading the signal is not so difficult with "BassWasapi.BASS_WASAPI_GetData Method (Single[], Int32)" [24].

This method retrieves the immediate sample data (or an FFT representation of it) of the current Wasapi device/driver (endpoint). This overload uses an IntPtr to reference the buffer data [24].

And this is absolutely incredible. With this method it is possible to get the sample of FFT representation of data.

The following parameters can be used in BASS_WASAPI_GetData Method.

Table 4: BassWasapi.BASS_WASAPI_GetData Method parameters

BASS_DATA_FLOAT	Return floating-point sample data.
BASS_DATA_FFT256	256 sample FFT (returns 128 floating-point values)
BASS_DATA_FFT512	512 sample FFT (returns 256 floating-point values)
BASS_DATA_FFT1024	1024 sample FFT (returns 512 floating-point values)
BASS_DATA_FFT2048	2048 sample FFT (returns 1024 floating-point values)
BASS_DATA_FFT4096	4096 sample FFT (returns 2048 floating-point values)
BASS_DATA_FFT8192	8192 sample FFT (returns 4096 floating-point values)

BASS_DATA_FFT_INDIVIDUAL	Use this flag to request separate FFT data for each channel. The size of the data returned (as listed above) is multiplied by the number channels.
BASS_DATA_FFT_NOWINDOW	This flag can be used to prevent a hanning window being applied to the sample data when performing an FFT.
BASS_DATA_AVAILABLE	Query the amount of data the device has buffered (the BASS_WASAPI_BUFFER flag isn't required for this, buffer can be null when using this flag).

So, for example, if I want to get the sampling rate of 44100Hz for my audio analyzing; I can take GetData with "BASS_DATA_FFT8192" parameter a little more than 5 times per second (5.4 times). With bass.dll and WASAPI I can get the powerful tool to receive the audio.

bass-wasapi.dll library will be integrated into the Dancing control system container and will be used as audio receiver for in all audio recognition technologies.

5.2 Audio Pattern recognition

This is the major part in signal processing and the overall dancing control system as well. As it was described below, there are three different technologies to be used in musical pattern recognition and each technology requires the specific approach.

5.2.1 Algorithms / Functions technology

This technology will be used by Engineer to develop the Audio pattern algorithms. If the Audio pattern, recognized by Artist could be described with specific mathematical functions – it will be first option to go then. If not – alternative technology will be analyzed.

Most common approach is to use FFT representation of the signal and compare every following sample with the previous one or with the series of previous samples.

All algorithmic patterns will be store in a separate library.

5.2.1.1 Example: Loudness difference audio pattern

"Loudness difference" patterns should analyze the signal and if there will be big difference in Loudness is a short period of time, then shoot from all the nozzles as powerful as possible.

BassWasapi.dll library has "`BassWasapi.BASS_WASAPI_GetLevel`" Method. I can use this method to take the loudness levels per each sample and compare it with the previous one. In this example it is not even matter the scale of maximum and minimum values. What matters is the difference between these two levels.

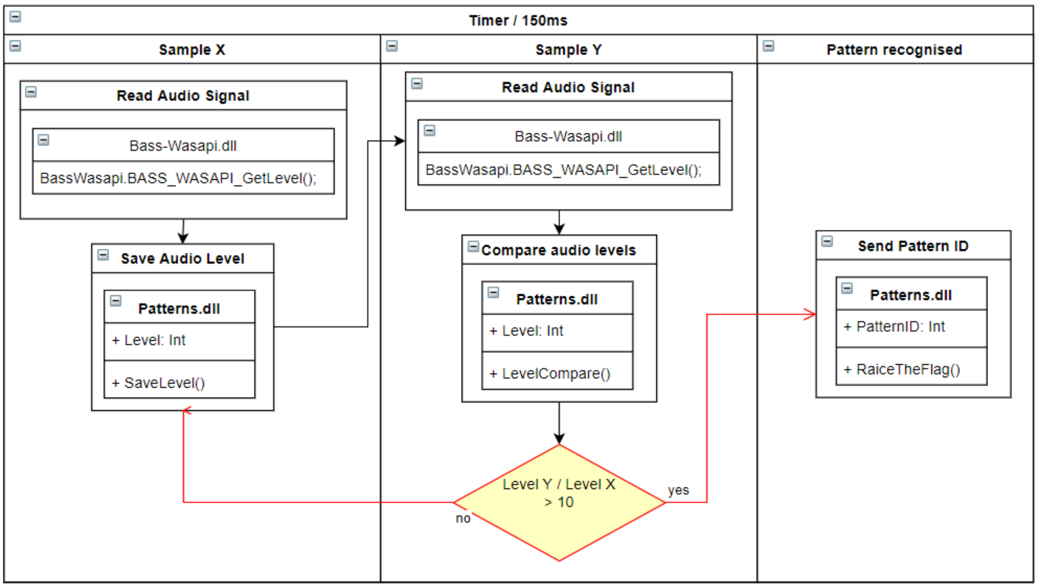


Figure 32: Loudness difference pattern logic

Maximum value from every sample has to be compared to the value from the previous sample. If the difference is more than 10 times (this value has to be tested, might be higher) then raise the flag with the pattern ID.

All the logic is running inside the Timer. Controlling the timer interval it is possible to control the number of samples per second.

The overall approach is to re-use already existing in the market high quality products, such as bass.dll library and create the tailor made functions for the specific needs.

5.2.2 Fingerprinting technology

Fingerprinting technology is an important part of audio pattern recognition module. It is required when artist wants to run the certain control pattern at a certain moment of a known audio track. It can be a song, or a vocal moment or anything else, the only requirement – it should be the exact match with the sample from the library.

It means that the fingerprinting technology requires at least two functionalities:

1. Possibility to add the audio sample (hash number) to the library

2. Possibility to catch this sample inside the audio file

Of course, it is possible to start developing the Fingerprinting engine myself based on different researches and scientific papers [32] [33], but at the same time so much work was already done in this field and as audio fingerprinting study is not the main topic for my master's thesis – it makes sense to use already existing on the marker solutions.

5.2.2.1 Open source audio fingerprinting in .NET

Specific library was found to be used inside the Fountain Control system container.

soundfingerprinting *is a C# framework designed for companies, enthusiasts, researchers in the fields of audio and digital signal processing, data mining and audio recognition. It implements an efficient algorithm which provides fast insert and retrieval of acoustic fingerprints with high precision and recall rate. [34]*

Soundfingerprinting library uses computer vision techniques to generate audio fingerprints. The fingerprints are generated from spectrogram images taken every N samples.

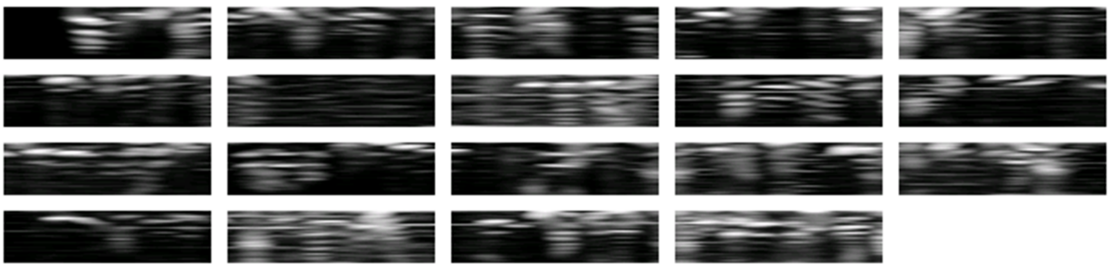


Figure 33: 30 seconds long non-overlapping spectrogram cut at 318-2000Hz frequency range [34]

After a list of subsequent transformations these are converted into hashes, which are stored and used at query time. So, any specific moment of an audio signal can be transformed into the hash value and added to the data store.

Library functionality required for dancing fountain system:

- Extract acoustic fingerprints from an audio

- Store the fingerprints in the datastore
- Query the storage in order to recognize the song those samples you have

Overall concept is to take the audio sample with certain length and query the fingerprints storage. The origin of query samples may vary: file, URL, microphone, radio tuner, etc.

The really important part of this library, that in version 6.2.0 it provides ability to query real-time datasources. It gives the opportunity to monitor a real-time stream and get matching results as fast as possible.

Query reply also contains the extensive information, such as number or matched track from the datastore, position where resulting track started, confidence (returns a value between [0, 1]. A value below 0.15 is most probably a false positive) and many more.

In my use case the matched track number is the most important parameter and it will correspond to audio pattern ID and in case of positive result will be forwarded to control part.

Audio fingerprinting technology and *Soundfingerprinting* library will be the second choice (after mathematical functions) to implement defined by artist audio patterns.

5.2.3 Machine learning technology

If algorithmic functions and audio fingerprinting technology is not able to implement the required audio patters – machine learning comes into play then.

Machine learning technology is cutting edge technology these days. As already mentioned before, the author of this Master’s thesis has an overall idea of the Machine/Deep learning technology, but he is definitely not the expert in this field.

Outsourced Machine learning expert is required to implement this module into the Dancing fountain control system container. This task has to be accomplished once. When generic algorithm is developed it will be up to Artist to train this algorithm by feeding it with training, validation and test patterns.

5.3 Control pattern configuration

Control pattern configurator will be fully created by Engineer and will contain three major parts:

1. Audio Pattern library: Catalog of all the patterns IDs with their priorities. Please don't confuse with the "real" audio patterns. They are different from one audio pattern recognition technology to another and will be stored in the relevant blocks (Functions, Fingerprints etc.).

2. Control Pattern Library: Catalog of Control patterns.

3. Library of Audio to Control Pattern combinations.

Each Pattern combination will have a separate *.config* file. Each control Pattern will have the Collection of Hydraulic Units. Each Hydraulic Unit will have its own set of parameters.

Visual studio "Property Grid" is a flexible tool to store all the required parameters. Hierarchical approach can be used with the Collections.

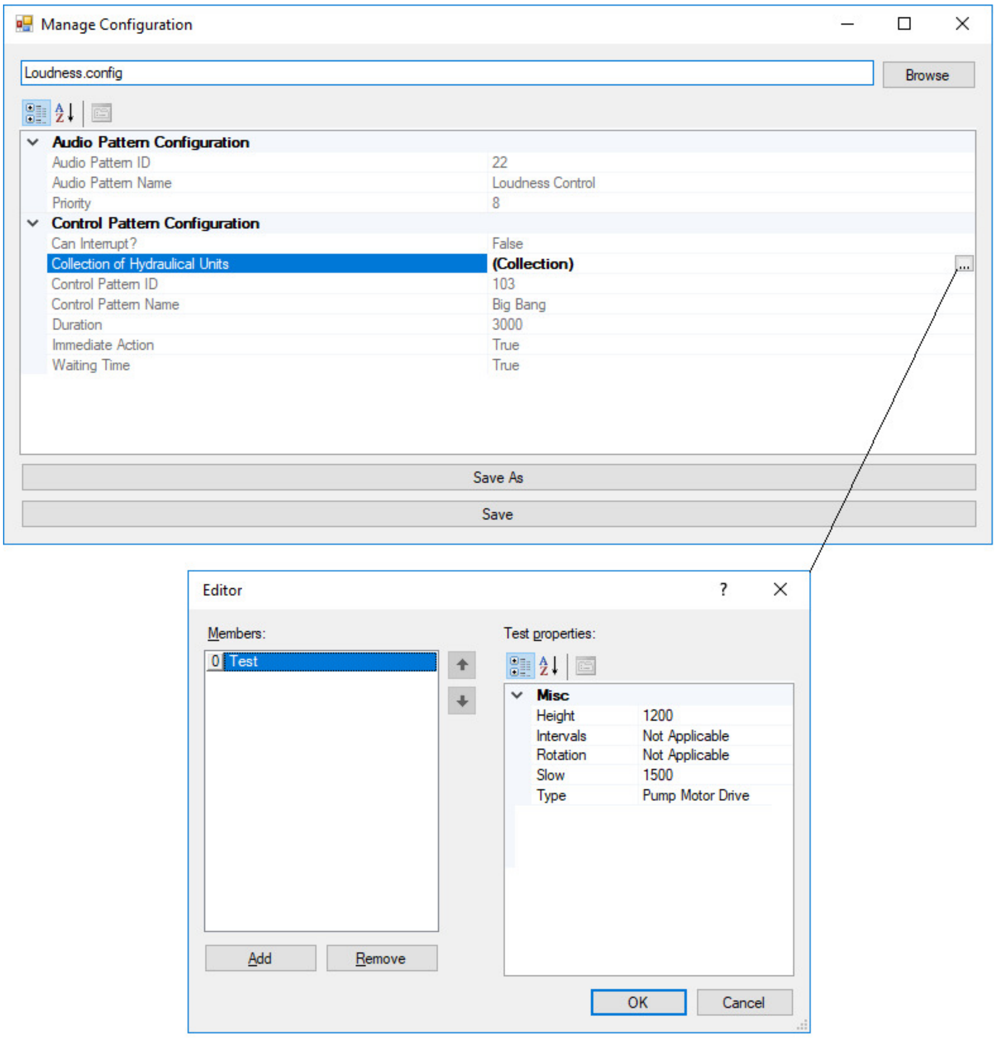


Figure 34: Pattern Configurator window

5.4 Validations & Hydraulics Control

5.4.1 Validations

As described before Availability and Timing control will be represented as a separate functions inside the main system container. These functions will be developed by engineer.

5.4.2 Hydraulic Control

Hydraulics control part will be the combination of tailor made DMX512 master microcontroller. It doesn't mean that specific microcontroller board will be created, but available on the marker board will be extended with DMX512 support considering the DMX specifics, such as packet structure [31].

This also means that each pattern configured in Control Pattern Configurator has to be replicated inside the DMX Controller library. When the controller will receive the control pattern ID it has to immediately send all the control signals

DMX controller is an end point. If it receives the pattern ID - it starts immediate execution. All validation and queuing logic implemented in validation block.

As DMX512 is a master-slave technology, each Hydraulic unit requires the DMX controller as well.

5.5 Hydraulic Units

All the Hydraulics parts are commercial products. No in-house development is planned. Each Hydraulic unit is specific and has to be analyzed separately. Important features are:

- Built-in DMX controller
- System integration possibility

Here are couple examples:

Pumps: There are quite many water pumps on the market with built-in DMX controller and as the protocol is the same, it can be attached to already existing system and this Hydraulic Unit can be added to the library.

3D Nozzles: Each 3D nozzle is a complex system and every vendor provides its own Nozzle behavior configuration software. The important feature of this software is the possibility of integration with the Dancing Control system described in this Master's thesis. Configuration software requires specific API or other interaction possibilities.

5.6 Simulator & tester

While prototyping, I've found the interesting possibility to use progress bars [22] to imitate the fountain water jet behavior

First, I've implemented the Light organ approach to this simulator. It is reading the FFT data received from the sound card, checks the ranges (Low Channel 60-150 Hz, Mid channel 200-600 Hz, and High channel 800-2200 Hz) and take maximum from these ranges.

Secondly, I've implemented the "Loudness change" audio pattern.

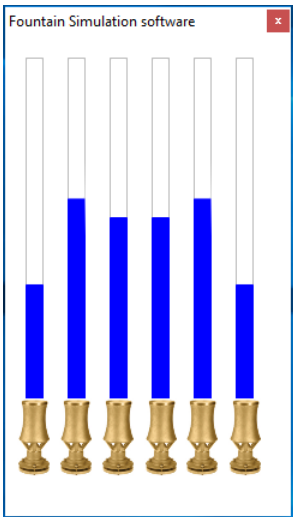


Figure 35: Dancing Fountain Simulator

Please see more detailed simulator development steps in Appendix 3.

I've also decided to attach my Hydraulics tester with one pump described in this master's thesis before. Arduino Uno will send the PWM control signal to motor driver, which means that I have to send the PWM values to Arduino first.

Please see Appendix 4 for more information about Simulator to Arduino connection.

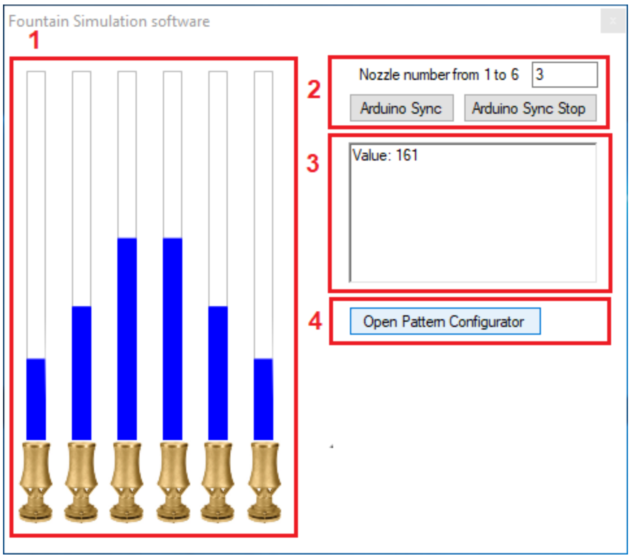


Figure 36: Fountain Simulation Software interface

1. Fountain water jets simulation area

2. Logic to start and stop sending data to Arduino. Select nozzle from 1 to 6 and start transmission. Progress bar values are from 0 to 255, so it can be directly used as PWM signal value to control the Water pump.

3. Feedback from Arduino. Basically, Arduino sends the received signal back. Required for testing and debugging.

4. Open Pattern Configurator

5.7 Prototyping outcome

This prototype is not the final version; it is not even the Project initiation system yet. It was required to prove the concept described before. Required features will be added during the Dancing fountain development process.

As a next step it would be good to add couple more Audio and more Control patterns to test Availability validation, Timing validation and Queue logic.

6 Summary

Master's thesis main objective was to plan and prototype the self-choreographed dancing fountain system, which is reacting on real-time audio signal and automatically synchronizes water movements with music to achieve the artistic effect.

After several iterations and major change of concept in the middle of research it is possible to say that this study has measurable outcomes:

- It was proved that the color organ approach in self-choreographed dancing fountain system could be implemented and is fully operational from technical point of view, but has no much artistic value.

- Considering all the artist requirements, the top level architecture of the self-choreographed dancing fountain system was planned. The major functionality of the system is audio pattern recognition (with use of different in-house or external technology) and hydraulics control pattern library to synchronize the incoming audio signal with water movements.

- Prototyping of the product with minimum viable functionality was initiated and several example modules were developed. At the same time, the possibility of using external libraries for specific system modules was analyzed and specific technology presented.

- One of the important outcomes of this study is the understanding that it is not possible yet to fully rely on machines in some areas. Even if the fountain will work autonomously without human interaction, all the pre-configuration of the fountain behavior has to be done by human.

It is necessary to understand that this study contains the overall proves of concept, but not the final product. Further development is required. The next step would be:

- Develop the fully functional engine of dancing fountain system including the following parts: Pattern configurator, Validations block, and Control block.

- Embed the audio fingerprinting external library into the system container.
- Involve an external expert to develop the machine learning part of audio pattern recognition module.
- Enrich the audio pattern library with defined by artist patterns per each audio pattern recognition technology.
- Find or develop the real life hydraulic part of the dancing fountain and add control patterns defined by artist to the library.

Next steps presented above are the high level overview of required actions to develop the fully operational system. To start the development process, project initiation document has to be created with overall project description; more detailed technical requirements per each module and roles for all the involved parties. When this is done it is possible to plan the budgets (time, money) and discuss the development approach/methodology.

As the main goal for this master's thesis was to plan, prototype and document the overall concept of the self-choreographed dancing fountain system with description of top level architecture, major processes and parameters, I can assume than this job is done.

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Appendix 1 – [Arduino codes]

```
// WATER DELAY TEST

#include <boarddefs.h>
#include <IRremote.h>
#include <IRremoteInt.h>
#include <ir_Lego_PF_BitStreamEncoder.h>

#define OUT1 12
#define EnB 5
#define In4 6
#define In3 7

int speed;
int RECV_PIN = 11;
IRrecv irrecv(RECV_PIN);
decode_results results;

void setup()
{
  Serial.begin(9600);
  irrecv.enableIRIn(); // Start the receiver
  pinMode(OUT1, OUTPUT);

  pinMode(EnB, OUTPUT);
  pinMode(In3, OUTPUT);
  pinMode(In4, OUTPUT);

  // turn off motor B
  digitalWrite(In3, LOW);
  digitalWrite(In4, LOW);

}

void loop()
{
  if (irrecv.decode(&results))
    {
      //LED ON & OFF
     if (results.value == 16582903)   digitalWrite(OUT1, HIGH);
     if (results.value == 16615543)   digitalWrite(OUT1, LOW);
```

```
    //Speed control
    if (results.value == 16599223)     speed = 100;  // Button 3
    if (results.value == 16591063)     speed = 150;  // Button 4
    if (results.value == 16623703)     speed = 200;  // Button 5

     // Turn OFF motor
    if (results.value == 16580863) { // Button Power
       digitalWrite(In3, LOW);
       digitalWrite(In4, LOW);
    }

     // Turn ON motor
    if (results.value == 16593103) { // Button 0
       digitalWrite(In3, LOW);
       digitalWrite(In4, HIGH);
       speed = 100;
    }

    Serial.println(results.value);
    irrecv.resume(); // Receive the next value
   }

    analogWrite(EnB, speed);
}
```

// SOUND VOLUME TO PWM SIGNAL

```
int sensorPin = A0; // select the input pin for the potentiometer
int sensorValue = 0; // variable to store the value coming from the
sensor

#define EnB 5
#define In4 6
#define In3 7

int speed;

void setup ()
{
  Serial.begin (9600);

  pinMode(EnB, OUTPUT);
  pinMode(In3, OUTPUT);
  pinMode(In4, OUTPUT);

  // turn ON motor
        digitalWrite(In3, LOW);
        digitalWrite(In4, HIGH);
        speed = 100;
```

```
}

void loop ()
{
  sensorValue = analogRead (sensorPin);
  speed = abs(sensorValue - 700) + 100;
  if (speed > 250) speed = 250;

  Serial.println (speed);

  analogWrite(EnB, speed);
}
```

Appendix 2 – [Matlab Code]

```
Fs = 8000 ; % Sampling rate
nBits = 16 ; % BitRate
nChannels = 1 ; % Number of chaneels
ID = -1; % Default audio input device

% Initiate COM port to send signal to Arduino
arduinoCom = serial('COM3','BaudRate',9600); % create serial
communication object
fopen(arduinoCom); % initiate arduino communication

% This loop is
% 1. Taking audio sample from Microphone every 0.5 seconds
% 2. Converting audio sample into Double array
% 3. Applying Low, Mid and High pass filters
% 4. Sends information to Arduino - not implemented


for x = 1:5 % 5 samples for now. Enough for testing

recObj = audiorecorder(Fs,nBits,nChannels,ID);
% Collect a five second sample of your speech with your
microphone.

%disp('Start speaking.')
% Start speaking.
recordblocking(recObj,0.3); % Record audio every half a second
%disp('End of Recording.');
% End of Recording.

%Play back the recording.
%play(recObj);

% transform audiorecoderder object into signal array
doubleArray = getaudiodata(recObj);

% Filters configuration
```

```
filtlp = designfilt('lowpassiir', 'PassbandFrequency', .13,
'StopbandFrequency', .15, 'PassbandRipple', 1,
'StopbandAttenuation', 60);
filtbp = designfilt('bandpassiir', 'StopbandFrequency1', .2,
'PassbandFrequency1', .22, 'PassbandFrequency2', .58,
'StopbandFrequency2', .6, 'StopbandAttenuation1', 60,
'PassbandRipple', 1, 'StopbandAttenuation2', 60);
filthp = designfilt('highpassiir', 'StopbandFrequency', .78,
'PassbandFrequency', .8, 'StopbandAttenuation', 60,
'PassbandRipple', 1);

% Run the filters
filteredlp = filter(filtlp,doubleArray);
filteredbp = filter(filtbp,doubleArray);
filteredhp = filter(filthp,doubleArray);

% Plot the Original and 3 filtered signals.

% figure;
% subplot(4,1,1);
% plot(doubleArray);
% title('Original');
% subplot(4,1,2);
% plot(filteredlp);
% title('Low-Pass')
%
% subplot(4,1,3);
% plot(filteredbp);
% title('Band-Pass')
%
% subplot(4,1,4);
% plot(filteredhp);
% title('High-Pass')

% Take maximum values of Filter arrays
OR = maxk(doubleArray,1); % Original signal
LP = maxk(filteredlp,1);  % Low-Pass signal
BP = maxk(filteredbp,1);  % Band-pass signal
HP = maxk(filteredhp,1);  % High-pass signal

% Display maximum values in console
disp(['Real',num2str(OR),';','Low-Pass',num2str(LP),';','Band-
Pass',num2str(BP),';','High-Pass',num2str(HP),';']);


ALP = round(LP*1000); % signal value is multiplied by 1000 and
all the outstanding decimals are removed to get the integer
value
disp(ALP);

fprintf(arduinoCom, '%i', AOR); % send answer variable content
to arduino


end

fclose(arduinoCom); % Close COM port
```

Appendix 3 – [Fountain Simulator]

I will use Microsoft Visual Studio 2017 and C# programming language to build the Fountain simulator software.

Spectrum Daemon example [22] shows the possibility of using FFT data received from the sound card with progress bars and Wave graphs.

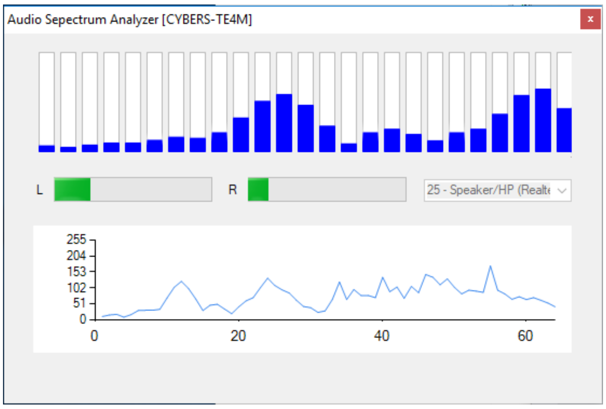

Figure 37: Audio Spectrum Analyser example

Wave graph is not something what we need, but progress bars are looks quite similar to the water jets and can be used as to emulate the water jet behavior.

Current example has 64 progress bars in a row (not all of them are visible). I've decided to decrease the amount to six. This number is not so important at this moment because it can be easily scalable. I've just decided to take the amount of Arduino Analog pins.

The goal for my first version of simulator would be the simulation of Light organ approach from my first iteration.

Current example is using the following code to split 4096 values into 64 progress bars:

```
//computes the spectrum data, the code is taken from a bass_wasapi
sample.
            for (x = 0; x < _lines; x++)
            {
                float peak = 0;
                int b1 = (int)Math.Pow(2, x * 10.0 / (_lines - 1));
                if (b1 > 1023) b1 = 1023;
                if (b1 <= b0) b1 = b0 + 1;
                for (; b0 < b1; b0++)
                {
                    if (peak < _fft[1 + b0]) peak = _fft[1 + b0];
                }
                y = (int)(Math.Sqrt(peak) * 3 * 255 - 4);
                if (y > 255) y = 255;
                if (y < 0) y = 0;
                _spectrumdata.Add((byte)y);
                //Console.Write("{0, 3} ", y);
            }
```

Where

```
_lines is a number of progress bars
fft[] is an array of floating-point value representing the frequencies
peak is the maximum frequency value within the range
_spectrum[] is an array of values for progress bars
```

Progress bar minimum is 0 and maximum is 255

I've decided to use same frequency ranges like I used in Light organ approach (Low Channel 60-150 Hz, Mid channel 200-600 Hz, and High channel 800-2200 Hz) and take maximum from these ranges.

Following logic was implemented for Low frequencies:

```
float peak2 = 0; // Maximum value

for (w = 60; w < 150; w++) // Low frequency range
  {
    if (peak2 < _fft[w]) peak2 = _fft[w]; // Max value
   }
  // Progress bar value from 0 to 255

k = (int)(Math.Sqrt(peak2) * 3 * 255 - 4);

if (k > 255) k = 255;
if (k < 0) k = 0;

_low.Value = k; // Progress bar value to be set to main class
```

Same logic was implemented for Mid and High frequencies:

```
peak2 = 0;
for (w = 200; w < 600; w++)
{
    if (peak2 < _fft[w]) peak2 = _fft[w];
}
k = (int)(Math.Sqrt(peak2) * 3 * 255 - 4);
if (k > 255) k = 255;
if (k < 0) k = 0;
_mid.Value = k;


peak2 = 0;
for (w = 800; w < 2200; w++)
{
    if (peak2 < _fft[w]) peak2 = _fft[w];
}
k = (int)(Math.Sqrt(peak2) * 3 * 255 - 4);
if (k > 255) k = 255;
if (k < 0) k = 0;
_high.Value = k;
```

As I have 6 progress bars in my simulator I've decided to implement them the way: LOW (Bar 3, 4), Mid (Bar 2, 5), High (Bar 1, 6).

The good thing is that I can easily modify all of that, if necessary.

All the programming code is running inside the timer, so it easy to modify how many times per second run the code. I've configured it to be taken 5 times per second.

Appendix 4 – [Simulator to Arduino Connection]

SerialPort object was added to my project:

⊞ (ApplicationSettings)	
(Name)	**serialPort1**
BaudRate	9600
DataBits	8
DiscardNull	False
DtrEnable	False
GenerateMember	True
Handshake	None
Modifiers	Private
Parity	None
ParityReplace	63
PortName	**COM3**
ReadBufferSize	4096

Figure 38: SerialPort object configuration

Now it is possible to use COM3 serial port (which is my Arduino Uno connection port) with the following commands:

```
serialPort1.Open();
serialPort1.Close();
serialPort1.WriteLine();
```

I've added one more timer to be able to control the frequency of sending the information to Arduino and added some elements to the interface.

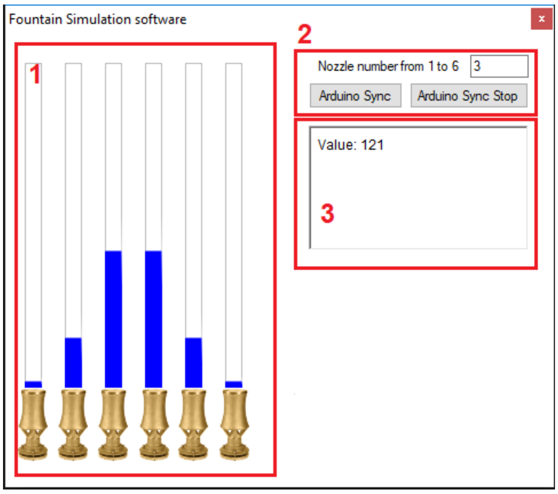

Figure 39: Fountain Simulation Software interface

1. Fountain water jets simulation area

2. Logic to start and stop sending data to Arduino. Select nozzle from 1 to 6 and start transmission. Progress bar values are from 0 to 255, so it can be directly used as PWM signal value to control the Water pump.

3. Feedback from Arduino. Basically, Arduino sends the received signal back. Required for testing and debugging.

Following Timer's logic was implemented in Visual Studio to send over COM port:

```
// Checks if Start Arduino trasfer button is clicked. When the button
is clicked COM3 port is opened then and this variable is set to true.
if (_arduinoSend == true)
{

    int _iNozzle;
    // Read the Nozzle number from the texbox
  _iNozzle = Convert.ToInt32(txtNozzle.Text);
```

```
                if (_iNozzle == 1)
                serialPort1.WriteLine(Convert.ToString(progressBar5.Value));
                if (_iNozzle == 2)
                serialPort1.WriteLine(Convert.ToString(progressBar4.Value));
                if (_iNozzle == 3)
                serialPort1.WriteLine(Convert.ToString(progressBar3.Value));
                if (_iNozzle == 4)
                serialPort1.WriteLine(Convert.ToString(progressBar3.Value));
                if (_iNozzle == 5)
                serialPort1.WriteLine(Convert.ToString(progressBar4.Value));
                if (_iNozzle == 6)
                serialPort1.WriteLine(Convert.ToString(progressBar5.Value));
               // Write sended value to consile for debugging
                //Console.WriteLine(Convert.ToString(progressBar5.Value));


            }
```

Not the most elegant code, but it works for testing purposes.

Following line was added to read the repeated signal from Arduino and write it to Rich TextBox.

```
richTextBox1.Text = serialPort1.ReadExisting() + "\n";
```

On the Arduino side [25] it was necessary to read the COM port information.

```
String inString = "";    // string to hold input

void setup() {
  // Open serial communications and wait for port to open:
  Serial.begin(9600);
  while (!Serial) {
    ; // wait for serial port to connect. Needed for native USB port
only
  }
}

void loop() {
  // Read serial input:
  while (Serial.available() > 0) {
    int inChar = Serial.read();
    if (isDigit(inChar)) {
      // convert the incoming byte to a char and add it to the string:
      inString += (char)inChar;
    }
    // if you get a newline, print the string, then the string's
value:
    if (inChar == '\n') {
      Serial.print("Value:");
      Serial.println(inString.toInt()); // Send received value

       // PWM Logic to be added here.

      inString = "";
    }
  }
}
```

It took a while to make the Serial Port reading part done, because data reading is happening per byte and it is necessary to make the full string by combining these bytes. But when this part is ready it is quite easy to extend it with Motor Drive PWM logic.

```
// Give to Speed variable value received by Serial
speed = inString.toInt();Port

 if (speed > 250) speed = 250; // Keep it under 250 all the time
 if (speed < 100) speed = 250; // Keep it above 100 all the time
 analogWrite(EnB, speed); // Send speed value to EnB analog pin (5)
```