Interdisciplinary course of

Design and Robotics

7° edition, 2019

Project:
Aretha & Franklin (Soul Music)

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Abstract

This report describes the evolution of the project carried out in the 7th edition of the course of Design and Robotics at Politecnico di Milano. The group developed a robot that dances to the rhythm of Soul Music.

The document opens with an analysis of the social context, aesthetics and sounds of soul music. Based on the findings of this research, the second section of the report focuses on the development of a concept for the robot: in this case a stage on which two singers resembling the chorus in soul music move to the rhythm given by the music played on a phone, that stands on a base in the position of the lead singer.

The document proceeds describing how the group arrived at the final form of the robot and explains the choices that led to the definition of interaction, shape, mechanics, electronics and informatics. At the end of the report, you can find our thoughts and learnings.

Description

“A robot is a device that receives data from a set of sensors and, basing on these, performs (autonomously) a task moving some of its parts.”

The goal of the project was to develop a robot that could dance to music from the soul genre with a dance style and a characterisation with clear references to the soul genre and era. We started from a deep analysis of the soul context and the music characteristics of this genre. From that we developed a basic concept that we then developed over the weeks, reaching a final prototype able to recognize the music, dance and interact with the user. Following the definition of a robot, we try to keep ourselves open-minded and try to define a design coherent with the research and what we want to communicate, and not bound by the common image of a robot.

Research

Music style story

Soul music developed in the US at the end of the 50s and during the 60s in the Afro-American community. It derives mainly from rhythm & blues and gospel.

The two main currents developed from R&B in this span of time are funk and soul. However, from our research, we can say that funk was born some years later that soul: around the end of the 60s and the beginning of the 70s, when R&B and soul singers started experimenting with more rhythmic dance sounds.

At the beginning of the 70s, soul started its fragmentation and many black artists at the time recorded funk, soul and pop songs in the same album. This makes difficult to define an artist as specifical soul: they might have started singing soul music but then moved to funk or pop music during their careers.

We looked for information on Google and searched at first only the keywords “soul music”. We read the Wikipedia English description to have a general idea about it and then researched on Google including keywords such as “history” or “culture”. We looked up the most important artists and record houses. To research the social context of soul music, we searched mainly “black culture in the 60s” and “civil rights movement”.

Music style footprint

Soul music derives mainly from R&B and gospel, and it takes from the latter some of its most significant characteristics: the lyrics structure, the call and response between lead singer and chorus and some of the gestures of gospel – such as the extemporaneous movements of the singer when singing the most acute verses and rhythmic movements from the chorus following the beat –.

In fact, examples of soul songs are dated to the 50s, when singers such as Ray Charles, James Brown and Sam Cooke transformed the lyrics of spiritual themes proper of the gospel into secular ones talking about love.

Soul sound was also largely influenced by the record label producing the music and by the geographical area in which it was developed.

“From the bouncy, catchy acts at Motown to the horn-driven, gritty soul of Stax/Volt, there was an immense amount of diversity within soul.” – Allmusic.com[1]

[1] https://www.allmusic.com/subgenre/soul-ma0000002865

Across the US, we can find two main currents of soul music: Detroit soul (or Motown soul) and southern soul (or Memphis soul). While the main band composition remains the same (lead singer, chorus and musicians), mayor changes in the two subgenres (and in the labels leading them) are in the rhythm, the relevance of main singers and groups in records and the target audiences.

Detroit soul is characterised by the prominent figure of Motown Records, the main production label in the city. Its sound is more polished in production and lyrics content and pop-oriented, with a strong rhythm and bassline, hand clapping, strings, brass and vibraphone. Motown was the main record label regarding soul music: the polished look and sound of its artists made the label's hits skyrocket to the top of the pop charts in the 60s making black singers known to the general white public.

Southern soul, on the other hand, is defined by a more energetic and up-tempo rhythm and southern more vibrant gospel sounds. Stax Records, based in Memphis, was the main driving production house of southern soul and developed a specific sound, deeper and more focused on the harmony, with greater use of horns.

Even though Memphis and Stax Records lead the development of the southern soul, other southern cities, like New Orleans and Birmingham, share the same characteristics of rhythmic sound and deeper harmonies and lyrics, while developing their own styles. At the same time other labels, such as Atlantic Records and Hi Records were producing singers with a distinctive southern soul sound across the region.

Aesthetics:

The attire of soul singers and groups was another characteristic derived from the gospel context, very elegant compared to other kinds of music. Men usually wore serious and elegant suits and women long shining dresses and big earrings. Although in later decades afro styled hair became more common, in the 60s it was not yet a style worn by soul groups. On stage, the attire of lead singer and chorus was usually coordinated in colour and fabric as demonstrated by the many soul music videos available online.

Social context:

Soul music is born in the late 50s and developed in the 60s and 70s inside the African American community in the US. These decades, especially the 60s, are marked by great turmoil in the US society: the non-violent Civil Rights movements, the Black Power movements, the Vietnam war, feminist movements, the murders of John F. Kennedy, Martin Luther King Jr. and Malcolm X were all taking place in this decade across the country.

Among all of the protests, soul music is mostly associated with the rise of the Civil Rights Movement led by Reverend Martin Luther King Jr.

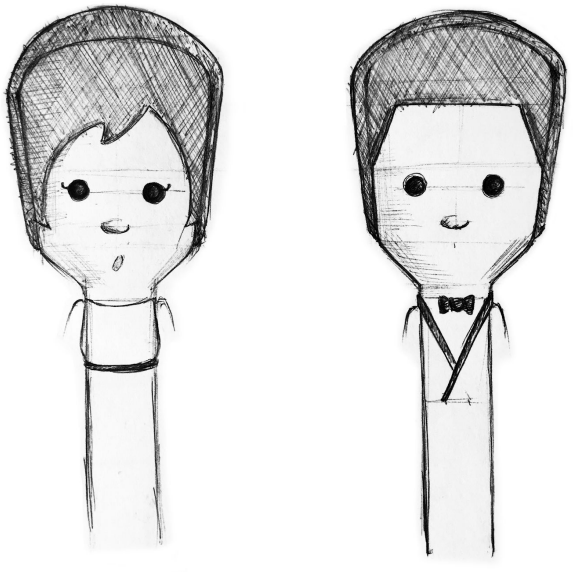
Moving from the gospel context, soul music secular lyrics reached the wider black community, but they didn't stop there: soul artists reached popularity in the pop charts, expanding their public to the white society.

In the first years of soul, lyrics were measured and treated themes as love and longing; the first soul record targeted to a wider public, such as "Please, Mr Postman" by The Marvelettes, didn't show the singer in on the cover. But at the beginning of the 60s, when singers (Marvin Gaye, Otis Redding, Sam Cooke and others) had gained a steady indisputed success, they released protest songs, singing about the struggles of their daily lives as black Americans.[2]

Even if soul musicians were seldom associated with the actual protests, their contribution to the Civil Rights movements was remarkable. They contributed to the overall atmosphere expanding their audience and making white people more aware and sensitive about black struggles, creating a social consciousness around R&B and soul music, promoting black pride and self-awareness and advocating for social and political change (the most famous song about this is Sam Cooke's "A Change Is Gonna Come).

Concept

The robot consists of two singers singing on a stage; they move to the rhythm of the music streamed by a phone, placed on the stage in front of them. We defined these positions because they resemble the ones of the lead singers and choruses in different soul music live videos we analysed.



The stage, whose shape and features derive from videos of the time as well, contains all the parts of electronics and is formed by an L shaped wood: the horizontal part will host the electronics and will be covered like a real stage, in the vertical part will go the speaker, behind a curtain. The internal space of the stage will be higher on the basis, to contain the electronics and mechanical parts, and tighter on the back, that will host the speaker and the curtains.

[2] https://www.youtube.com/watch?v=VnRfyVQS_iA

Development

Day 1 - 02/04/19

We made a brief research about soul music, its sound, the most famous artists and the historical context in which it developed, and prepared a first moodboard to convey all these pieces of information to the class.

The main issue we found was to understand the iconic characteristics of soul music, since it shares most of its history and sounds with gospel, funk, blues and other music genres related to black culture after WWII in the US.

We created a first moodboard to understand the context and atmosphere of soul music and to explain it to the rest of the class. We added to it images of soul singers, posters of concerts and vinyl records, to show the importance of live performances and the role of Motown Records in the development of soul music. We also addressed the context of the 60s, the peak of soul, via images of the social atmosphere with parties but also the marches of the Civil Rights Movement.

Day 2 - 09/04/19

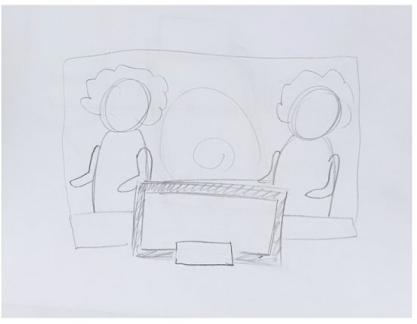
We decided which robot to build and presented two options to the review: the “diva”, a soul singer that moves the head and one arm to point to the user that stands in front, and the “chorus”, two connected singers that move their bodies and arms according to the music, mimicking a soul chorus. We chose to focus on the “chorus” because it seemed easier to make the robot interact with people.

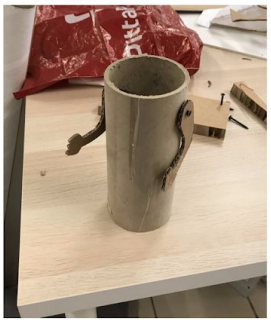
We decided that the robot will interact with the people near it via a proximity sensor and it will ask them, through gestures or words, to play some music; then, when the people will pay attention and turn the music on, it will start to dance.

We made a first pre-prototype, to understand the rough look of the robot and we also made a list of the things to do and to buy before the next class.

We chose to put a stage under the two singers, but we faced problems regarding how to join them to the stage to pass the “fall test”. We managed to solve the problem, in theory, via a joint between the basis of the puppets and the stage.

A pending problem is how to cover the electronic part that will go inside the stage: we thought about thermoforming the cover but we are not sure about the feasibility and the resistance of the material.


Day 3 - 07/04/19

We defined the interaction of the robot with the user: when a person arrives close, the robot says something and moves the arms to call the user to action.

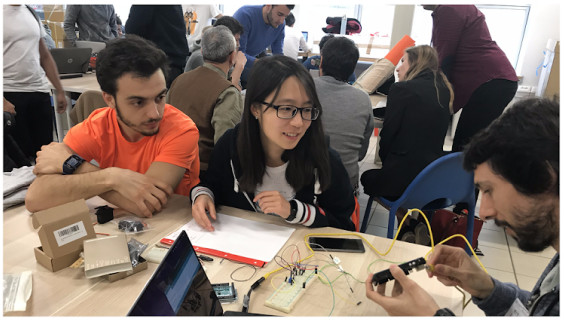
We tested the audio circuit to get the data from the jack audio and it works. We found an algorithm that detects beats and tested it.

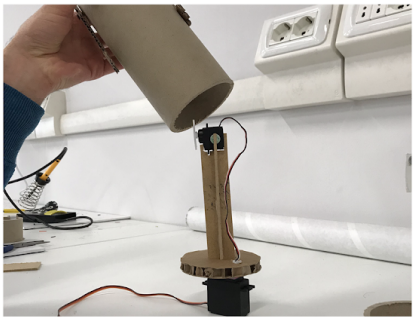
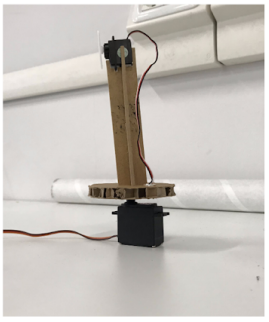
We defined the final look and materials for the shell of the singers: they will have the shape of specific microphones used in the 60s in soul and pop music. The microphones will have the features of soul singers, so black hair and elegant dresses.

We also defined all the materials we will need for the shell: they will be 3D printed and then painted in silver to resemble the microphones, the hair will be applied later and modelled with Fimo, the dresses will be painted and the details applied in the end.

We found problems regarding the servo motors: when we tested the movements using only one big motor the movement was smooth, but using both servos the movement was slow or completely absent.

Moreover, when we tested the audio with one servo, the music was not working and we still have to understand the reason.

During the week we reviewed the mood-board and changed it since the first one we did was too generally about the 60s and did not depict the “essence” of soul music as we analysed it. The new version shares few elements with the old one: the singers are still in a position of significance but they are surrounded by the context in a more distributed way. The colours of the artists’ photos are taken by examples of vinyl recorded at the time. The name of Motown Records stands out because of its significance to the music genre, as well as an image of the protests, signifying the specific context of the early 60s in which soul developed. In the back there are some images of records: they are some of the most famous ones and show the music and the style of the time.

Day 4 - 14/05/19

Dario and Giulia modelled the shape of the singers, defined the shape of their internal skeleton and the way to join the skeleton and external shell.

Mirko, Shiyao and Diego started the day with functioning and tested code for the beat detection. We kept working for high pitch detection for the rest of the morning.

We ended up with a code which computes a global moving average, over a high number of samples, and compares it with a local moving average, which considers a smaller number of samples. This code is applied after an high-pitch-voice filter has been applied. If the local moving average is bigger than the global one, then we assume that the singer is currently singing a high pitched note. This code will be optimized if there will be enough time. We also started to write the code for the robot in an organized and complete way, to manage the overall complexity of the application. We started from the code skeleton to be sure to correctly manage time and coordinate the different domains, and then we integrated the working code already developed. We now need to optimize the computation abilities of the Arduino since by unifying both beat and pitch we have found a slight deterioration in the sensitivity of the beat detection algorithm.

Regarding the user interaction domain, we decided and coded the movements that make the robot move the hand to catch the user attention. The interaction has to be completed with the proximity sensor signal and an emitted sound from the robot to catch the user attention and asking him to put some music on for him.

We also coded the movement related to the “loading” mode of the robot: the robot needs some seconds of computation to correctly follow the beat and pitch, so we decided to cover these few seconds with some movements that make the robot seem happy because he is finally receiving music and he can dance.

For the next time, we expect to be able to have a working code which allows the robots to move according to the beat and pitch found and to finally code the proper dancing movements of the robot.

Today we have received the proximity sensor, the power supply and the 3D structural prototype of the robot. For the next week according to the schedule, we are going to have all the electrical components needed.

At the end of class, we talked with Professor Romero about the shape and materials for the stage: our doubt was if to build only its lower part in wood - thermoforming the upper part -, or if to make the whole stage in wood. In the second case, we had other doubts about how to proceed. We then concluded to build the whole stage in wood, leaving the vertical part open to the speaker and only covered by a curtain, and the horizontal part closed by a wooden stage. We still have to clearly understand how to place the LEDs under the stage even Prof. Romero suggested us to use an RGB led strip so we can reduce the overall current consumption and use only 4 pins.

Day 5 - 21/05/19

During the previous week, we bought the wood to build the stage and Giulia cut it. Meanwhile, Dario finished the model of the singers and printed the base, shell and arms of one. Mirko continued to design the code to base the movement on the music. Diego started to build the electronics and test the power supply. We met on Saturday to continue working and discuss the developments.

During the morning, Giulia and Dario realised that some of the measurements for the stage were wrong so Giulia went to buy other wood for the sides of the stage.

Still in the morning we glued the front of the stage and cut it to make space for the proximity sensor. In the afternoon we tried to place the proximity sensor in the front the stage but it would not fit so we spent the afternoon fixing it.

Dario finished printing the arms of the robot and 3d printed it in the lab.

We had some problems with the audio signal, so the robots start dancing even with no music playing. We figured out that there was noise coming from the power supply and due to bad

connections in the circuit. Moreover, the servo motors were not moving according to the beats detected by the analysis, so we spent half the day working on it.

We decided to postpone the pitch detection and movements because we wanted to solve the issues with the connections and beat detection first. This problem could be addressed later on.

Finally, we decided to use a LED strip because of the current consumption of the RGB LEDs alone, and because the number of pins the LED strip uses: 2 for all the LEDs in the strip compared with 3 per each RGB LED.

We have received all the electronic components, which so far are:

- Arduino Mega 2560 Rev3
- Resistors & Capacitors
- RGB LEDs
- Generic LED strip
- SG90 (2)
- MG996R (2)
- Step-down DFR0379
- Adafruit Mono 2.5W Class D Audio Amplifier - PAM8302
- Adafruit Audio FX Mini Sound Board
- proximity sensor HC-SR04
- Power supply - 12V 5A
- Prototyping board

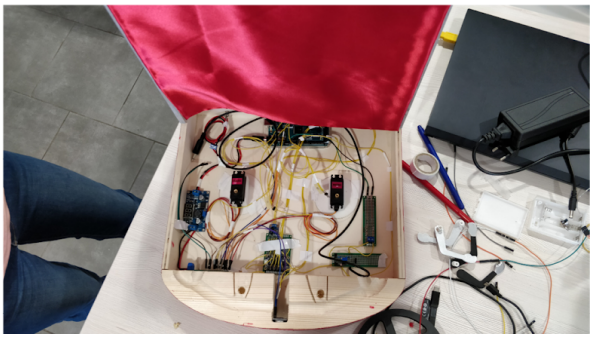
Following steps

In the following week Shiyao, Diego and Mirko continued to work on the code fixing the issues we noticed on Tuesday. Giulia finished building the stage and Dario continued printing the singers.

We bought the material to paint and “dress” the puppets and Giulia was supposed to make them the hair with Fimo, but the material is difficult to keep in shape while it cooks, so we had to find another solution. We resorted to using foam for the hair: it is easier to shape and it looks more like hair. Moreover, it softens the impact on the singers if they were to fall in the drop test.







Decision-making process

We first had, as already pointed out in the section “Day 2”, two options: diva and chorus. We opted for the chorus solution because it was easier to define the interaction with the user and for the personal taste of the members of the group.

Interaction

Right from the start, the idea about the interaction has been about the robot asking to play some music. We decided to detect the presence of the user in front of the stage and define a few interactions to play when the user is in front of the stage and others to play when it is not.

Later on, we identified three different situations: user not present, user approaching, user near the robot. The idea was to have three different interactions for these three situations. In the end, we removed the middle situation because the technical implementation was not precise enough to distinguish between three different distances.

Shape

We chose to shape the whole robot to remind the style of the soul genre and time: in particular, the shape of the two singers reminds the shape of microphones of that era, as it is for the stage. The back of the stage has been added both to host the speakers and to improve the overall style of the robot thanks to the use of the curtains. The stage is quite deep because it hosts the mechanical and electrical components.

Mechanics

We decided to use separate motors for the two bodies of the singers since the servo motors can be easily synchronized and the mechanical part with only one motor would have been much more complex. The same happens for the motors of the arms, with each singer having his own separate motor.

Electronics

We decided to use an Arduino Mega because we thought it had enough resources for our robot, to analyse the music and to manage the movements.

We used a led strip to minimise the number of pins used and we used an audio jack to prevent transmission error and noise.

Informatics

We first wrote the general structure of the code that was relying on the usage of four different states, one without music, one for computing the beat, one for following the beat and one dedicated to the high-pitch moments. In the last development steps we realized we could use a simplified algorithm for the beat detection that didn't need a lot of time for the computation, and so we removed the computing phase. We then removed the 'high-pitch' phase because the high pitch detection algorithm was not precise enough.

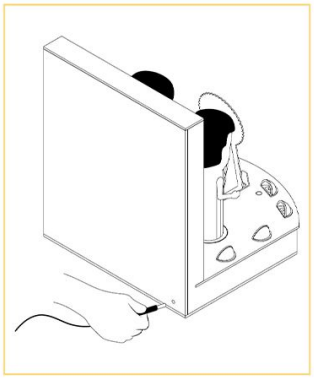
Final Robot

Interaction

The interaction of the robot with people can be divided into three phases: attracting the attention, interaction and dance:

1. When people turn on the robot, an applause will play cheering them.
2. To attract the attention of people passing by, the singers will play "come closer to me" or "come on, come on" and move the arms.
3. If a person passes by, the robot recognizes the distance between itself and that person.

4. If a person is within 50 cm from the robot, it will play “let the music play” or “let’s get it on” and move the body asking to interact with it.
5. To play the music, the person plugs the phone to the headphones cable in the stage and positions the phone on the phone holder at the main singer place.
6. To make the robot dance, the person chooses a soul song and makes the music play.
7. Once the music starts the singers will start dancing to the beat moving their bodies and arms: watch it dance and tag along!



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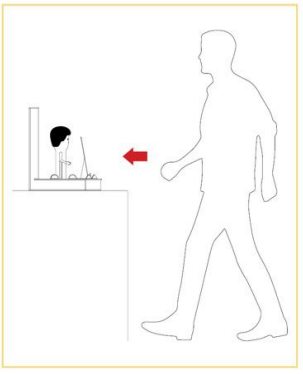

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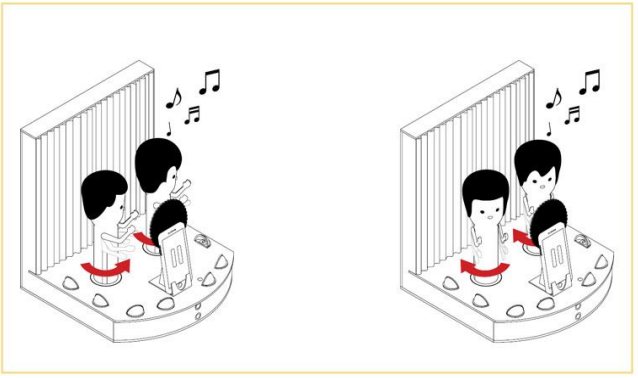

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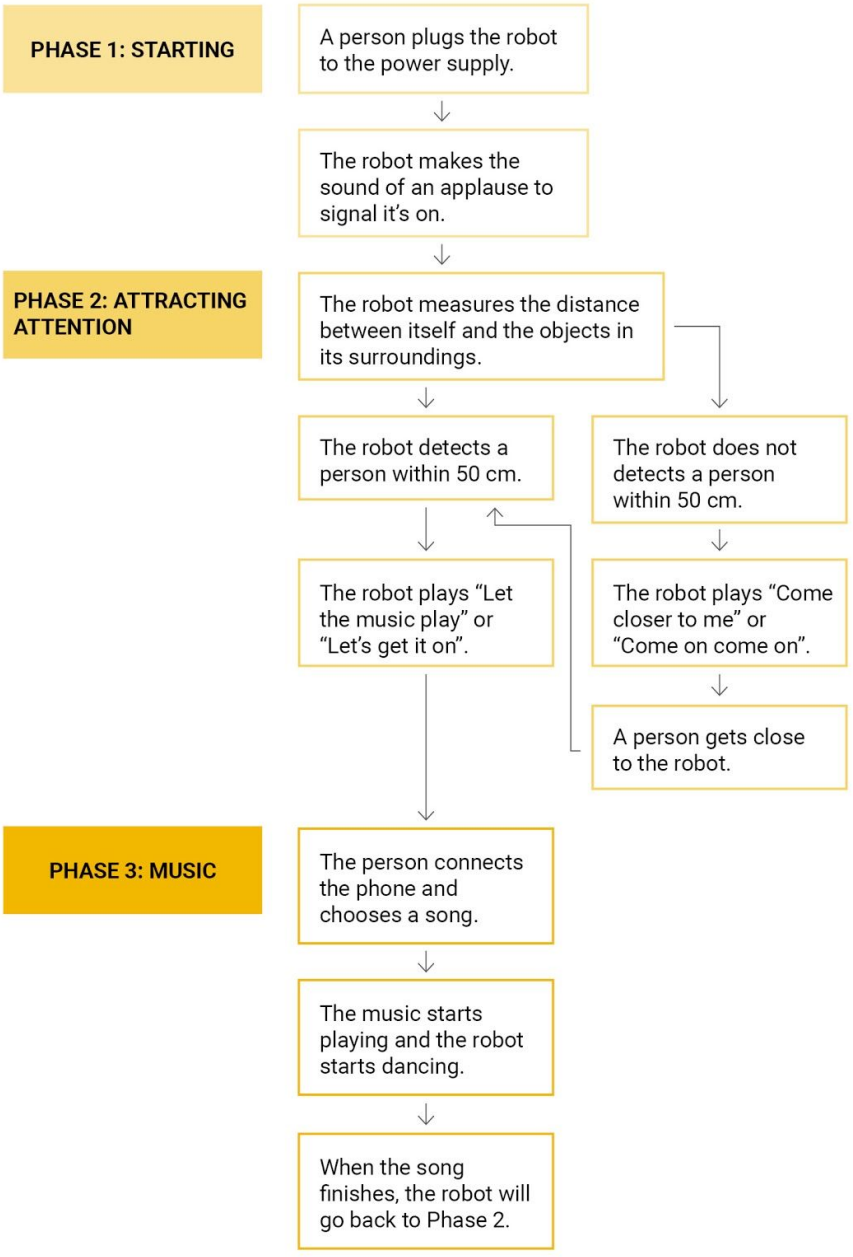


Shape

The robot is mainly composed of two sets of pieces: one comprehends the singers and the other the stage.

The singers are 3D printed in PLA with a Creality Ender 3 FDM printer, and then painted with acrylic colours. The details are made in satin and the hair in foam.

The structure of the stage is made in plywood, the pieces are attached with glue. The actual stage, that covers the electronics, lodges in the two lateral L shaped pieces and is blocked

by two wooden dowels in its front part. On the upper part of the stage, the spotlights are glued and host the led strip.

The back of the stage, that hosts the speaker, is covered by a satin curtain. It is glued to the wood only in the upper part, so it can be lifted to access the speaker.

Since all soul groups wore colour-matching clothes, the details on the whole robot are cherry red. The singers, since they are shaped as microphones, are silver coloured, while their hair is black. The lady-singer “wears” a cherry red dress, while the sir has a black tuxedo with the reverse and bow-tie made in satin.

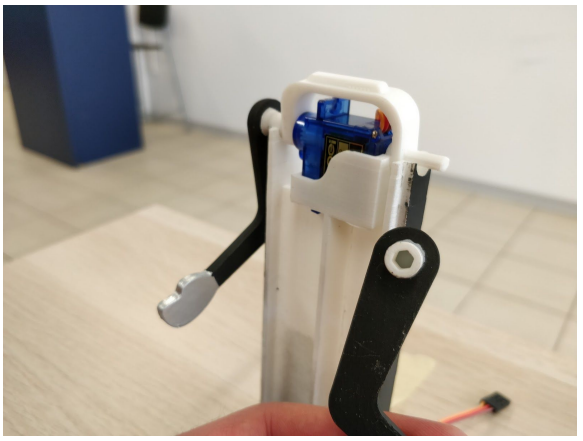
Mechanics

Aretha & Franklin is a robot equipped with 4 servos. We have two bodies with the same internal structure. The former robot represents Aretha and the latter represents Franklin.

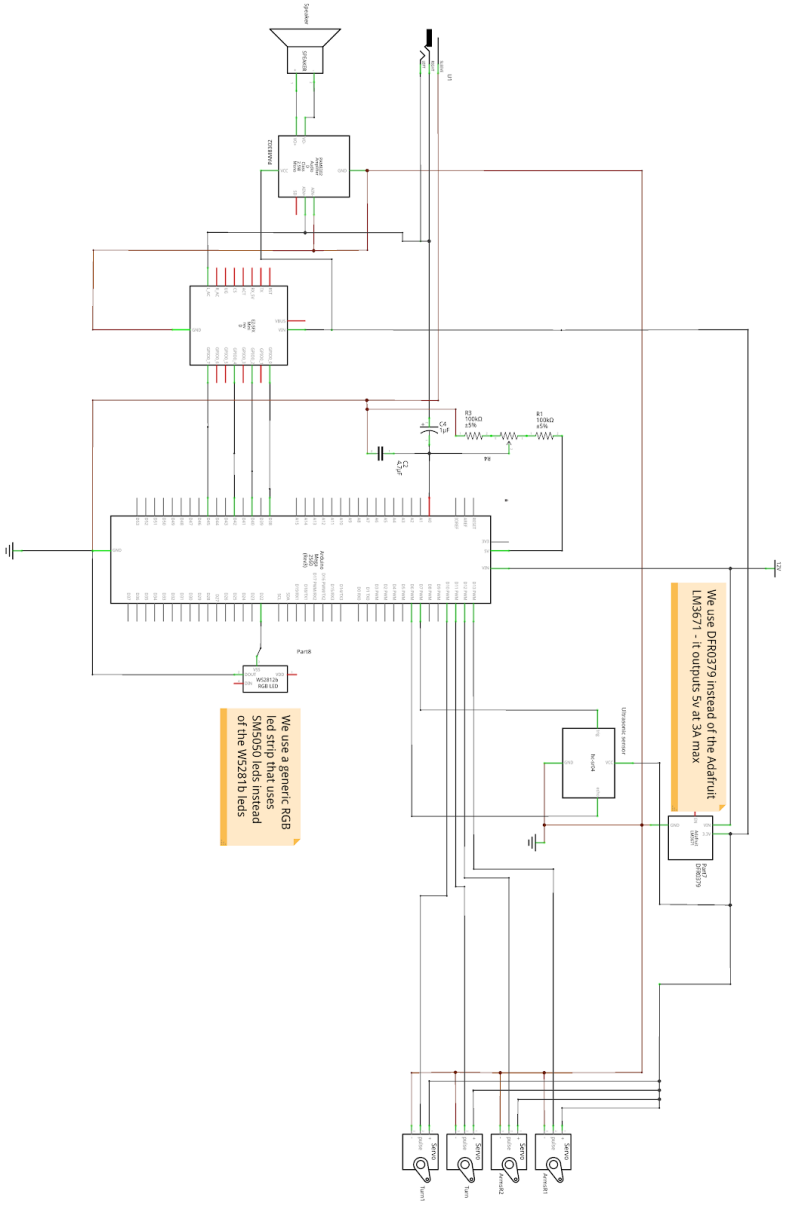
For each robot, we have 2 motors one regarding the movement of the body along the z-axis (Mapei SG996R) and the other (Mapei SG90) which deals with the movement of the arms.

The body z-axis is aligned with the axis of the motor so we attached directly the body to the servo motor horn. This servo motor is directly fixed to the base of the stage through a 3D printed motor holder. The internal body also holds the servo motor used to move the arms.

We decided to use one motor to move both the arms. To do so we positioned the motor axis aligned the axis of the robot shoulder and printed an ad hoc bridge in order to move both the arms, in the bridge there is a reinforcement to prevent bending problems. Since everything has been 3D printed (inside and outside) we have been able to design all custom made components in order to avoid any possible collisions and connection problems (glue, screws etc).



Electronics



Our robot is based on the Arduino Mega2560 Rev3 board, which uses an ATMega2560 running at 16MHz. We have chosen this board because of its amount of digital ports (54) and because it has enough power to let us analyze the audio signal.

Moreover, the audio input signal is provided by the output audio jack of the connected phone. This signal is shifted to a base of 2.5 V, because the Arduino analog input can handle signals that move from 0 V to 5 V, and an audio signal moves from -2.5V to 2.5V.

For the movements of the robot, we have chosen 4 servo motors: 2 of them for the arms (SG90 model) and the other 2 for the body (MG996R model). The SG90 model is a small servo that has a torque of 1.8 kg/cm, with plastic gears. On the other hand, the MG996R model is a bigger servo, with metal gears, which has a torque of 9.4 kg/cm.

Since the current consumed by the 4 servo motors is almost 2 A, we decided to use a 12 V with 5 A power supply, which is more than enough to feed the Arduino board, the servos, and everything else in the robot. But, due to the excess of voltage provided by the power supply, we need a step-down voltage regulator. We have chosen the DFR0379 which is an adjustable device able to provide an output voltage of 5 V with a maximum current of 3 A.

Moreover, we have bought a generic LED strip that uses SM5050 RGB LEDs. SM5050 LEDs have one pin for the power (5V) and one pin for each colour. When some of the colours are connected to ground, that LED is turned on. We decided to use only the red LEDs, so we connected red pin of the LED strip with the ground of the Arduino board, and the VCC of the LED strip into the pin 22 of the Arduino. Whenever we want the lights on, we set the 22 pin of the board on, which feeds the LED strip with the needed 5V. Furthermore, since we are using only one colour and 8 LEDs, the current consumed by all of them together is not too high for the board. The Arduino board can provide up to 200mA, and each LED consumes 20mA, so the total amount of current consumed is 160mA.

Finally, for the interaction of the robot, we have chosen the proximity sensor HC-SR04, which is an ultrasonic sensor, and the Adafruit AudioFX soundboard without the amplifier. This soundboard is able to reproduce up to 8 audio files stored in its 2MB storage, but since it does not come with an amplifier, we have chosen the Adafruit PAM8302 mono amplifier. The amplifier is connected to the soundboard and to the input jack coming from the phone. This is done in this way in order to be able to reproduce the music coming from the phone and the sounds coming from the soundboard altogether.

Informatics

The software part relies on two states: the no-music state and the beat following state. We continuously update the state of the Arduino using a moving average on the volume of the audio input. When the average gets above a threshold we assume it is music and we go to the beat following state. When the average gets below that same threshold we assume the music has been turned off and we return to the no-music state.

The beat is detected using three filters applied in succession: a bandpass filter to filter out static noise and very high frequencies, a lowpass filter to keep only the low frequencies part and again a bandpass filter to identify the beat, between 1hz and 2hz.

The beat reaction algorithm is pretty simple in its current implementation: whenever we detect a beat we start moving with a speed that depends on the average distance between beats, updated every time a beat is detected.

To manage the speed of the servo motors we used the library VarSpeedServo from https://github.com/netlabtoolkit/VarSpeedServo.

Our codebase has been uploaded in the drive shared folder and is available in GitHub at https://github.com/mirkosalaris/SoulBotDancer.

Conclusion

The whole project has been really funny and interesting, it pushed us to learn more about Soul music and to have fun listening to it.

In the end, we all have learnt to work in a group with people with different schedules since every one of us had different plans and tasks to do. The team is made of students from different majors and departments and despite the differences in the working approach we managed to work together and to stay focused on the final goal.

Another important skill we have learnt from this experience is how to manage a project from the very beginning with a good division of the basic tasks according to each one's ability. The timing has been really short and we had to learn how to do quick decisions and changes on the go.

We are really satisfied with our result since the robot dances on the music and the interaction works well but unfortunately, we have not been able to implement the high pitch movement which was supposed to be a further movement for the dancing state.

Bibliography

Soul Music History

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https://www.allmusic.com/artist/aretha-franklin-mn0000927555/biography

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Video references

Neither One Of Us - by Gladys Knight and the Pips
https://www.youtube.com/watch?v=n_Lh4MFiw08

Midnight Train to Georgia - by Gladys Knight and the Pips
https://www.youtube.com/watch?v=HwbmufPphP0

I've Been Loving You Too Long - by Otis Redding
https://www.youtube.com/watch?v=rl_zG2eWGE4

Annex

Link to User Manual

https://drive.google.com/open?id=11elUvNFfOH0BMm_lJx5HWK2ydIqjGC9y

Link to Bill of Materials

https://drive.google.com/open?id=1Zx-XcErPai9rhHKit9P17e_c8hBNTcTj

Link to Technical Drawings

https://drive.google.com/open?id=110pRUSpw4uWO-pyH5s_rnahsvxm6qVAx

Link to 3D model

https://drive.google.com/open?id=17sVBeGmQKMSFQI9gt9Szn3fGGQDPuxcu

Link to photo and video material

https://drive.google.com/open?id=1rxsJlQ4FEO79og9GMOpyMRJzRbJjGuuc

Link to code

https://github.com/mirkosalaris/SoulBotDancer