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Thesis Report

Mechatronic prototype design of an innovative Automatic Mussel Display

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Mechatronic prototype design of an innovative Automatic Mussel display

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Summary

The company ‘Mossel Culinair' hopes to increase mussel sales and the company's competitiveness by developing an intelligent and innovative mussel display stand. In 2018 and 2019, Chinese SMU/HZ students designed an incomplete display. In the old prototype, there was no automatic lifting system, no temperature control system, no decoration system, and no cooling system. Therefore, these systems are supposed to be built in the new 'Automatic Mussel Display' design based on the security and cost-effective aspects. The entire project includes software design and hardware design. The software design focuses on the design of the control logic, while the hardware design focuses on the connections between the various subsystems. This report describes the process of completing the 'Automatic Mussel Display' design and building the prototype. First introduced the company background and mission, and then rise the main research question of the project: *What is the best design to complete the Automatic Mussel Display mechatronic design (with all requirements) in the form of a prototype and uses the resources (money, workshop, and tools) provided by the company?*

The related theoretical knowledge of the project, mainly including the working principles of the relevant components are presented. Followed by the design method adopted in this project and the corresponding deliverables of each phase.The results obtained in the project are described. The system is divided into five sub-systems:

1. Control subsystem: Control the subsystems;
2. Lifting subsystem: Open and close the upper shell;
3. Human detection subsystem: Detect the human movement;
4. Decoration subsystem: Turn on the music and LED light;
5. Spray subsystem: Spray the sea smell.

The design of each sub-system, the test plan of the sub-system, and the test results of the sub-system are described in different sections. The test results of integrating all the subsystems into one system are introduced.

A discussion of the results of this project is inserted. First, discuss whether the requirements are met, and the conclusion is that all test results meet the list of demands. Then the unresolved problems in the project are discussed and possible solutions are given. Then discussed the effort of the V-model in the project.

Finally, the conclusions and recommendations of the project were drawn. Through the construction and test results of the prototype, it was demonstrated that the new "Automatic Mussel Display" design is realized. It is recommended to increase the number of sensors to improve the accuracy of the system and combine the electrical part of this project with the mechanical part of the designer Martijn Moerland to obtain a complete muscle display design (Moerland, 2021).

Abbreviations

FMCW	Frequency-modulated Continuous Waves
RF	Radio Frequency
PLC	Programmable Logic Controllers
MCU	Micro-Control Units
SCM	Single-Chip Microcomputers
EEPROM	Electrically Erasable Programmable Read Only Memory
RISC	Reduced Instruction Set Computing
PWM	Pulse Width Modulation
RGB	Red, Green Blue
LED	Light-emitting Diode

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1. Description of the assignment

This chapter introduces the background of the company, the description of the assignment and the research questions.

1.1 Company background

Mussel Culinair is a company that prepares mussels for customers and their guests in a traditional way and already has 23 years of experience in this aspect. In addition, the company could provide customer a package with all the necessities that might be needed for a successful mussel party. With the package, the customers could prepare the mussels easily by themselves. But also professional care and advice for the preparation might also be provided. The basic information of Mossel Culinair is shown in Table 1.

Table 1 The basic information of Mossel Culinair

Company name	**Mossel Culinair**
Address	De Poortweq 22, Rilland
Post code	4422 PA
Website	www.mosselculinair.nl
Telephone	+31 0641046147
E-mail	infor@mosselculinair.com

Mossel Culinair believes that the quality and taste of mussels are inseparable, and they see it as the company's vision. Their mission is to combine the quality of mussels with the quality of raw materials, the quality of all necessities, and the final quality of the organization! Coupled with their humor, enthusiasm, and job satisfaction. They guarantee that they will turn a mussel party into an unforgettable top experience. They believe that the quality of mussels starts here, but there is more (Mosselculinair, 2017).

1.2 Assignment description

This chapter introduces the background information of the assignment and the statement of the problem.

1.2.1 Assignment backgrounds

Marco Scheele owns a company that organizes Mussel parties and has many relationships in the Mussel world. Marco noticed the need for an innovative display for mussel sales. In 2018 and 2019, Chinese SMU/HZ students designed a display as shown in Figure 1 to promote mussels in a supermarket. This design was unfortunately not finished yet and did not result in a prototype. Molds have been made that a “one on one” polyester model is made functional as a “Mock-Up”. However, some interior elements have not yet been designed, such as hinges, cooling element, and holder. A client of Marco Scheele would like to see the completed and realized design. On top of that, the design must be ready for production, which means that the production process must be designed, and the completed research achieve the governmental subsidiaries and patent-requirement. Considered about the requirements, the assignment is suitable for executing by a D&I student and a Mechatronic student.

Figure 1The existing prototype display for mussel sale.

1.2.2 Problem statement

As introduced in the assignment backgrounds, there is an incomplete design, which indicates that a lot of money and effort has been spent with no profitable result yet. In the old prototype, there was no automatic lifting system, temperature control system, and cooling system. To make the Mussel display more convenient to use, to keep the mussel fresh for a long time, and to attract more customers. These systems are supposed to be built in the new Mussel display design. All these systems need to be realized that the security and cost-effective aspects should be taken into account. One of the issues is that the company lacks a development crew and a mechatronic engineer. An experienced technical crew and an equipment workshop are available at the premises in Rilland.

1.3 Research questions

The research questions can be divided into three different categories: Theoretical questions ("T") which can be answered by literature research. Empirical questions ("E") should be answered depending on the situations and requirements of the company. Analytical questions ("A") are the combination of the former questions. The answers normally come from the theory research and the desk research executed at the office of the company in Rilland.

1.3.1 Main research question.

In order to solve the problem of company, the main research question is defined as follows:

What is the best design to complete the Automatic Mussel Display mechatronic design (with all requirements) in the form of a prototype, and uses the resources (money, workshop, and tools) provided by the company (A)?

1.3.2 The sub-questions

In order to meet all the requirements of the client, There are sub questions that should be answered during the whole process of the project：

1. What design can be made to open and close the shell automatically and safely based on the motion of the customers? (T)
2. Which sensors can be applied to detect the motion of customers? (T)
3. Which is the best cooling system can be applied to keep the temperature in a stable level (7℃)？(T)

4. Which is the suitable control unit for the automatic lifting system and temperature control system? (T)
5. What is the suitable audio system to play the music for the customers? (E)
6. What suitable LED lights should be installed in the mussel display? (E)
7. How to generate and spray a sea smell? (T)

1.3.3 Research objective.

The research objective for this assignment is to complete the Automatic Mussel Display design (with all requirements) in the form of a prototype by using the resources(money，workshop，tools）provided by the company..

1.4 The project boundaries

The project is conducted by two students from different majors. Designer Wei Wei is mainly working on the electrical part and designer Martijn Moerland is mainly on the mechanical part and product production. The designer needs to complete the design during the internship (4 months, 840 working hours). The total cost of building a working prototype should not exceed 500€.

2. Theoretical framework.

This chapter introduces the relevant knowledge of different aspects in this project.

2.1 Motion detection

The motion detection is the most important part to realize the automatic lifting function. The automatic lifting function in this project means that the prototype could recognize the approaching action of a potential customer as a door opening signal, then the mussel display model would open the upper shell through the motor, and automatically close the upper shell after the customers leave.

There are two different sensors being widely applied in this situation as the input signal capturer, which are infrared sensor and millimeter wave radar sensor.

2.1.1 Infrared sensor.

The photoelectric sensor emits infrared rays through the transmitter and emits reflection when it encounters the target object. After the receiver receives the reflected light, it converts the optical signal into an electrical signal through the photoelectric device and inputs it to the control unit to realize the function of detecting potential customers (as shown in Figure 2).

The strength of the signal will increase as the distance between the object and the sensor decreases. Photoelectric infrared sensors have advantages and disadvantages in detecting targets. The detection distance of this kind of sensor is usually over 10 meters, while the response speed is fast, and the detection target range is wide. However, the internal components of the sensor are very sensitive and need to be protected in harsh environments and the cost is higher than other sensors.

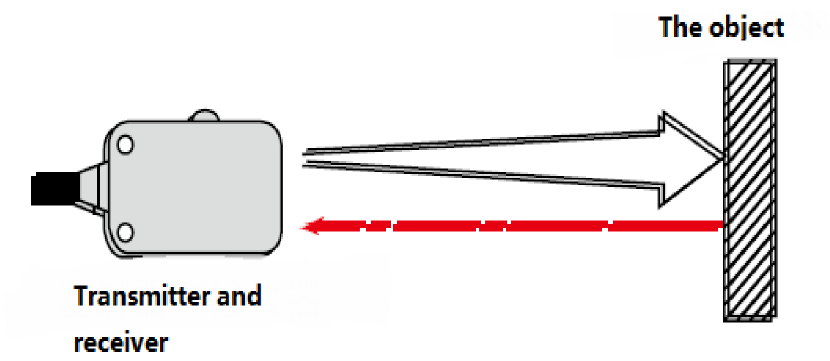

Figure 2 The working principle of infrared sensor (Keyence, 2021).

2.1.2 Millimeter wave radar sensor

Millimeter-wave radar refers to radars that work in the millimeter-wave band whose electromagnetic waves have a frequency in the range of 30 to 300 GHz, and the wavelength is 1 to 10 mm (Xing, 2006). The millimeter-wave radar transmits FMCW (i.e. Frequency-modulated continuous waves) millimeter waves through a microstrip array antenna, receives target reflection signals, and obtains the surrounding physical environment information after processing (SUN Meiling, 2019).

The system structure block diagram is shown in Figure 3. There are 3 main modules in the radar systems: the RF front-end module, intermediate frequency processing module, and signal processing module. The RF front-end module will generate and transmit a FMCW. The intermediate frequency processing module will mix the transmitted and reflected signals into an intermediate frequency signal. Then the signal processing module analyze the intermediate frequency signal to acquire the range, velocity, and angle of the object through formulas.

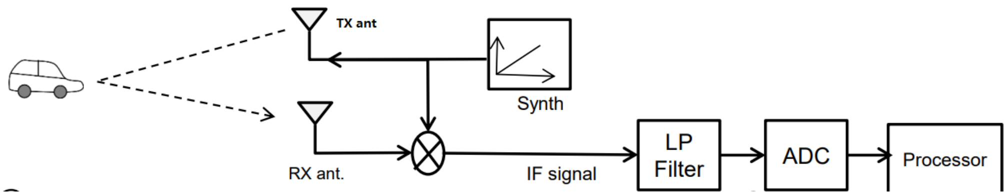

Figure 3 The system block diagram of the FMCW radar (Rao, 2017).

2.2 The control unit

There are two types of control units being commonly used in the field of automatic control, which are Programmable Logic Controllers (PLC) and Micro-Control Units (MCU). They are also known as Single-Chip Microcomputers (SCM).

In the former project, the designer Zehang Wu had applied the SCM ATmega328(shown in Figure 4) as the controller for the whole design. This project is based on his research and try to complete his design. So the control unit in this project would also be the SCM.

ATmega328 is on of the single-ship microcomputers in the megaAVR series developed by Atmel. ATmega328 has 1KB Electrically Erasable Programmable Read Only Memory (EEPROM). This means that the controller can store the data when the power supply is removed. ATmega328 has several different features which make it the most popular device in today’s market. These features consist of advanced RISC architecture, good performance, low power consumption, real timer counter with a separate oscillator, 6 PWM pins, programmable Serial USART, programming lock for software security, throughput up to 20 MIPS etc. (Wu, 2018).

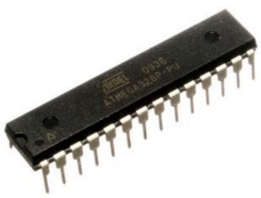

Figure 4 The ATmega328 Microcomputer (Wu, 2018).

2.3 The automatic lifting

In order to realize the function of automatically opening and closing the upper shell, a transmission system is needed to convert the rotation of the motor or other power source into the up and down movement of the upper shell. There are three different transmission systems: Pneumatic linear actuator, Hydraulic linear actuator, and Electric linear actuator.

2.3.1 Pneumatic linear actuator

The pneumatic linear actuator (shown in Figure 5) consists of a simple piston in a hollow cylinder. A manual pump or external compressor will move the piston in the cylinder housing. When the pressure increases, the cylinder moves along the piston axis, generating the required linear force. It can be returned to the original retracted length by rebounding force or adding liquid to the opposite side of the piston (shown in Figure 5.)

Figure 5 Pneumatic linear actuator.

2.3.2 Hydraulic linear actuator

The electric hydraulic linear actuator (shown in Figure 6) is mainly composed of a hydraulic cylinder, an oil pump, an electric motor, an oil tank, and a hydraulic control valve. Through the forward and reverse rotation of the motor, the hydraulic oil is outputted by the two-way gear oil pump, and the hydraulic control valve is used to send the pressure oil to the working oil tank to realize the reciprocating movement of the piston rod.

Figure 6 The Hydraulic linear actuator.

2.3.3 Electric linear actuator

The electric linear actuator (shown in Figure 7) is mainly composed of a drive motor, a reduction gear, a screw, a nut guide sleeve, and a push rod. After the motor being decelerated by the gear, it drives a pair of screw nuts to turn the motor's rotary motion into linear motion. The forward and reverse rotation of the motor is used to complete the reciprocating motion of the pushrod.

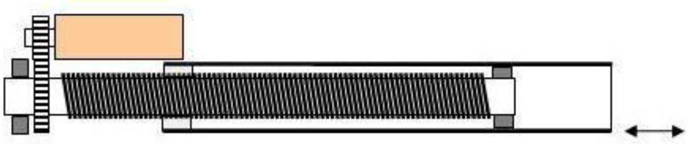

Figure 7 Electric linear actuator.

2.4 The audio system

A loudspeaker is a sound-producing device that converts electrical signals into acoustic signals and is usually composed of a diaphragm, voice coil, permanent magnet, bracket, and so on. When the voice coil of the speaker receives an audio current, the voice coil generates an alternating magnetic field under the action of the current, and the permanent magnet also generates a constant magnetic field with the same size and direction. Since the size and direction of the magnetic field produced by the voice coil are constantly changing with the change of the audio current, the interaction of the two magnetic fields makes the voice coil move perpendicular to the direction of the current in the voice coil. Because the voice coil and the diaphragm are connected, The vibrating membrane is driven to vibrate, and the vibration of the vibrating membrane causes the vibration of the air to produce sound. The greater the current input to the voice coil, the greater the force of its magnetic field, the greater the amplitude of the vibration of the diaphragm, and the louder the sound.

2.5 The LED light

LED is the abbreviation of Light Emitting Diode. It is a device that can convert electrical signals into optical signals. Like ordinary diodes, light-emitting diodes are composed of a PN junction and have unidirectional conductivity. When the forward voltage is applied to the light-emitting diode, the electrons in the N area will be pushed to the P area, where they recombine with the holes in the P area, and the holes in the P area are pushed to the N area and recombined with the electrons in the N area. Then it emits energy in the form of photons. The energy states of electrons and holes in different semiconductor materials are different, and the color of the light emitted is also different. Commonly used diodes are those ones emitting red, green, or yellow light.
RGB LED: RGB LED (show in Figure 8) is the most popular decorative lamp in the market. Compared with ordinary white LEDs, the color of light emitted by RGB LEDs is clearer and brighter. The RGB color model is a common color standard in the industry. Various colors can be obtained through the change and superposition of the three basic colors of red, green, and blue. Each color has 256 brightness, and the superposition of three primary colors can get more than 1670 colors.

Figure 8 RGB LEDs.

2.6 Cooling system

In this project, when the mussels are placed in the display, they are required to maintain the freshness for a long time, which means that a cooling system is needed to keep the mussels in a low-temperature (7℃) environment.

There are two different cooling methods which are commonly used and suitable for this project: Vapor compression refrigeration and Semiconductor refrigeration.

2.6.1 Vapor compression refrigeration

This refrigeration method is widely used in household appliances, such as air conditioners and refrigerators. This refrigeration method consists of 4 main components: compressor, evaporator, expansion valve, and condenser.

The compressor sucks in the low-temperature and low-pressure refrigerant vapor from the evaporator, then compressed by the compressor to become high-temperature and high-pressure overheated vapor. This overheated vapor is pressed into the condenser and cooled into an overcooled liquid refrigerant. Then the expansion valve converts this liquid refrigerant into a low-pressure liquid refrigerant and evaporates in the evaporator and absorbs the heat in the air to achieve the purpose of refrigeration. The low-pressure refrigerant is sucked into the compressor in the end and works in a loop (shown in Figure 9).

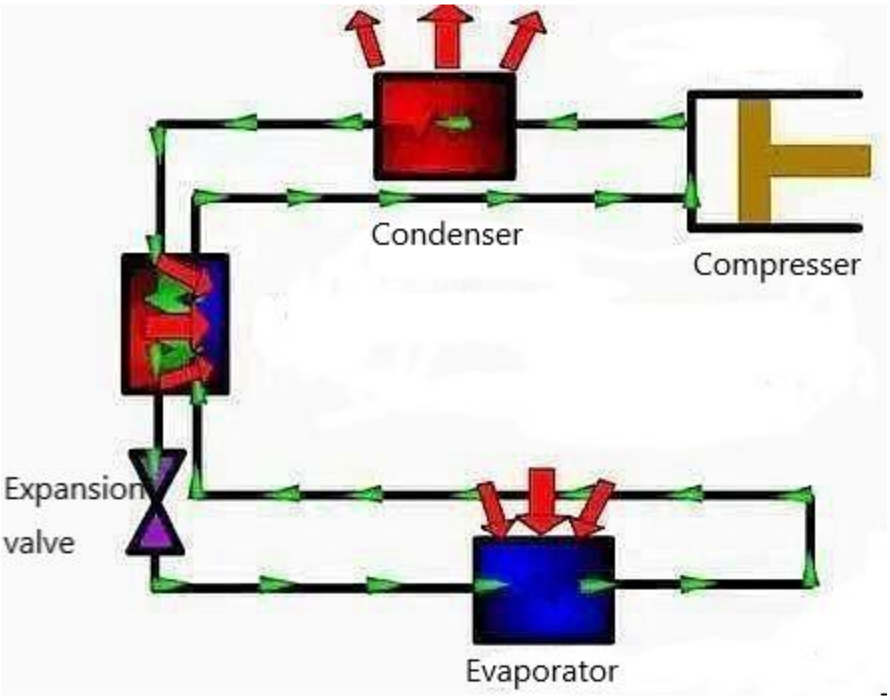

Figure 9 Vapor refrigeration cycle process (Baolan Environmental Technology Co., Ltd., 2020)

2.6.2 Semiconductor refrigeration

Semiconductor refrigeration is different from vapor refrigeration in that it does not require compressors or refrigerants. Semiconductor refrigeration equipment is composed of semiconductor materials with high efficiency and good thermoelectric effect.

Connect a piece of N-type semiconductor material and a piece of P-type semiconductor material into a galvanic pair and supply this circuit with a DC current to generate the energy transfer (Shown in Figure 10). The current flows from the N-type element to the joint of the P-type element to absorb heat and become a Cold end. The current flows from the P-type element to the joint of the N-type element releases heat and becomes the hot end. The magnitude of heat absorption and heat release is determined by the magnitude of the current and the number of pairs of semiconductor materials N and P elements (Chen Jianhua, 2019).

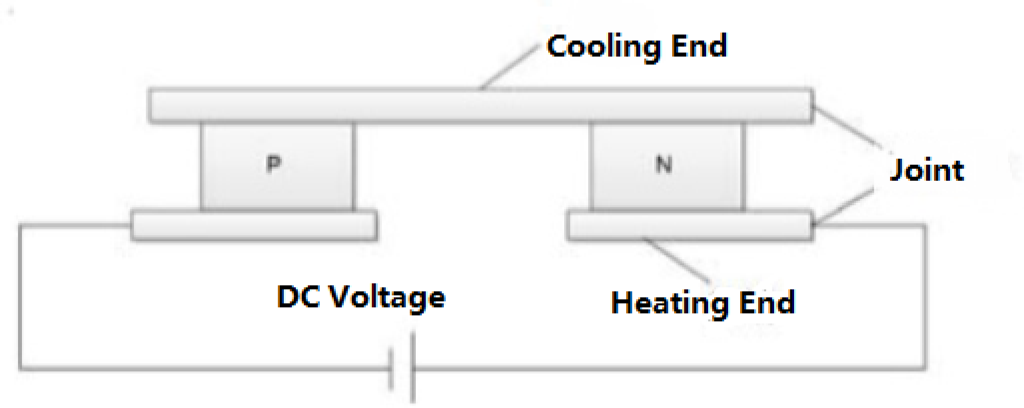

Figure 10 Principle of Semiconductor Refrigeration (Liu Xinglong, 2021)

2.7 Spray

In this project, when the mussel display is opened, the system is supposed to generate and spray a sea smell, which means that a spray system is needed to atomize and spread the liquid with a sea smell

The most common device for liquid atomization on the current market is the ultrasonic atomizer. This device applies an oscillator to convert electrical energy into mechanical energy, generates 1,700,000 Hz high-frequency oscillations, atomizes water into ultrafine particles of 1 to 5 microns, and then diffuses into the environment through a wind-driven device or natural movement to achieve humidification or the function of spreading smell (as shown in Figure 11).

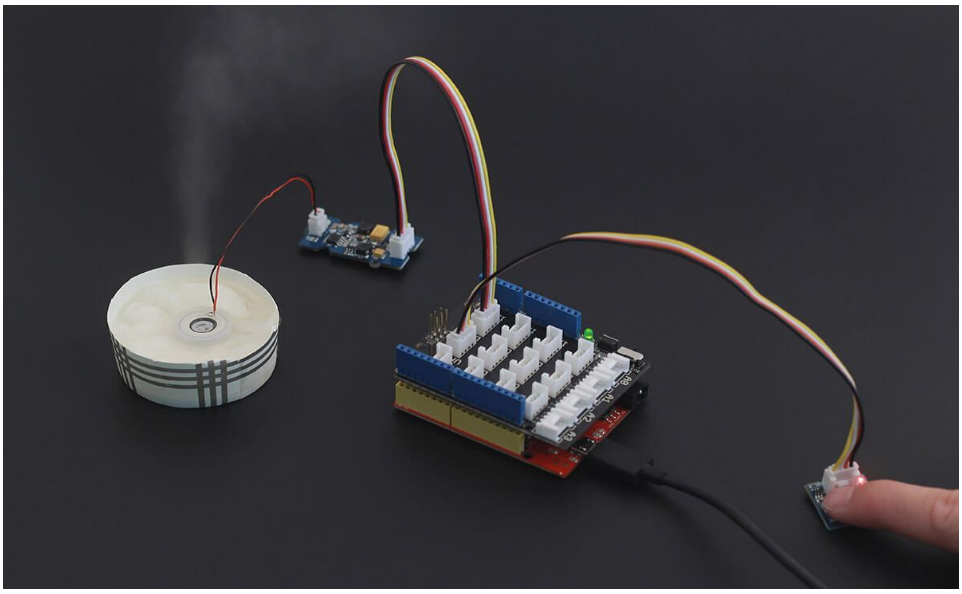

Figure 11 The ultrasonic atomizer.

3. Research Methods

This chapter will give the introduction about the applied research method and design method in this project. The research method will introduce the plan in conducting the research. The design method is the instructions of the different phases in designing the system in which the corresponding activities and deliverables are listed.

3.1 Research methods

There are three common approaches to conduct a research, which are quantitative, qualitative, and mixed method (Williams, 2007). In this project, the quantitative method and qualitative method will be applied in different scenarios.

Quantitative research

Quantitative research is collecting the numerical information which will be stored into the database and analyzed by the statistical techniques (Verhoeven, 2015). The way to conduct the quantitative research include the survey, secondary analysis, and experimental research. A survey can be used to gather numerical information about opinions, attitudes, and knowledge from large groups of people (Verhoeven, 2015). Secondary analysis is collecting the existing data and the researcher uses the data again by addressing a new question. The experimental research is testing the effect of a specific situation and accessing the results.

In this project, the second analysis method will be applied to collect the data. For example, the dimensions of the simulator's head and the capacity of the battery. The experimental research will be applied to find out the influence of the environmental factors on the system. The suitable parameter settings of the system can be find based on this method.

Qualitative research

Qualitative research is the method that takes the researchers into the "filed" which has nothing to do with the numerical information (Verhoeven, 2015). The methods in qualitative research to collect the data include the observation, interviews, qualitative desk research and case study.

In this project, the interviews will be applied to acquire the requirements of the system. The qualitative desk research and the case study will be applied to study the working principle and algorithms, and to generate the initial concept through the existing applications.

3.2 Design methods

With HZ University of Applied Sciences there are two different design methods supported: The Oskam design method and the V-model design method. The V-model is originally designed for software but now is widely applied in engineering design aspects (Kwekkeboom, 2019). Table 2 shows the situations for choosing the corresponding design method.

Table 2 The situations for different design method (Kwekkeboom, 2019)

The V-model design method	The Oskam design method
1. The product is the software or highly relevant to the software; **2. Design a functional product instead of finding the ideal solution to the problem;** **3. The V-model aims to validate instead of innovating, it lacks the idea generation part;** **4. The product that mainly focuses on the technical part, barely on the ergonomics and environmental parts;** **5. The principle of the product is clear or limited.**	**1. The aim is not clear or undefined;** **2. Looking for the creative and innovative solutions;** **3. The product should take technical, environmental, market and user parts into consideration;** **4. The product that mainly focuses on the technical part, barely on the ergonomics and environmental parts.**

For this project, the principle is clear and the final product for the company should be a functional prototype. Besides, the mainly focused aspect of this product is the technical part which meets the situation of the V-model design method perfectly. What is more, in the process of building the prototype, it is necessary to design the test plans and conduct the tests for each subsystem, which suits the situation of applying the V-model design method. So, the project will apply the V-model design method as the design methodology. Figure 12 shows the process of the V-model design method.

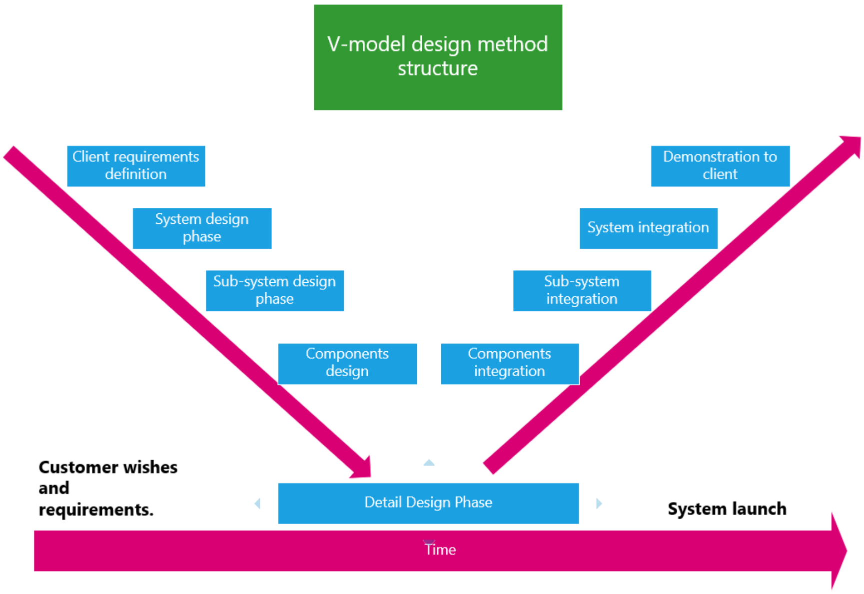

Figure 12 The process of the V-model design method (Kwekkeboom, 2019).

3.3 Deliverables and activities

The whole project will be divided into different phases based on the V-model design method. The corresponding activities and deliverables of each phases are listed as follow.

Planning and analyze phase

This is the start phase of the whole project. The researcher will fully understand the project and make the specific plan for the project in this phase. The relevant activities and deliverables are listed in Table 3.

Table 3 The activities and deliverables in planning and analyze phase.

Activities	Research methods adopted	Deliverables
The interviews with the client.	Qualitative research	Problem background information The list of requirements (draft)
Analyze the assignment	Quantitative research	The main research question and sub questions
Literature research and case study	Qualitative research	The theoretical framework and methods
Write the research proposal	Qualitative research and Quantitative research	The research proposal

System design phase

In this phase, the specific list of requirements will be defined, and the description of the system will be made. The system will be divided into serval sub systems and the connections between sub systems are demonstrated. The relevant activities and deliverables are listed in Table 4.

Table 4 The activities and deliverables in system design phase

Activities	Deliverables
Specify the requirements and wishes of the client	The list of requirements with the approval of the client.
Make the system overview and decompose the main system	The flowchart of the system
Write the system test plan	The system test plan
Define the input and output of the system	The system description

Sub system design phase

In this phase, the descriptions of each sub system will be made, and each sub system will be divided into the components. The connections between each component are introduced. The relevant activities and deliverables are listed in Table 5.

Table 5 The activities and deliverables in sub system design phase

Activities	Deliverables
Make the sub system overview and decompose the sub systems	The flowcharts of the sub system
Write the sub system test plans	The system test plans
Define the input, output of sub systems	The sub system descriptions

Component design phase

In the component design phase, the description of the components will be made. The components test plan and the integration plan will be made. The relevant activities and deliverables are listed in Table 6.

Table 6 The activities and deliverables in component design phase

Activities	Deliverables
Define the input and output of the sub system	The components descriptions
Write the components test plans	The component test plans
Write the components integration plan	The components integration plan

Sub system integration phase

In this phase, the components will be integrated into the sub systems and the sub systems will be tested according to the corresponding test plans. The relevant activities and deliverables are listed in Table 7.

Table 7 The activities and deliverables in sub system integration phase

Activities	Deliverables
Integrate the components into sub systems	The sub systems.
Conduct the sub systems tests	The test data and report
Debug the sub systems	The log of debug process
Write the system integration plan	System integration plan

System integration phase

In this phase the sub systems will be integrated into the main system. The system will be tested according to the system test plan. The relevant activities and deliverables are listed in Table 8

Table 8 The activities and deliverables in system integration phase.

Activities	Deliverables
Integrate the sub systems into the main systems	The prototype main system.
Conduct the systems tests	The test data and report
Debug the main system	The log of debug process

Completion phase

In this phase, the researcher will finish the final report and write the system manual. There will be a presentation to introduce the whole project. The relevant activities and deliverables are listed in Table 9.

Table 9 The activities and deliverables in the completion phase.

Activities	Deliverables
Write the project report	The project report
Write the system manual	The system manual
Improve the prototype and prepare the presentation	The prototype and the presentation

4. Results

In this chapter, the results and deliverables of different phases are presented based on the V-model design methodology.

4.1 Demo design phase and system design phase

In this section, the deliverables of list of requirements, function overview and system description and demo/system test plan are generated to build the automatic mussel display.

4.1.1 List of requirements

Table 10 is the list of requirements based on the background information and problem analysis from the client.

Table 10 List of requirements

NO.	Requirements	Requirement description
1	System voltage supply	5V-24V
2	Switch the upper shell	Lift and drop the upper shell based on the approaching or leaving of human.
3	Force of lifting	≥100N
4	Opening angle	0°-60°
5	Detecting range	0-1M
6	The opening time	10s-15s
7	The detection area of system	The 0°-30° area in front of the sensor.
8	Play the music	Play and turn off the music based on the approaching or leaving of human
9	Turn on the LED	Turn on and off the music based on the approaching or leaving of human
10	Change the color of light	The color of light can be changed automatically.
11	The cost of system	≤500€
12	The temperature of working environment	0℃-40℃
13	The maximum holding time of lifting	≥1 hour
14	The maximum playing time of music	≥1 hour
15	The maximum spray time	≥1 hour

4.1.2 Function overview

Figure 13 shows the function overview of the 'Automatic Mussel Display prototype'. The system has five main functions: detect human approaching; control the lifting motor, speaker, and lighting; Lift the mussel's upper shell; display music; lighting demonstration.

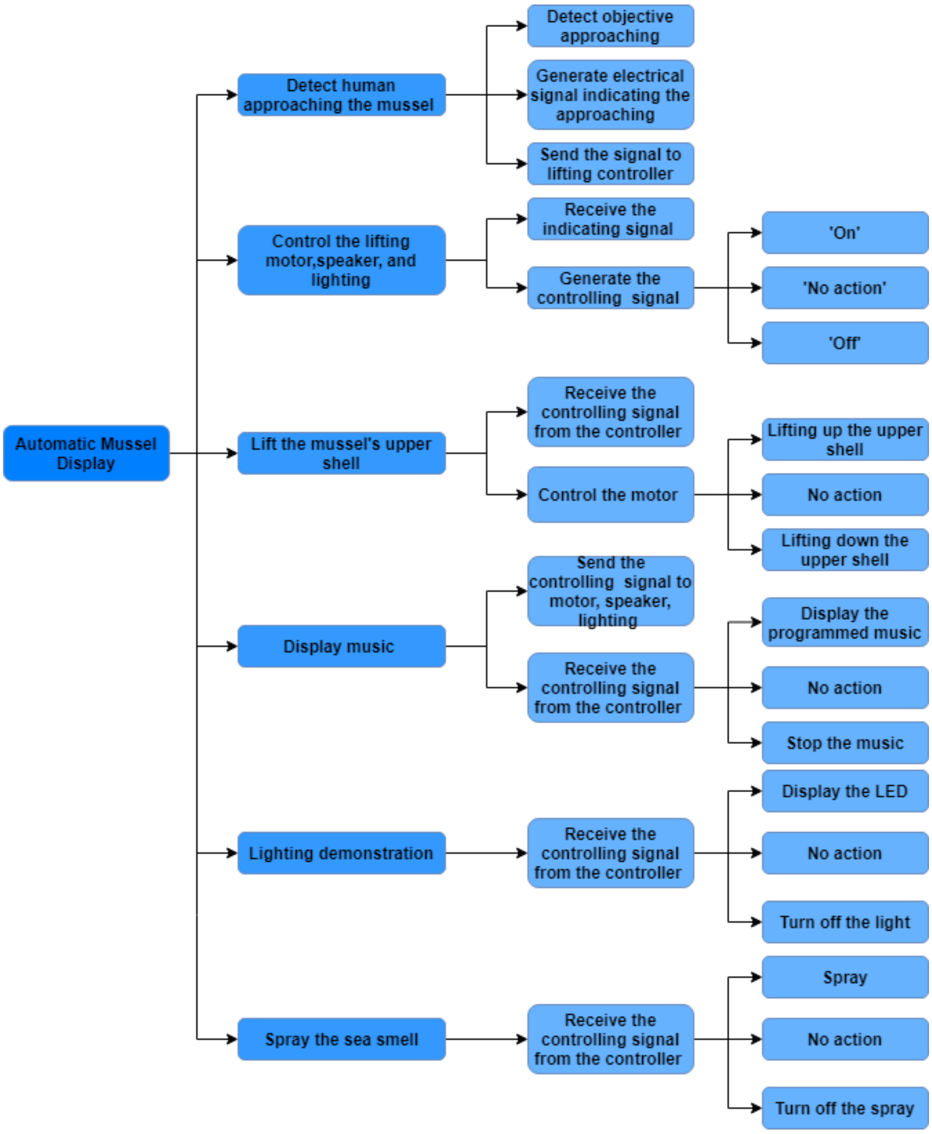

Figure 13 The function overview

The six main functions are divided into several sub-functions to present the functions more clearly. There are two scenarios in all: humans are standing in front of the mussel; humans are not standing in front of the mussel. The detector will generate a different indicating signal based on the two situations. The controller analyzes the indicating signal and generates the corresponding controlling signal for the motor, speaker, and lighting. The motor, speaker, and lighting react based on the controlling signal.

4.1.3 System description

Figure 14 shows the system overview of the automatic mussel display system, which defines the boundaries between the mussel display system and external systems. The power source provides the necessary power 'E1' to the mussel display system. When human approaches the mussel display system, it will output torque 'T1' on the mussel shell model to lift the upper shell. The mussel display system will also output a programmed music and light up a few LED as decoration.

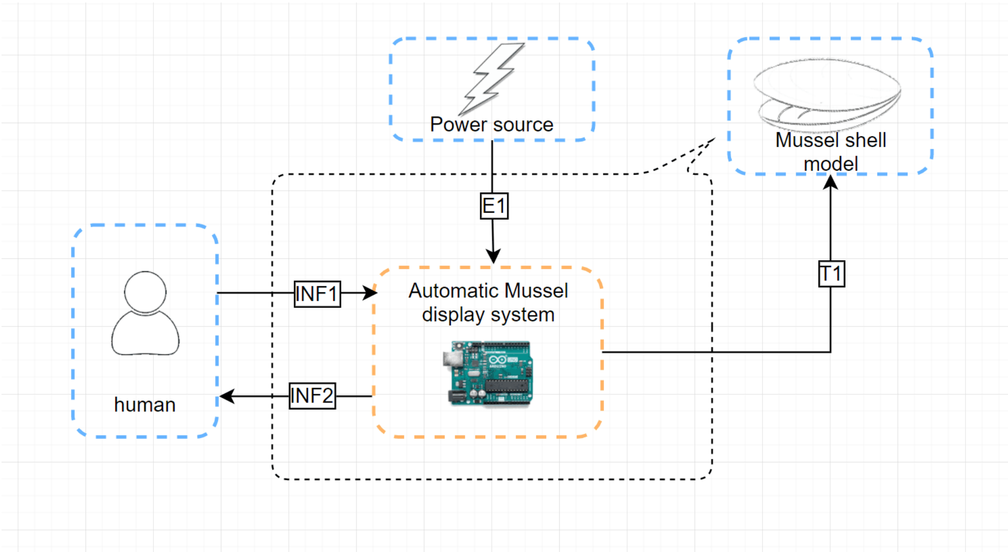

Figure 14 System overview

Table 11 describes the details of the input and output between the 'Automatic Mussel Display' system, human and external system.

Table 11 The description and property of whole system

Symbol	Description	Max	Min	Average
INF1	Human motion: The behavior that human approaching the system	This information cannot be quantified.		
INF2	Infrared or Ultrasound send by sensor	45KHz for the frequency ultrasound.	40KHZ	40Khz
E1	DC voltage (0-12V) to power the whole system	12V	3.3V	5V
T1	The force generated by the motor to lift and close the upper shell.	750N	750N	750N

4.1.4 Demo/System test plan

In this project, since the test equipment and personnel are the same in demo test and system test, these two tests will share a test plan. The purpose of the test is to show the client that the prototype of 'Automatic Mussel Display' meets the list of requirements. The detailed demo test plan can be found in ‘Appendix Ⅰ: Demo/System test plan’. All requirements should be achieved after the demo system test.

4.2 Subsystem design phase

In this phase, the subsystems of the ‘Automatic Mussel Display’ is generated according to the ‘function overview’ in section 4.1.2. The overview and description of each subsystem is presented in this phase.

4.2.1 System division

The ‘Automatic Mussel Display’ is divided into 5 subsystems according to the ‘function overview’ in section 4.1.2:

Lifting Subsystem: This subsystem receives the control signal from the control system and generates a torque through the motor to lift and close the upper shell.

Human Detection Subsystem: This is the subsystem which converts the human approaching information to the electric signal and transmits it to the control signal.

Decoration Subsystem: This subsystem receives the control signal from the control system to turn on or off the speaker and light.

Control Subsystem: The main system which receive the information and transmit the control signal with the related subsystems.

Spray Subsystem: This subsystem receives the control signal from the control system to spray the sea smell.

4.2.2 Subsystem Overview

Figure 15 shows the interactions between the subsystems in 'Automatic Mussel Display' system.

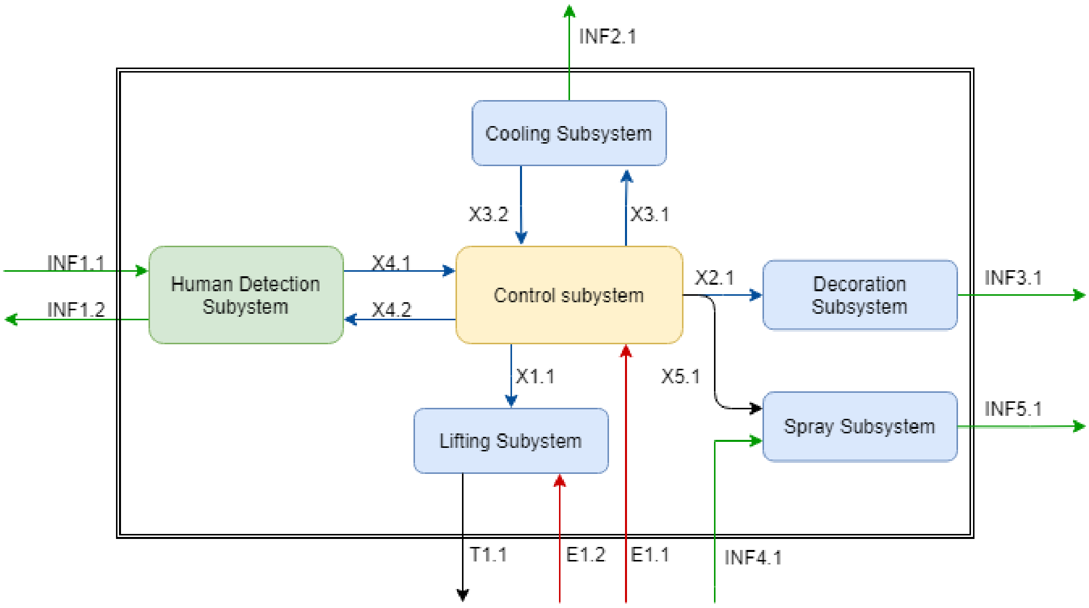

Figure 15 The subsystem overview

Table 12 demonstrates the specifications and property of the symbols between the subsystems.

Table 12 Property of transmitting signals in the subsystems

Symbol	Description	Max	Min	Average
INF1.1	Human motion (This information cannot be quantified).	0	0	0
INF1.2	Infrared or Microwave send by sensor.	45KHz for the frequency ultrasound.	40Khz	40Khz
INF 2.1	Low temperature air or low temperature circulating water	7℃	0℃	5℃
INF 3.1	The sound and light (The property of this information will not be considered in this project).	0	0	0
INF 4.1	Water	0	0	0
INF 5.1	Spray	0	0	0
E1.1	DC voltage to power the control system.	12V	5V	5V
E1.2	DC voltage to power the lifting system.	24V	12V	12V
X1.1	Digital signal to control the lifting system.	5.0V	0V	5.0V
X2.1	Digital signal to control the decoration system.	5.0V	0V	5.0V
X3.1	Digital signal to control the Cooling system.	5.0V	0V	5.0V
X3.2	Reflected signal (digital signal) of the temperature in the environment.	5.0V	0V	5.0V
X4.1	Reflected signal (digital signal) from the human detection subsystem.	5.0V	0V	5.0V
X4.2	Control Signal from the control system	5.0V	0V	5.0V
X5.1	Digital signal to control the Spray subsystem.	5.0V	0V	5.0V
T1.1	The force generated by the motor to lift and close the upper shell.	750N	750N	750N

4.2.3 Control subsystem

This section interduces the description and test plan for the control subsystem.

4.2.4.1 Subsystem description

Figure 16 shows the input and output of the control subsystem. This subsystem is the central subsystem in the 'Automatic Mussel Display' which communicates and sends the control signals ('X1.1', 'X2.1', 'X3.1', 'X4.1') to the rest subsystems. It receives the reflected signals ('X3.2', 'X4.1') from the other subsystems. The subsystem will receive feedback signals from other subsystems, after calculation by the processor, and output control signals to control the switch of the upper shell, the play of music, the flashing of lights, and the switch of the cooling system. The control subsystem is powered by the 5V DC voltage.

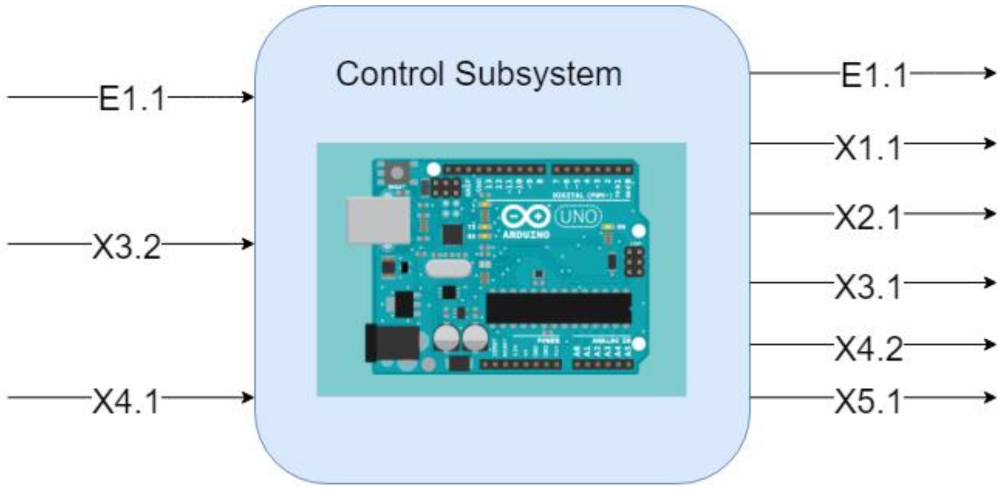

Figure 16 The Control Subsystem

Table 13 introduces the specific values of the input and output signals of the subsystem at high level and low level respectively.

Table 13 The property and description of control subsystem

Symbol	Description	High level	Low level
E1.1	Power the control subsystem	DC 12V	0V
X3.2	Reflected signal (digital signal) of the temperature in the environment.	>3.0V	<1.5V
X4.1	Reflected signal (digital signal) from the human detection subsystem.	>3.0V	<1.5V
X1.1	Digital signal to control the lifting subsystem.	5.0V	0V
X2.1	Digital signal to control the decoration subsystem.	5.0V	0V
X3.1	Digital signal to control the Cooling system.	5.0V	0V
X4.2	Control Signal from the control system	5.0V	0V
X5.1	Digital signal to control the Spray subsystem.	5.0V	0V

4.2.4.2 Subsystem test plan

'The detailed test plan of control subsystem can be found could be found in 'Appendix Ⅰ: Control subsystem test plan'.

4.2.4 Lifting Subsystem

This section interduces the description and test plan for the lifting subsystem.

4.2.3.1 Subsystem description

Figure 17 demonstrates the input and output of the lifting subsystem. The lifting subsystem is powered by a 12V DC voltage. The subsystem receives the control signal 'X1.1' from the control subsystem. The rotation of the motor is depended on whether the lifting subsystem receives a high level (5V) or a low level (0V). The lifting subsystem generates a 750N force as the power source to lift the upper shell of the 'Automatic Mussel Display' when receives the high level(5V) from the control subsystem.

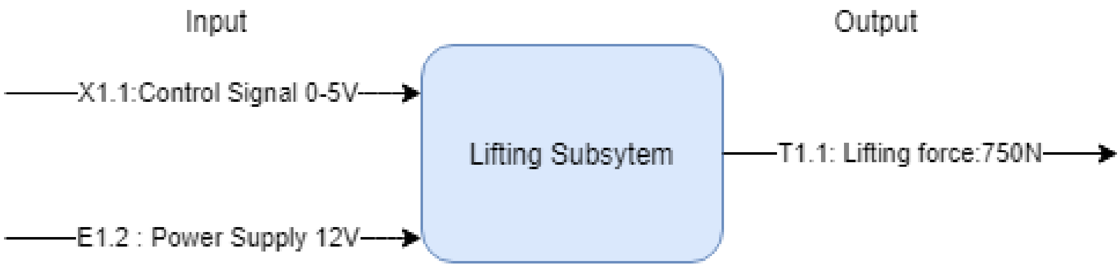

Figure 17 The Lifting Subsystem

4.2.3.2 Subsystem test plan

The detailed test plan of 'Lifting subsystem could be found in Appendix Ⅰ: Lifting subsystem test plan'.

4.2.5 Decoration Subsystem

This section interduces the description and test plan of the 'Decoration subsystem'.

4.2.5.1 Subsystem description.

Figure 18 shows the input and output of the decoration subsystem. This subsystem is powered by the control subsystem and receives control signals 'X2.1' from the control subsystem. This subsystem could play music and emit lights ('INF 3.1') to the external environment to realize the function of enhancing the attractiveness of the 'Automatic Mussel Display'.

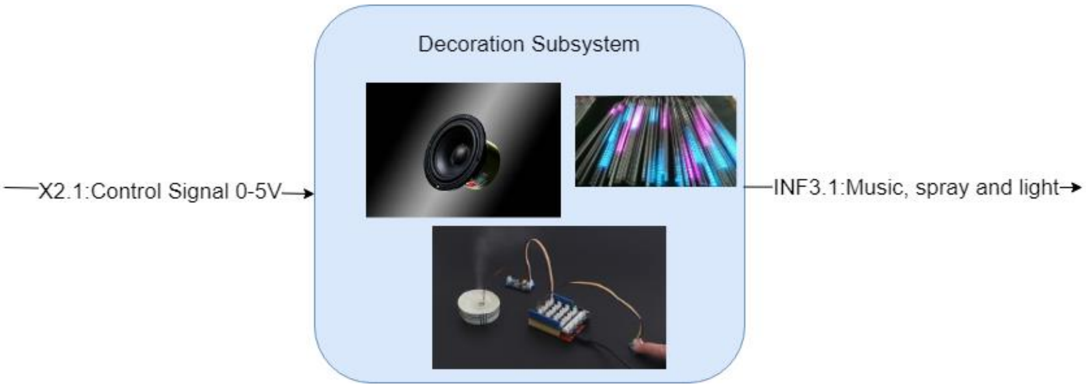

Figure 18 The Decoration Subsystem.

4.2.5.2 Subsystem test plan

The test plan of decoration subsystem could be found in Appendix Ⅰ: Decoration subsystem test plan'.

4.2.6 Human Detection Subsystem

This section introduces the description and test plan of the human detection subsystem.

4.2.6.1 Subsystem description

This subsystem detects the human motion(‘INF1.1) in the environment and receives the control signal (‘X4.2’) from the control subsystem. When the human motion is detected by the output signal (‘INF 1.2’) the subsystem sends the reflected signal (‘X4.1’) as the trigger to the control subsystem. Figure 19 shows the input and output of this subsystem.

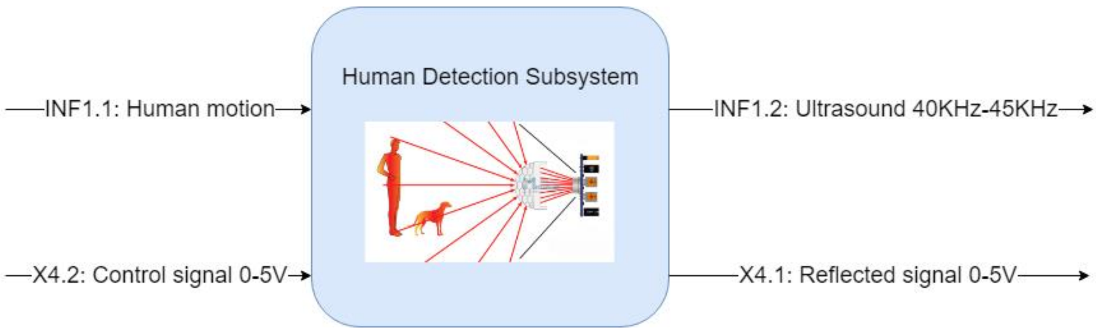

Figure 19 The Human Detection Subsystem

4.6.2.2 Subsystem test plan

The detailed test plan of human detection subsystem could be found in Appendix Ⅰ: Human detection subsystem test plan’.

4.2.7 Spray subsystem

This section introduces the description and test plan of the spray subsystem.

4.2.7.1 Subsystem description

This subsystem converts the water(‘INF4.1) from the environment into the spray (INF 5.1) and receives the control signal (‘X5.1’) from the control subsystem. Figure 20 shows the input and output of this subsystem.

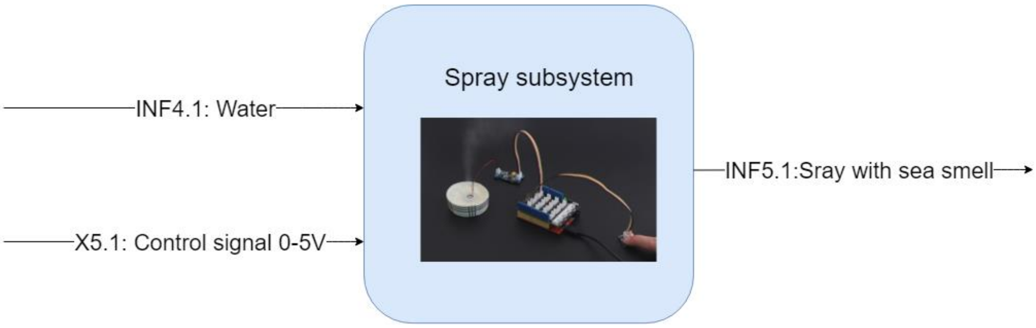

Figure 20 The spray subsystem

4.2.7.2 Subsystem test plan

The detailed test plan of human detection subsystem could be found in Appendix Ⅰ: Spray subsystem test plan'.

4.3 Component design phase

The selected components of each subsystem are introduced in this section. In this section, the 1st, 2nd ,3rd ,4th, 5th, 6th, and 7th sub- research questions are answered.

1. What design can be made to open and close the shell automatically and safely based on the motion of the customers? (T)
2. Which sensors can be applied to detect the motion of customers? (T)
3. which is the best cooling system can be applied to keep the temperature in a stable level (7℃)? (T)
4. Which is the suitable control unit for the automatic lifting system and temperature control system? (T)
5. What is the suitable speaker to play the music for the customers? (E)
6. What suitable LED lights should be installed in the mussel display? (E)
7. How to generate and spray a sea smell? (T)

4.3.1 Component description of Control Subsystem

In order to realize the control of each subsystem, a microcontroller is selected as the central unit in the control subsystem to receive information and send control signals.

Microcontroller: To realize the automatic switch function of 'Automatic Mussel Display' and collect information from the environment. A microcontroller is required to collect the response digital information from the sensors, calculate and store the information, and send logic signals to control each subsystem. The basic functions of a microcontroller are demonstrated in ‘Appendix Ⅳ: Microcontroller composition.’

ATmega328 P: The microcontroller which is applied in this project is selected as ATmega328 P. ATmega328 is one of the single-ship microcomputers in the megaAVR series developed by Atmel. ATmega328 has 1KB Electrically Erasable Programmable Read Only Memory (EEPROM). This means that the controller can store the data when the power supply is removed. ATmega328 has several different features which make it the most popular device in today’s market. These features consist of advanced RISC architecture, good performance, low power consumption, real timer counter with a separate oscillator, 6 PWM pins, programmable Serial USART, programming lock for software security, throughput up to 20 MIPS etc. (Wu, 2018). This microcontroller is widely used in Arduino Uno Rev3 development board.

Arduino Uno Rev3: In this project, the Arduino Uno Rev3 development board is selected as the main control element. Arduino Uno Rev3 (Shown in Figure 21) is a microcontroller development board based on the ATmega328P which is capable to calculate the received information and send the control signals. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button (Arduino, 2021). The 14 input/output pins are enough to connect with the other subsystems. These features make it easy to communicate with the laptop and program for the system. For instance, Users can easily use the Arduino language (based on C/C++) to program the development board through the Arduino software (IDE). The programming environment is simple and easy to understand, and the software and hardware are open sources.

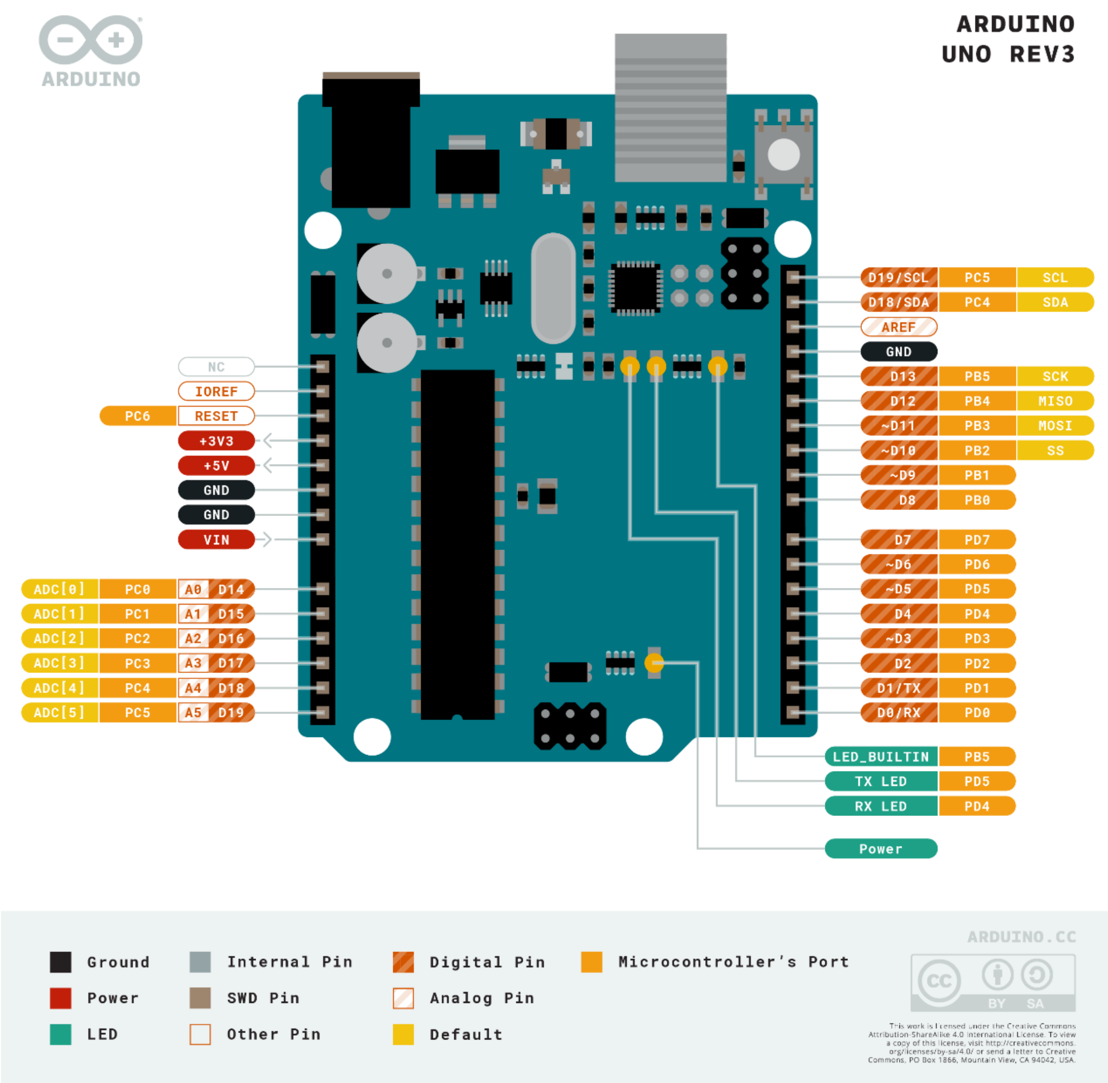

Figure 21 Arduino Uno Rev3 development board (Arduino, 2021).

Figure 22 shows the programming logic of the Arduino Uno microcontroller. The program is to detect the human motion and environment temperature and send the control signals to the lifting subsystem, decoration subsystem, and cooling subsystem.

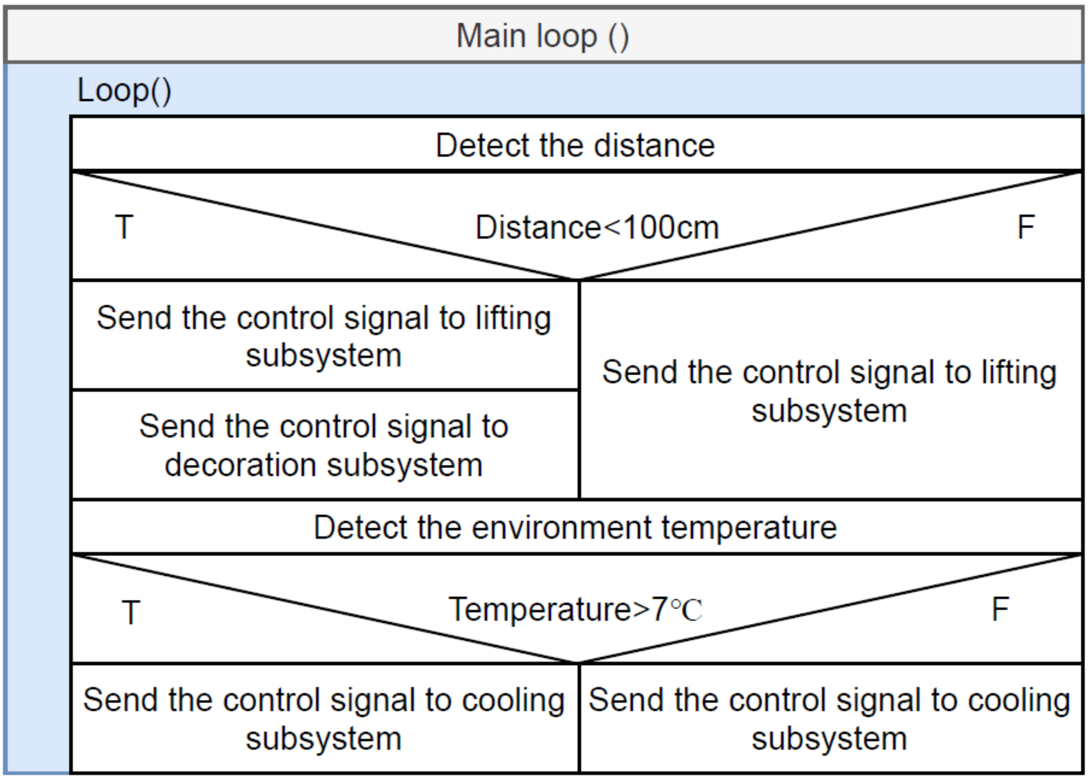

Figure 22 Programming logic of control subsystem

4.3.2 Component description of Lifting Subsystem

The lifting subsystem contains two components, a power supply module, and a linear electric actuator module.

To achieve the function of switching the upper case of the "Automatic Mussel Display", an electric linear actuator was selected as the power source to provide power.

Electric linear actuator JSP005: The housing of the linear actuator is made of aluminum alloy, waterproof grade IP54, which is sturdy and durable. The forward and reverse rotation of the 12V DC motor is converted into the up and down movement of the push rod through a mechanical transmission device to realize the function of raising or lowering an object. Figure 23 shows the structure of Electric linear actuator JSP005.

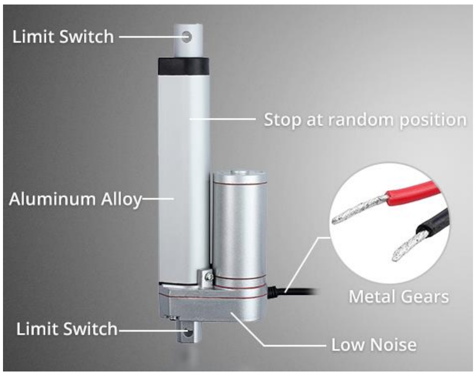

Figure 23 Composition of Electric linear actuator.

The parameters of JSP005 linear driver are listed in Table 14.

Table 14 Parameters of the JSP005 electric linear actuator.

Items	Parameters
Material	aluminum alloy
Operating voltage	DC 12V
Operating current	0-4A
Rated power	20W
Load capacity	750N/160LBS
Retracted length	205MM
Stroke length	100MM
Speed	10MM/S

Power supply module L298N: Since the working voltage of the motor is 12V, which far exceeds the voltage that the control chip could provide. At the same time, to control the forward and reverse rotation of the motor by switching the positive and negative electrodes of the power supply, the L298N motor drive module is selected to control and drive the JSP005 electric linear actuator.

As shown in the Figure 24 are the main components of the L298N motor drive module. Table 15 listed the function of each section.

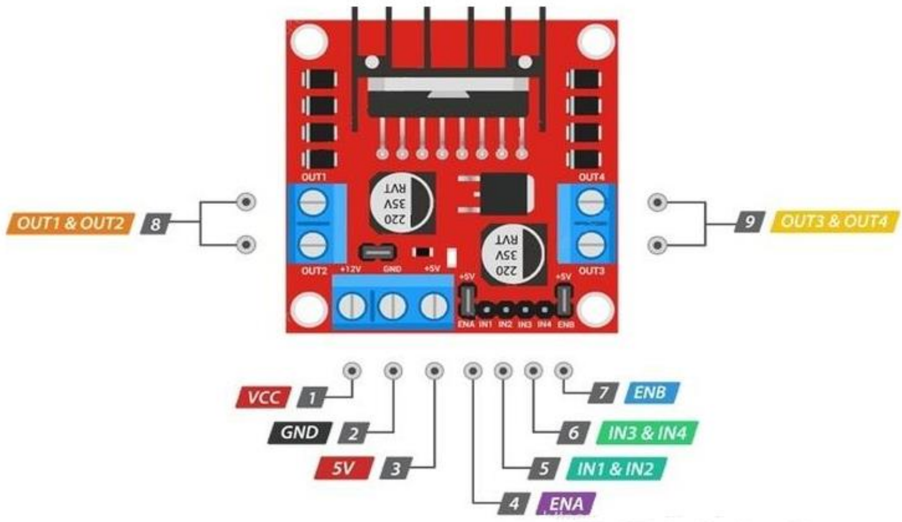

Figure 24 L298N Motor Drive Module.

Table 15 Symbols and specification for L298N motor drive module.

No.	Function
1. VCC	12V power supply port
2. GND	Ground port
3. 5V	5V power supply port
4. ENA	Channel A enable port
5-6. IN1,2,3,4	Logic input (Input 0/1 or 1/0 is forward or reverse).
7. **ENB**	Channel B enable port
8-9. Out1,2,3,4	Output A port & Output B port

4.3.3 Component description of Decoration Subsystem

There are two main components in this subsystem: Audio system and LEDs, which are powered and controlled by the control subsystem, and emit music and lights to the environment.

Audio system: The speaker module (shown in Figure 25) of Arduino which is applied in this project is directly powered by the DC 3.3V power supply terminal of Arduino develop board, and a short piece of music can be played by preset different tones.

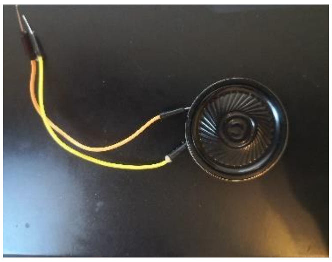

Figure 25 The Audio system.

WS2812B LED strip: The light bar consists of multiple LEDs (show in Figure 26) with WS2812B driver IC (integrated circuit) in series. The existence of the driver IC enables users to control all the LEDs only through one digital output on the Arduino development board.

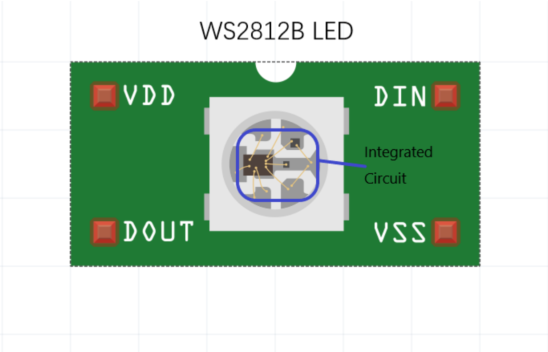

Figure 26 The WS2812B LED

4.3.4 Component description of Human Detection Subsystem.

The detecting sensor for the human detection subsystem is selected as the ultrasonic sensor

Ultrasonic Sensor HC-SR04: The ultrasonic ranging module HC-SR04 provides a non-contact ranging function from 2cm to 400cm, with an accuracy of up to 3MM. The sensor sends the reflected signal to the controller to calculate the distance between the sensor and human. The module consists of an ultrasonic transmitter, receiver, and control circuit (shown in Figure 27).

Figure 27 The Ultrasonic Sensor.

4.3.5 Component description of Spray Subsystem.

The main component of spray subsystem is Grove - Water Atomization Module.

Grove - Water Atomization Module: The Grove-Water Atomization Module (shown in Figure 28) is applied in this project, which can be directly connected to the Arduino development board and is controlled and powered by the Arduino development board. The prototype of the atomizer can be easily realized through the oscillator and module.

Figure 28 Grove-Water Atomization module

4.4 Subsystem Integration Phase

In this section, each subsystem is assembled according to the assembly plans in Appendix and tested based on the corresponding subsystem test plan in Appendix. The test results are also introduced in this section.

4.4.1 Control Subsystem Integration

System assembly: There is no system assembly plan for this subsystem because the control subsystem only has one component 'Arduino Uno Rev3 development board'.

Test set-up: As shown in Figure 29, the computer and the Arduino development board are connected by a USB data cable, and the computer provides 5V DC voltage and communication for the Arduino development board.

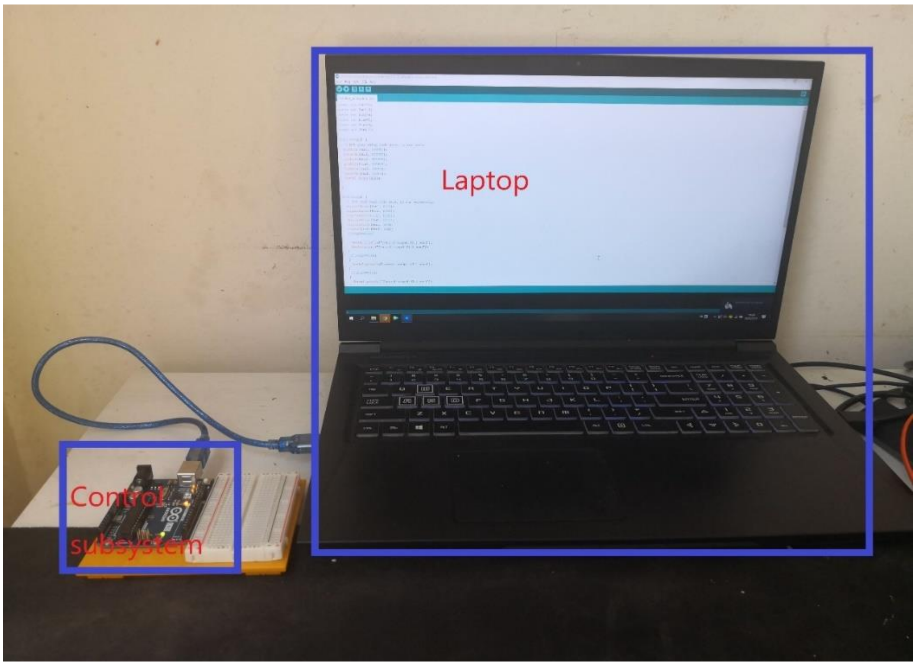

Figure 29 Test set-up of control subsystem

Test Results: As shown in Figure 30. When the system is connected, the ON indicator of the development board lights up, indicating that the system is powered normally. Uploaded and run the test code of the control subsystem. It was found that the on-board L light continues to flash and the IDE's serial monitor output preset text which proves that the programming and communication of the control subsystem are realized. The test codes can be found in 'Appendix Ⅲ: The control subsystem test codes.'

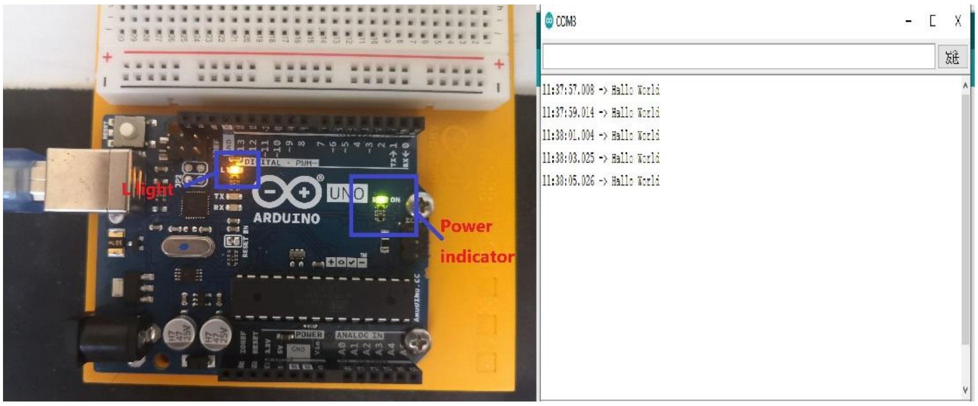

Figure 30 Control subsystem power supply and communication test results.

Table 16 lists the test results of the control subsystem output and control signal functions. The tested results indicates that the control subsystem can send out the control signals (X1.1, X2.1, X3.1, X4.2) and receive the reflected control signals (X3.2, X4.1) from the other subsystems.

The control subsystem passed the test.

Table 16 Test results of input and output control signals

Tested items		Results
Output control signals	X1.1	Detected
	X2.1	Detected
	X3.1	Detected
	X4.2	Detected
	X5.1	Detected
Reflected control signals	X3.2	Detected
	X4.1	Detected

4.4.2 Lifting Subsystem Integration

System assembly: The subsystem was assembled based on the subsystem assembly plan in 'Appendix Ⅱ: Lifting subsystem assembly plan.'

Test set-up: Figure 31 shows the test set-up of the lifting subsystem. The 230V-12v transformer provides a stable 12V DC voltage source for the motor drive module L298N to drive the motor. At the same time, the output end of the control subsystem is connected to the output end of the motor drive module L298N to output a control signal X1.1 to control the electric linear actuator to rise and fall.

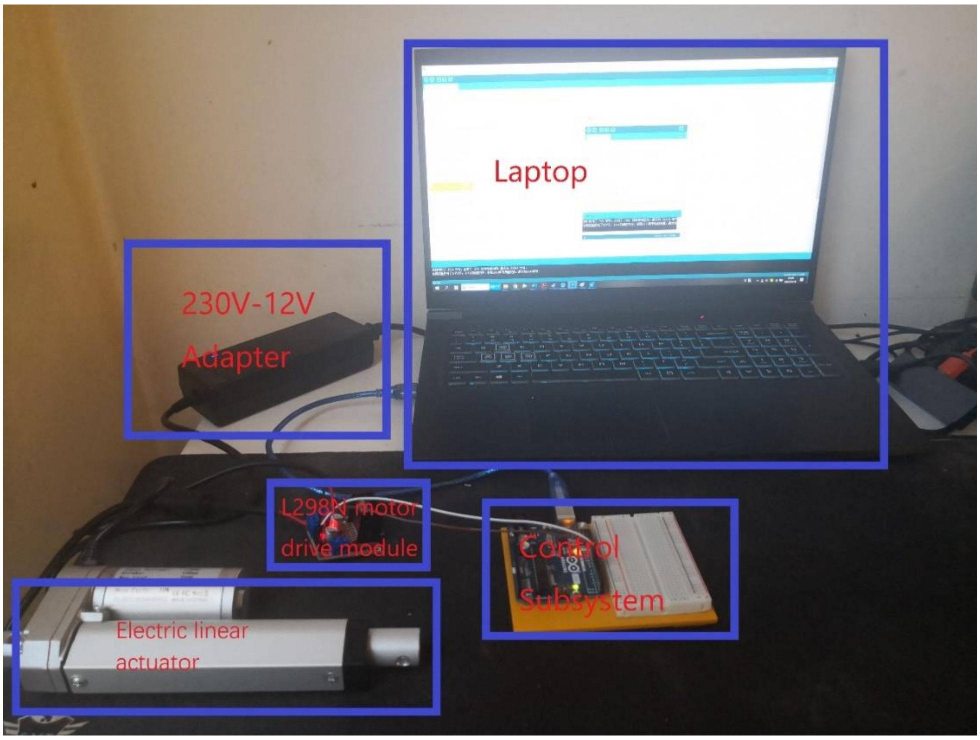

Figure 31 Test set-up of lifting subsystem

Test Results: The detailed test results of lifting subsystem are listed in 'Appendix Ⅳ: Lifting subsystem test results' based on the subsystem test plan in 'Appendix Ⅰ: Lifting subsystem test plan'. The test codes can be found in 'Appendix Ⅲ: The lifting subsystem test codes.'

The results shows that the lifting subsystem realizes the function of lifting and lowering a certain load, and the time to lift or lower the load is between 11 seconds and 12 seconds, and the stroke is between 9-10cm. These results meet the expected requirements and design. The lifting subsystem passed the subsystem test.

4.4.3 Decoration Subsystem Integration

System assembly: The subsystem was assembled based on the subsystem assembly plan in appendix.

Test set-up: Figure 32 shows the test set-up of the decoration subsystem.

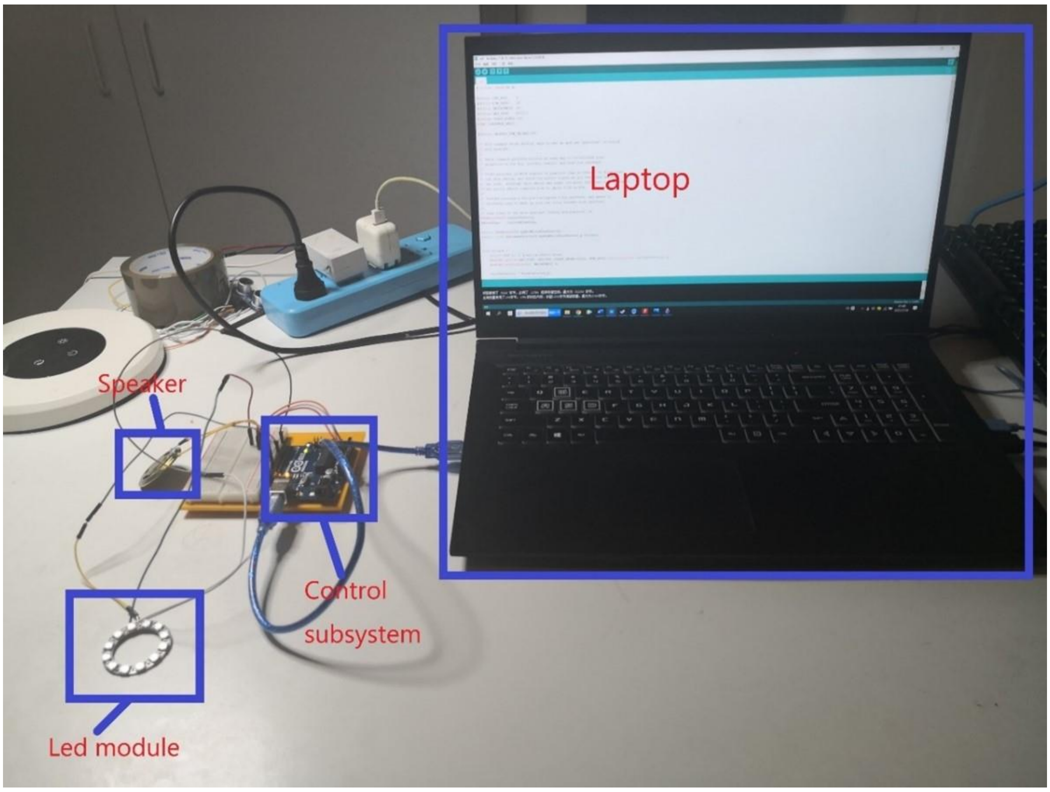

Figure 32 Test set-up of decoration subsystem

Test results: When the decoration subsystem was connected correctly and the test program was run, the speaker played the preset music and the LED module changed the light color automatically, and the decoration subsystem shut down after the power was off. The detailed test results of decoration subsystem are listed in 'Appendix Ⅳ: Decoration subsystem test results'. The test codes can be found in 'Appendix Ⅲ: The decoration subsystem test codes.'

The decoration subsystem passed the subsystem test.

4.4.4 Human Detection Subsystem Integration

System assembly: There is no system assembly plan for this subsystem because the control subsystem only has one component 'Ultrasonic Sensor HC-SR04'.

Test set-up: Figure 33 shows the test set-up of the human detection subsystem.

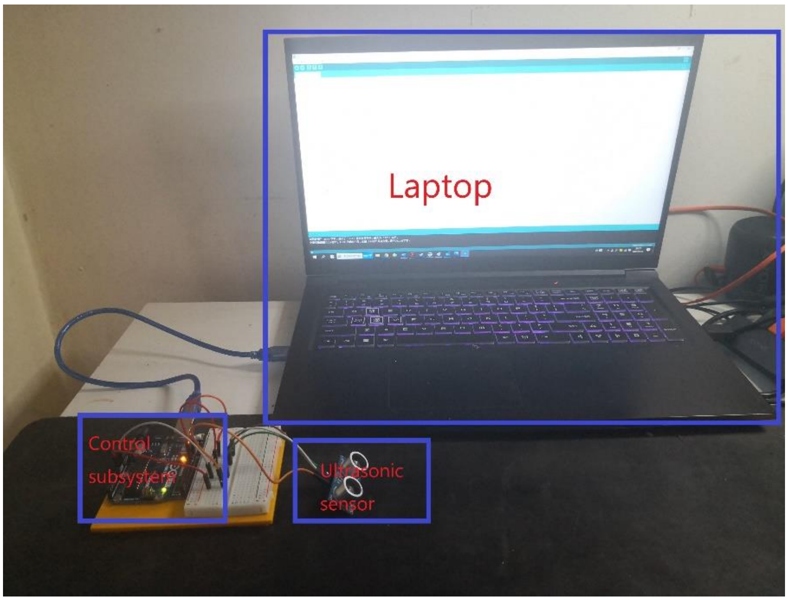

Figure 33 Test set-up of human detection subsystem

Test Results: When an object was placed in front of the sensor, the serial monitor on the computer outputs the detected distance. The detailed tested results of human detection subsystem are listed in 'Appendix Ⅳ: Human detection subsystem test results'. Includes the test scenarios, exact distance, test distance, and error. The test was conducted based on the test plan in 'Appendix Ⅰ: Human detection subsystem test plan'.

The test results shows that the human detection subsystem can detect the distance between the object and the sensor and output it to the control subsystem. There is an error (5%-10%) between the test distance and the exact distance, which is acceptable.

The human detection subsystem passed the test.

4.4.5 Spray Subsystem Integration

System assembly: There is no system assembly plan for this subsystem because there is only one component.

Test set-up: Figure 34 shows the test set-up of the spray subsystem.

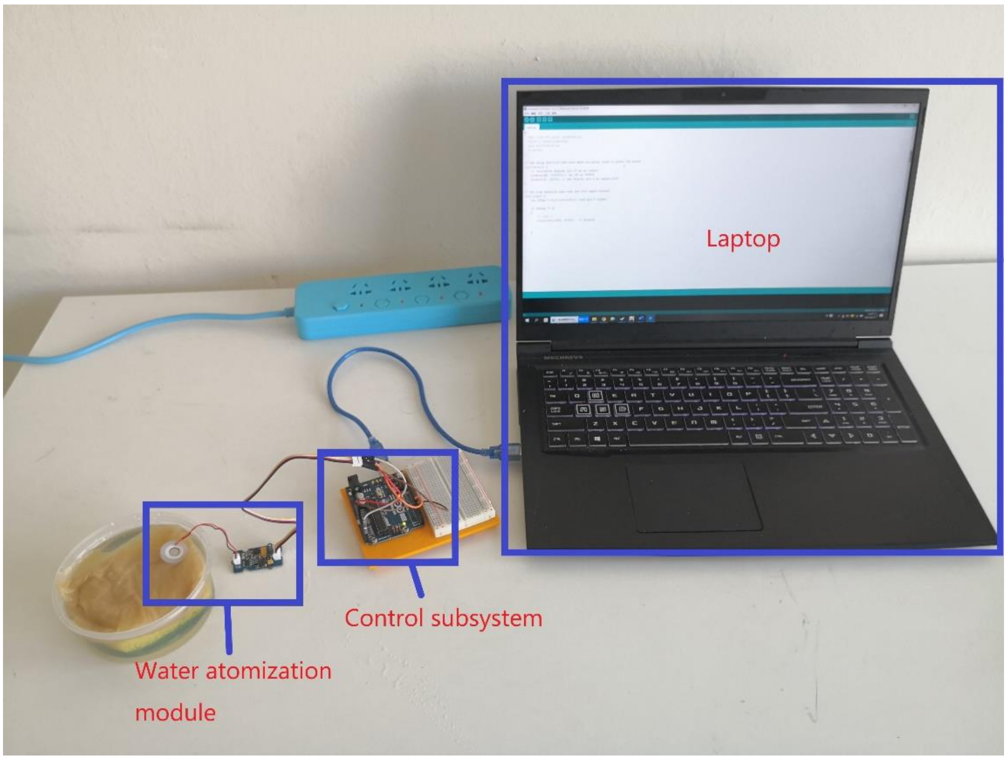

Figure 34 Spray subsystem test set-up.

Test Results: The detailed test results of spray subsystem are listed in 'Appendix Ⅳ: Spray subsystem test results' based on the subsystem test plan in 'Appendix Ⅰ: Spray subsystem test plan'. The test codes can be found in 'Appendix Ⅲ: The spray subsystem test codes.' The subsystem atomized the water and spread the sea smell in the air.

The spray subsystem passed the test.

4.5 System integration phase.

System assembly plan: The system was assembled based on the assembly plan in 'Appendix Ⅱ: The system assembly plan.'

System test set-up: Figure 35 demonstrates the test set-up of the 'Automatic Mussel Display' prototype. The control subsystem is connected to the lifting subsystem, decoration subsystem, and the human detection subsystem and output signals are sent to the laptop.

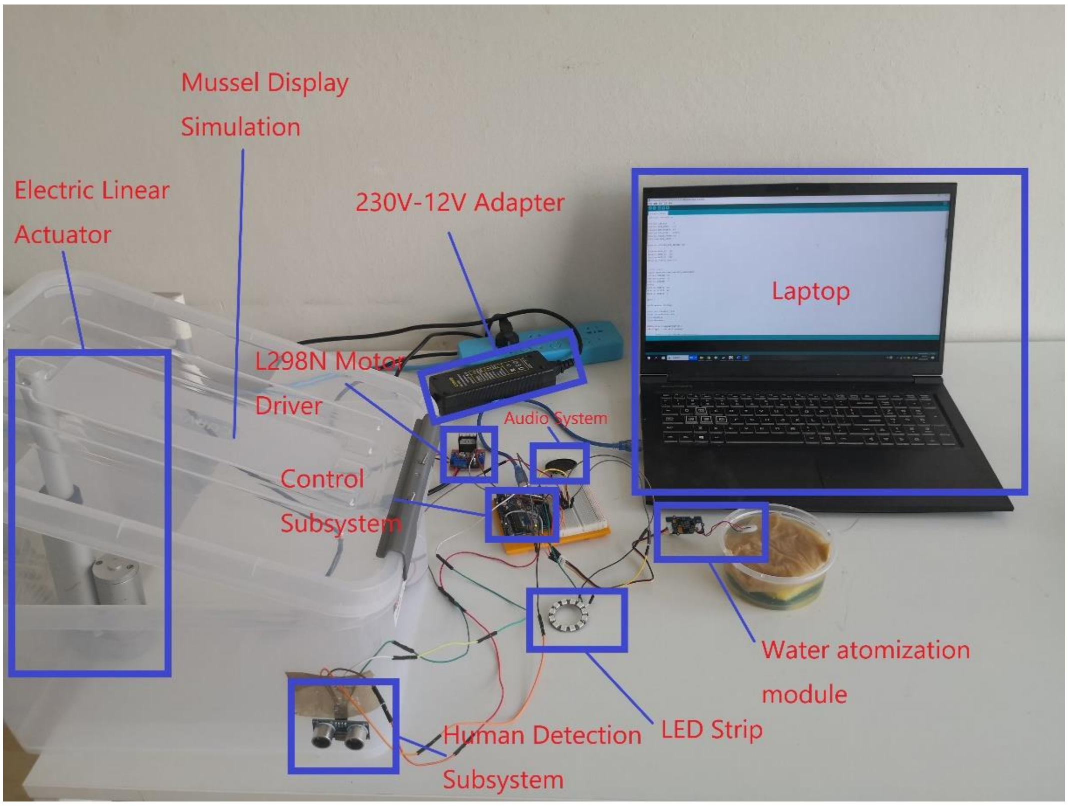

Figure 35 System test set-up.

System test result: The test was conducted based on the test plan in 'Appendix Ⅰ: Demo/System test plan.' The detailed tested results of 3 different scenarios are listed in 'Appendix Ⅳ: System test results'. The system test codes con be found in 'Appendix Ⅲ: System test codes'

'Automatic Mussel Display' prototype system realizes the function of automatically opening the upper shell, playing music, and automatically changing the light color when someone appears in the detection range. The system will remain open until human beings leave the detection range of the showcase. The opening time and opening angle of the upper shell meet the requirements, and the prototype of the system passed the test.

5. Discussion

Section 5.1 'Result discussion' discusses whether the practical results meet the requirements in the list of requirements. Section 5.2 discusses the issues that have not been figured out in the project. Section 5.3 discusses the design method 'V-model' applied in the project.

5.1 Result discussion

In this section, each requirement in section 4.1.1 'List of requirements' is discussed respectively. The discussion shows that the requirements for the Automatic Mussel Display are all met.

5.1.1 System voltage supply: 5V-24V

The components applied in the system can be all powered by the Arduino uno except the power source of the component 'linear electric actuator module'. This means all the components can be powered with 5V or 12V, which meets the requirement.

5.1.2 Force of lifting≥100N

The electric linear actuator used in the lifting subsystem can provide a force of 750N, and successfully lifted a load of 10Kg in the subsystem test. The system meets the requirements.

5.1.3 Opening angle 0°-60°

In the demo/system test, the measured opening angle of the upper shell is 51 degrees, which meets the requirements.

5.1.4 Opening time 10S-15S

In the demo/system test, the measured opening time of the upper shell lifting process is 12.4 seconds, which meets the requirements.

5.1.5 Play the music, turn on the LED and change the color automatically.

In the demo/system test, the prototype played the music, turn on the LED, and automatically changed the light color when someone appears in the detection range.

5.1.6 The cost of system ≤ 300 €

The cost of system can be found in 'Appendix Ⅳ: System cost,' which is 83.95€.

5.1.7 The temperature of working environment: 0℃-40℃

The test of the system was carried out at room temperature (25℃), and there was no detection error or failure of the system.

5.1.8 The maximum holding time of lifting, spray time and playing time of music ≥ 1hour.

In the system test, if the power supply to the system was maintained, the upper shell was kept open and sprayed, and music and lights were played until the person disappeared in the detection range.

5.2 Discussion on the problems that appeared in the project.

In this section, the unresolved problems in the project are discussed, and possible solutions are given.

5.2.1 Cooling subsystem design is not including in the prototype.

Problem statement: Due to constraints of project period and installation place, the cooling system stayed at the level of theoretical solutions, the components purchase and tests are not carried out.

Possible solution: To keep mussels in an environment of 7 degrees in the display process, the cooling system needs to choose an appropriate refrigeration method based on aspects such as cooling space and power supply. At the same time, the real-time temperature needs to be fed back to the control system to adjust the refrigeration system.

5.2.2 False detections occur in the process of human detection.

Problem statement: During the system test, the situation that when a person was in the detection range but the system did not respond happened. After the system was debugged, it was found that the ultrasonic sensor sent out the wrong information due to interference (noise) from the external environment during the detection process, which caused the misdetection of the system.

Possible solution: In the project, only one ultrasonic sensor was used for signal detection. This problem can be reduced or avoided by increasing the number of sensors. Besides, reduce the external noise interference can also improve system accuracy.

5.3 Method discussion

The project chose the V-model as the design methodology. V-model first divided the system into various subsystems, splits each subsystem into components, then combines the components into subsystems, and finally integrates the subsystem to the system. At the same time, test plans at various stages are used to ensure the realization of subsystem functions. This design process ensures the functional perfection and stability of the final prototype. There is no doubt that the V-model is very suitable as the design methodology of this project.

6. Conclusions and recommendations

The main question was: What is the best design to complete the Automatic Mussel Display mechatronic design (with all requirements) in the form of a prototype, and uses the resources (money, workshop, and tools) provided by the company?

The main question is answered as follows:

The ‘Automatic Mussel Display’ prototype design includes four subsystems: control subsystem, lifting subsystem, decoration subsystem, and human detection subsystem. The system starts from the human detection subsystem, when the ultrasonic sensor of the human detection subsystem detects the human approaching motion within the detection range, it will send a digital signal to the microcontroller 'Arduino Uno Rev 3' of control subsystem. After the Arduino Uno Rev 3 receives the digital signal, the central processing unit calculates and sends the control signal to the lifting subsystem to open the upper shell. It also sends the control signals to the decoration subsystem to spray, play the music and turn on the LED. When the person leaves the detection range, the control subsystem will shut down the lifting subsystem and the decoration subsystem to turn off the upper shell, music, spray and LED.

The ‘Automatic Mussel Display’ prototype design needs to be further developed and modified.

The recommendations are presented below:

1. Complete the design and construction of the cooling system, choose an appropriate refrigeration method based on aspects such as cooling space and power supply;
2. Combine the electrical part of this project with the mechanical part (Moerland, 2021) of designer Martijn Moerland to get a complete mussel display stand design;
3. Avoid system misdetection by increasing the number of sensors or reducing noise infection.

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Appendix I : Test plans

The test plans for each system (Lifting subsystem, control subsystem, decoration subsystem, human detection subsystem) are presented in this appendix.

Demo/system test plan

Aim

The aim of the demo/system test is to evaluate that if the prototype of the 'Automatic Mussel Display' meets the requirements of the list. The prototype should be able to perform certain functions in different scenarios.

Functionality to be test

1. Detect the human motion (0-1m in front of the sensor);
2. Open the upper shell;
3. Play the music;
4. Turn on the LED light;
5. Close the upper shell;
6. Spray the sea smell.

Hypothesis

If someone stands in front of the sensor, the prototype can automatically lift the upper shell, spray, and turn on the music and the LED lights at the same time. The upper shell and spray will automatically turn off, and the music and lights will also turn off until the person leaves the detection range of the sensor. Then the functions of the prototype can be ensured in this case.

Target group & Measuring tools

Target group

1. The behavior of the lifting motor;
2. The opening angle of upper shell;
3. The output of the speaker;
4. The output of the LED.

Measuring tools

1. Human evaluation (listen and watch);
2. Timer;
3. Protractor;
4. Laptop.

Actions

1. Preparation phase;
   a. Set up the prototype;
   b. Power the whole set-up and switch on.
2. Test phase 1(exceed the detection range);
   a. Simulate the human standing exceed the detection range;
   b. Observe the response of the lifting motor;
   c. Timing the opening process of the upper shell;
   d. Measure the opening angle of upper shell;
   e. Observe the response of the speaker;
   f. Observe the response of the LED;
   g. Observe the response of the spray.
3. Test phase 2 (Inside the detection range);
   a. Simulate the human standing inside the detection range;
   b. Repeat step b-g in Test phase 1.
4. Test phase 3 (Leave the detection range);
   a. Simulate the human leaving the detection range;
   b. Repeat step b-g in Test phase 1.
5. Conclusion phase.
   a. Compare the responses with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the system is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
Response of the lifting motor	Situation A: When the human is standing in front of the sensor, the upper shell opens and stops at the pre-set position. When human leaves the front of the sensor, the upper shell closes. Conclusion: The lifting motor is functional to open the shell and the human motion is detected.	Situation B: When the human is standing in front of the sensor, The upper shell opens and stops before the preset position. When human leaves the front of the sensor, the upper shell closes. Conclusion: The lifting motor is functional to open the shell and the human motion is detected. But the accuracy of the system is not high enough.	Situation C: When the human is standing in front of the sensor, the upper shell keeps steady. Conclusion: The lifting motor is not functional, or the human motion is not detected.
The time of opening process	Situation A: The time of the opening process is between 10s-15s. Conclusion: The time meets the requirement perfectly.	Situation B: The time of the opening process is longer than 15s. Conclusion: The time does not meet the requirement but acceptable.	Situation C: The time of the opening process is shorter than 5s. Conclusion: The opening process is too short which is dangerous for the whole process.
Response of speaker	Situation A: The speaker plays the programmed music when a human is standing in front of the sensor. The speaker also turns off when a human leaves. Conclusion: The speaker is functional and meets the	Situation B: The speaker plays the unexpected sound when a human is standing in front of the sensor. The speaker also turns off when a human leaves. Conclusion: The speaker is not fully functional, but the result is	Situation C: The speaker keeps salience when a human is standing in front of the sensor. Conclusion: The speaker is not functional.

	requirement.	acceptable	
Response of LED	Situation A: The LED light is on and the color is changing automatically when a human is standing in front of the sensor. The LED also turns off when a human leaves. Conclusion: The LED is functional and meets the requirement.	Situation B: The LED light is on and the color keeps steady when a human is standing in front of the sensor. The LED also turns off when a human leaves. Conclusion: The LED is not fully functional, but the result is acceptable.	Situation C: The LED light does not turn on when a human is standing in front of the sensor. Conclusion: The LED is not functional.

Predicted conclusions

If the reactions are all situation A, then the prototype of ‘Automatic Mussel display’ exceed the expectation.

If the reactions are all situation B or situation A + situation B, then the test result is acceptable. The prototype of ‘Automatic Mussel display’ is functional enough.

If there is situation C in the reactions, the result does not meet the expectation. The prototype of ‘Automatic Mussel display’ is not functional.

Control subsystem test plan

Aim

The control subsystem test is aiming to test whether the control subsystem can send and receive the control signals through the corresponding digital I/O ports and communicate with the laptop.

Functionality to be test

1. Power the control subsystem using power signal E1.1;
2. Subsystem communication with the laptop;
3. Send control signals: X1.1, X2.1, X3.1, X4.2;
4. Receive reflected signals: X3.2, X4.1.

Hypothesis

If the control subsystem can be powered by the power signal E1.1 and communicate with the laptop and Scan send and receive the listed control signals (X1.1, X2.1, X3.1, X3.2, X4.1, X4.2), then the control subsystem test can be passed.

Target group & Measuring tools

Target group

1. Power signal E1.1;
2. System communication;
3. Control signals X1.1, X2.1, X3.1, X4.2 (sending);
4. Reflected signals X3.2, X4.1 (receiving).

Measuring tools

1. Human evaluation (listen and watch);
2. Laptop;
3. Multimeter;
4. Pen and paper.

Actions

1. Preparation phase;
   a. Prepare the testing program on the controller.
2. Test phase;
   a. Connect the controller to the power source;
   b. Measure the input power and check whether the controller is working properly;
   c. Run the program for sending the signal;
   d. Measure and record the signal sent by the controller (X1.1, X2.1, X3.1, X4.2);
   e. Run the program for receiving the signal;
   f. Input signal X4.1 and X3.2 to the corresponding I/O ports;
   g. Check and record whether the controller has received signals X4.1 and X3.2.
3. Conclusion phase.
   a. Compare the results with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the system is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
Power supply and communication	Situation A: When the system is powered on and run the program, the control subsystem runs and sends the preset text on the laptop. Conclusion: The subsystem is powered on and the communication between the subsystem and laptop is	Situation A: When the system is powered on and run the program, the control subsystem runs and sends the preset text on the laptop. Conclusion: The subsystem is powered on and the communication between the subsystem and laptop is	Situation A: When the system is powered on and run the program, the control subsystem has no response. Conclusion: The subsystem is not functional, needs to be adjusted or changed.

	functional.	functional.	
The output control signals	Situation A: All the output control signals (X1.1, X2.1, X3.1, X4.2) are detected. Conclusion: The control subsystem can send out the control signals.	Situation A: All the output control signals (X1.1, X2.1, X3.1, X4.2) are detected.\ Conclusion: The control subsystem can send out the control signals.	Situation C: There is no output control signals (X1.1, X2.1, X3.1, X4.2) detected or some of them are missed. Conclusion: The subsystem is not functional, needs to be adjusted or changed.
The reflecting control signals.	Situation A: All the reflected control signals (X3.2, X4.1) are detected. Conclusion: The control subsystem can receive the control signals.	Situation A: All the reflected control signals (X3.2, X4.1) are detected. Conclusion: The control subsystem can receive the control signals.	Situation C: There is no reflected control signals (X3.2, X4.1) detected or some of them are missed. Conclusion: The subsystem is not functional, needs to be adjusted or changed.

Predicted conclusions

The control subsystem can be powered properly by the outside power source and communicate with the laptop. The control subsystem can send signals X1.1, X2.1, X3.1 and X4.2 through its digital I/O ports. The control subsystem can receive input signals X4.1 and X3.2 on the corresponding digital I/O ports.

Lifting subsystem test plan

Aim

The aim of the lifting subsystem test is to evaluate that if the lifting subsystem could lift and put down the load in the certain weight. The lifting subsystem should be able to perform this function in different scenarios.

Functionality to be test

1. Lift the upper cover;
2. The maximum weight that the system can load;
3. Close the upper shell.

Hypothesis

If the lifting subsystem is powered with the DC voltage, the lifting system should be activated and lift the load and stop in a certain position. The load can also be put down when the positive and negative poles of the power supply are reversed. Then the functions of the lifting subsystem can be ensured in this case.

Target group & Measuring tools

Target group

1. The behavior of the lifting motor;
2. The stroke distance of the lifting subsystem;
3. The speed of the lifting process;
4. The load of the lifting motor.

Measuring tools

1. Human evaluation (listen and watch);
2. Timer;
3. Tape measure;
4. Weighing instrument.

Actions

1. Preparation phase;

a. Set up the lifting subsystem;

c. Power the whole set-up and switch on.

2. Test phase 1 (No load);
   a. Observe the response of the lifting motor;
   b. Timing the lifting process;
   c. Measure the stroke distance of the lifting subsystem;
   d. Switch off and reverse the positive and negative poles of the power;
   e. Observe the response of the lifting motor;
   f. Switch off and connect the lifting subsystem with a load (10Kg).
3. Test phase 2 (load=10Kg);
   a. Switch on and repeat the steps a-e in Test phase 1;
   b. Switch off the lifting subsystem.
4. Conclusion phase.
   a. Compare the results with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the system is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
Response of the lifting motor	Situation A: When the system is powered on, the system lifted the load to the preset position in three scenarios (no load, load=10Kg). And returned to the starting position when the power polarity is reversed Conclusion: The lifting motor is functional to lift the	Situation B: When the system is powered on, the system lifted the load to the preset position in the no-load situation and load=10Kg. And returned to the starting position when the power polarity is reversed Conclusion: The lifting motor is not fully functional to	Situation C: When the system is powered on, the system failed to lift the load to the preset position when the load is 10Kg or 0Kg. Conclusion: The lifting motor is not functional which needed to be improved.

	load.	lift the load but acceptable.	
The time of lifting process	Situation A: The time of the Lifting process is between 10s-15s. Conclusion: The time meets the requirement perfectly.	Situation B: The time of the Lifting process is longer than 15s. Conclusion: The time does not meet the requirement but acceptable.	Situation C: The time of the lifting process is shorter than 5s. Conclusion: The lifting process is too short which is dangerous for the whole process.
The stroke distance	Situation A: The stroke distance=100MM	Situation B: 30MM<the stroke distance<100MM	Situation C: 0MM<The stroke distance<30cm

Predicted conclusions

If the reactions are all situation A, then the Lifting subsystem exceed the expectation.

If the reactions are all situation B or situation A + situation B, then the test result is acceptable. The Lifting subsystem is functional enough.

If there is situation C in the reactions, the result does not meet the expectation. The Lifting subsystem is not functional.

Decoration subsystem test plan

Aim

The aim of the Decoration subsystem test is to evaluate that if the decoration subsystem could play music and turn on the LED light. The decoration subsystem should be able to perform this function to attract the customers' attention.

Functionality to be test

1. Play the programmed music;
2. Turn on the lights;
3. Switch the colors of lights automatically.

Hypothesis

If the decoration subsystem is powered with the voltage and run the program, the decoration subsystem should be activated and play the programmed music. The light should be turned on and switch the colors automatically in the meantime. Then the functions of the decoration subsystem can be ensured in this case.

Target group & Measuring tools

Target group

1. The programed music;
2. The Led lights.

Measuring tools

1. Human evaluation (listen and watch);
2. Camera;
3. Pen and paper.

Actions

1. Preparation phase;
   a. Set up the decoration subsystem;
   b. Power the whole set-up and switch on.
2. Test phase;

   a. Observe the response of the speaker;
   b. Observe the response of the LED;
   c. Record the results;
   d. Switch off the system.

3. Conclusion phase.
   a. Compare the results with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the system is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
Response of the speaker	Situation A: When the system is powered on, the programmed music is played. Conclusion: The speaker is functional.	Situation A: When the system is powered on, the programmed music is played. Conclusion: The speaker is functional.	Situation C: When the system is powered on, the speaker has no response or played the unexpected music. Conclusion: The speaker is not functional and needs to be adjusted or changed.
Response of the LED.	Situation A: When the system is powered on, the LED is on and changes the color automatically. Conclusion: The LED is functional	Situation A: When the system is powered on, the LED is on and changes the color automatically. Conclusion: The LED is functional	Situation C: When the system is powered on, the LED has no response or the color doesn't change. Conclusion: The LED is not functional and needs to be adjust or changed.

Predicted conclusions

If the reactions are all situation A, then the decoration subsystem exceed the expectation.

If the reactions are all situation B or situation A + situation B, then the test result is acceptable. The decoration subsystem is functional enough.

If there is situation C in the reactions, the result does not meet the expectation. The decoration subsystem is not functional.

Human detection subsystem test plan

Aim

The aim of the Human detection subsystem test is to evaluate that if the Human detection subsystem could detect objectives approaching and output indicating signals that represent the distance between the detection subsystem and the approaching objective.

Functionalities to test

1. It can analyze the human motion information 'INF 1.1' from external systems;

2. It can output indicating signals 'X4.1' which represent the distance between the detection subsystem and the approaching objective;

3. The indicating signals 'X4.1' can be interpreted into the distance value by the control subsystem;

4. The detector should detect range between 20cm to 1m;

Functionalities to test

It can analyze the human motion information 'INF 1.1' from external systems.

It can output indicating signals 'X4.1' which represent the distance between the detection subsystem and the approaching objective.

The indicating signals 'X4.1' can be interpreted into the distance value by the control subsystem.

The detector should detect range between 20cm to 1m.

Hypothesis

If the human detection subsystem is correctly connected to the control system, it should output indicating signals to the control subsystem that represent the distance between the detection subsystem and the approaching objective when the distance is between 20cm and 1m.

Target group & Measuring tools

Target group

1. The output of the Ultrasonic Sensor Module;

Measuring tools

1. Passenger (to provide human motion 'INF 1.1');

2. Arduino Uno (to power, program the Ultrasonic Sensor Module and interpreter the output of it);

3. Laptop（to program the sensor and upload the codes to the Arduino uno）:

4. Ruler (to verify the detection range of the ultrasonic sensor);

5. DuPont wires（to connect the Arduino and the sensor)；

6. One USB wire (to connect the Arduino and the laptop).

Actions

1. Preparation phase;

a. Connect the ultrasonic sensor to Arduino uno using Dupont wires. (The specific connection will be shown in the assembly plan) ;

b. Power the Arduino uno and connect the Arduino to the laptop using USB wire;

c. Upload the pre-programmed codes to the Arduino on laptop.

2. Test phase 1 （distance）；

a. Place an object at 1M, 0° in front of the sensor;

b. Check the output and record the test distance;

c. Reduce the distance between the object and the sensor by 20CM;

d. Check the output and record the test distance;

e. Repeat step c, d until the distance between the object and sensor is 20CM.

3. Test phase 2 (angle);

a. Place an object at 1M, -30° in front of the sensor;

b. Check the output and record the test distance;

c. Repeat step c, d in test phase 1 until the distance between the object and sensor is 20CM;

d. Move the object to 1M, 30° in front of the sensor;

e. Repeat step c, d in test phase 1 until the distance between the object and sensor is 20CM;

4. Conclusion phase.

a. Compare the results with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the subsystem is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
The measure distance of the detecting subsystem	Situation A: When the subsystem is correctly connected to the control subsystem and runs the program, when a human is approaching the detecting subsystem from a distance between 20cm and 1m, the output signals indicates the exact distance between the passenger and the detector. Conclusion: The subsystem detected the human motion and calculated the distance.	Situation B: When the subsystem is correctly connected to the control subsystem and run the program, when a human is approaching the detecting subsystem from a distance between 20cm and 1m, the output signals can indicate the relative change of the distance between the passenger and the detector. For example, it is acceptable when the real distance is changing from 70cm to 40cm and the measured output changes from 60cm to 35cm. Conclusion: The subsystem detected the human motion but the accuracy of the detected distance is not high which is acceptable. .	Situation C: When the subsystem is correctly connected to the control subsystem and runs the program, when a human is approaching the detecting subsystem from a distance between 20cm and 1m, the output signals cannot indicate even the relative change of the distance. Conclusion: The subsystem cannot detect the human motion and the subsystem needs to be adjust or changed.
The measure angle of the detecting	Situation A: When the subsystem is correctly	Situation B: When the subsystem is correctly	Situation C: When the subsystem is correctly connected to the

subsystem	connected to the control subsystem and runs the program, when a human is approaching the detecting subsystem from angles between -30°to 30° in the detection range (20cm to 1m), the exact distance between the human and sensor is output. Conclusion: The subsystem detected the human motion and calculated the distance.	connected to the control subsystem and runs the program, when a human is approaching the detecting subsystem from angles between -30°to 30° in the detection range (20cm to 1m), the output can indicate the relative change of the distance between the passenger and the detector. Conclusion: The subsystem detected the human motion but the accuracy of the detected distance is not high which is acceptable.	control subsystem and runs the program, when a human is approaching the detecting subsystem from angles between -30°to 30°, in the detection range (20cm to 1m), the output is wrong. For example, the values are jumping randomly when the objective is standing still. Conclusion: The subsystem cannot detect the human motion and the subsystem needs to be adjust or changed.

Predicted conclusions

If the reactions are all situation A, then the Lifting subsystem exceed the expectation.

If the reactions are all situation B or situation A + situation B, then the test result is acceptable. The human detection subsystem is functional enough.

If there is situation C in the reactions, the result does not meet the expectation. The human detection subsystem is not functional.

Spray subsystem test plan

Aim

The aim of the spray subsystem test is to evaluate that if the subsystem could convert the water into the spray to spread a sea smell.

Functionality to be test

1. Atomized water;
2. Spread the sea smell.

Hypothesis

If the spray subsystem is powered with the DC voltage, the spray system should be activated and atomize the water. The sea smell is spread. Then the functions of the spray subsystem can be ensured in this case.

Target group & Measuring tools

Target group

1. The behavior of the spay subsystem;
2. The spray;
3. The sea smell.

Measuring tools

1. Human evaluation (smell and watch);
2. Phone(photo);
3. Water;
4. Laptop.

Actions

1. Preparation phase;
    a. Set up the spray subsystem;
    b. Power the whole set-up and switch on.
2. Test phase 1 (No load);

a. Observe the response of the spray subsystem;

b. Smell the spray;

c. Record the result.

3. Conclusion phase.

a. Compare the results with the expecting results.

Average and bandwidth of reactions

The average and bandwidth of the reactions in table demonstrate the possible results of the test which help to evaluate if the system is functional. The Situation A, B, and C in the table represent the best situation, acceptable situation, and insufficient situation.

Reactions	Bandwidth of reactions		
Response of the spray subsystem	Situation A: When the system is powered on, the system atomized the water and the spray comes out. Conclusion: The spray subsystem is functional to atomize the water.	Situation B: When the system is powered on, the system atomized the water and the spray comes out. Conclusion: The spray subsystem is functional to atomize the water.	Situation C: When the system is powered on, the system doesn't atomize the water and there is no spray. Conclusion: The spray subsystem is not functional which needs to be modified.
The sea smell	Situation A: When the system is powered on, there is a sea smell spread in the air. Conclusion: The spray subsystem is functional to spread the sea smell.	Situation B: When the system is powered on, there is no sea smell spread in the air. Conclusion: The spray subsystem is not functional to spread the sea smell in the air but acceptable.	Situation B: When the system is powered on, there is no sea smell spread in the air. Conclusion: The spray subsystem is not functional to spread the sea smell in the air.

7

Predicted conclusions

If the reactions are all situation A, then the spray subsystem exceed the expectation.

If the reactions are all situation B or situation A + situation B, then the test result is acceptable. The spray subsystem is functional enough.

If there is situation C in the reactions, the result does not meet the expectation. The spray subsystem is not functional.

Appendix II : Assembly Plans

The assembly plans for system and subsystems are presented in this appendix. There are 4 subsystems in the subsystem design phase: Control subsystem, lifting subsystem, decoration subsystem, and human detection subsystem.

Lifting subsystem assembly plan

Figure 36 shows the schematic of the lifting subsystem.

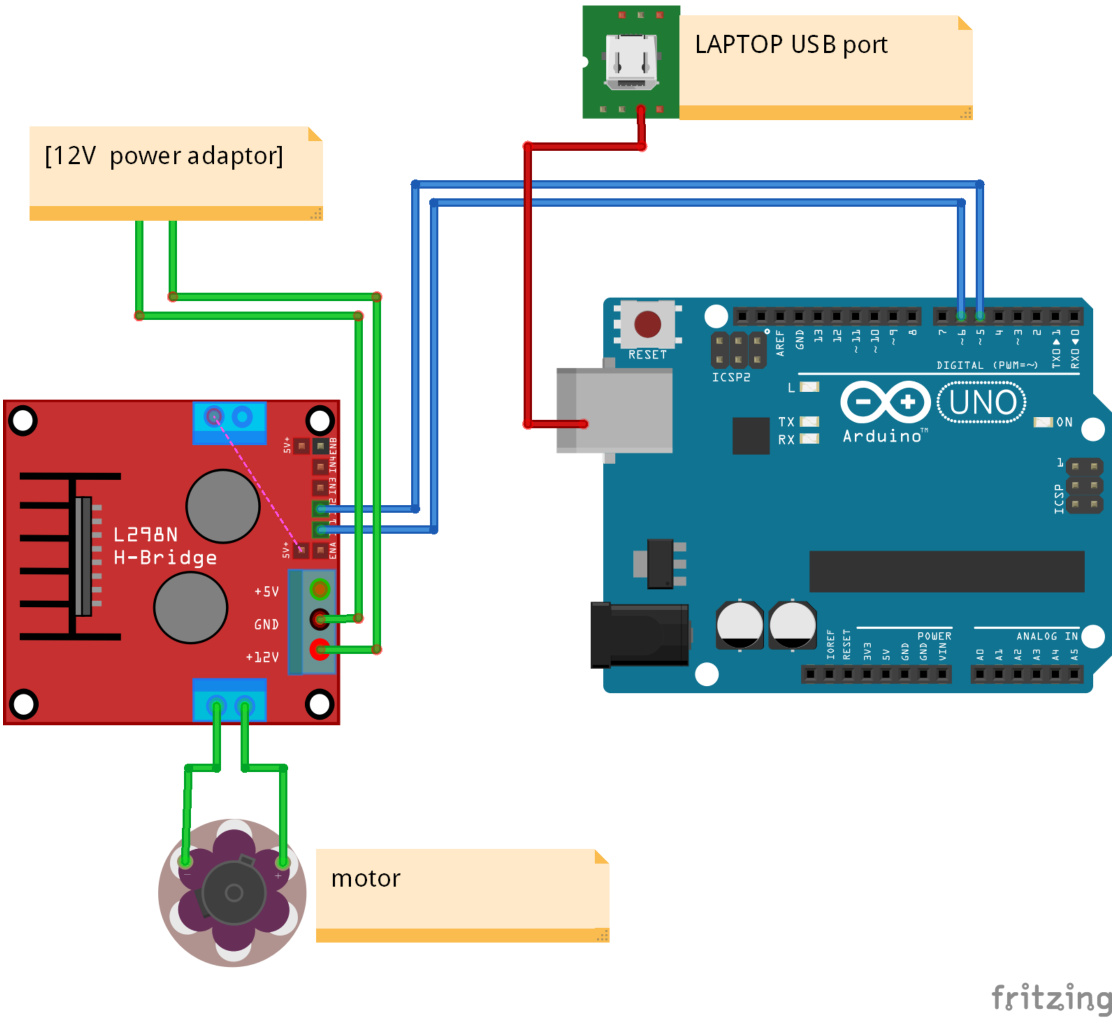


Figure 36 Schematic of lifting subsystem

Decoration subsystem assembly plan

Figure 37 shows the schematic of the decoration subsystem.

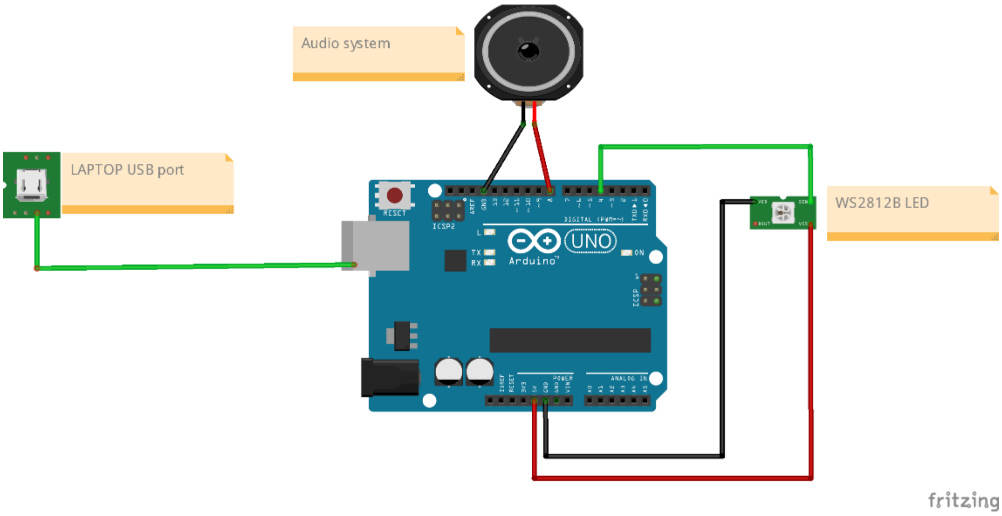


Figure 37 Schematic of decoration subsystem.

System assembly plan

Figure 38 shows the schematic of the 'Automatic Mussel Display' prototype system.

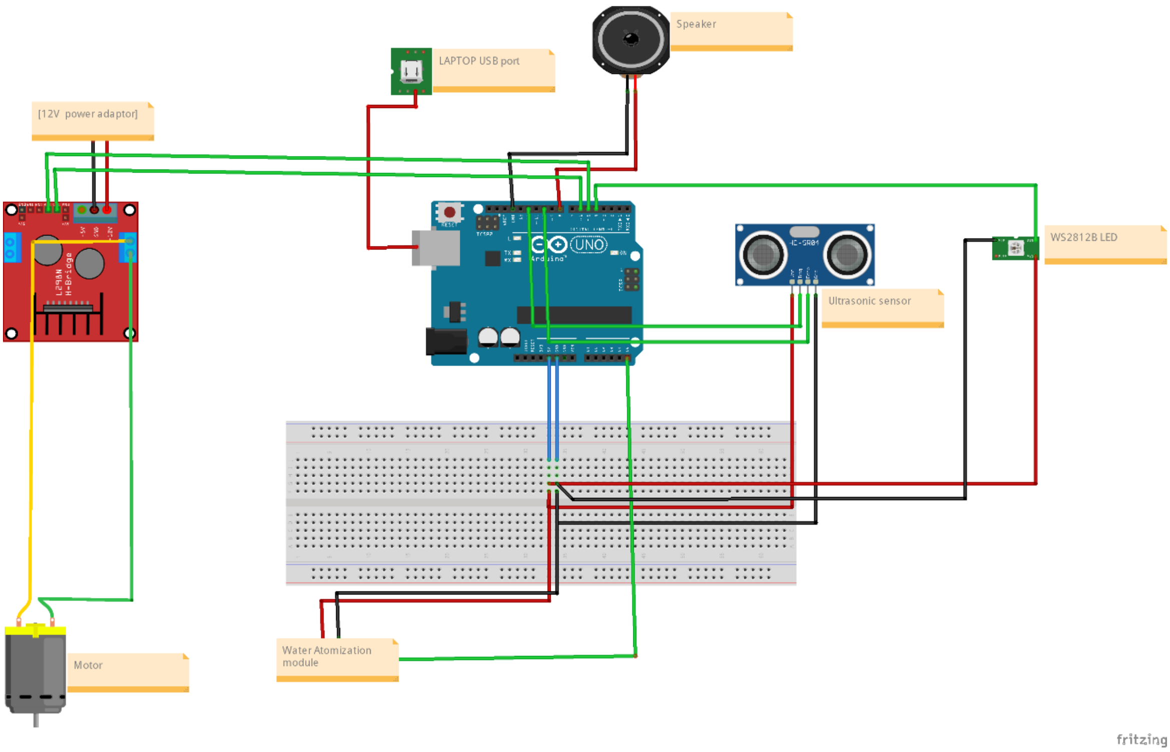


Figure 38 Schematic of 'Automatic Mussel Display' system.

Appendix Ⅲ: Test codes

The test program codes are presented in this appendix.

Control subsystem test codes

```
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(LED_BUILTIN, OUTPUT);
  Serial.begin(9600);
}


// the loop function runs over and over again forever
void loop() {
  Serial.println("Hallo World ");      // print the text
  digitalWrite(LED_BUILTIN, HIGH);   // turn the LED on (HIGH is the voltage level)
  delay(1000);                       // wait for a second
  digitalWrite(LED_BUILTIN, LOW);    // turn the LED off by making the voltage LOW
  delay(1000);                       // wait for a second



}
```

Lifting subsystem test codes

```
const int Pin1=5;
const int Pin2=6;
void setup() {
  // put your setup code here, to run once:
   pinMode(Pin1, OUTPUT);/Define pin
   pinMode(Pin2, OUTPUT);
}

void loop() {
  // put your main code here, to run repeatedly:
  digitalWrite(Pin2, HIGH);/Output high level
  digitalWrite(Pin1, LOW);/Output low level

}
```

Decoration subsystem test codes

```
#include <FastLED.h>
#include <FastLED.h>

#define LED_PIN     4
#define NUM_LEDS    12
#define BRIGHTNESS  64
#define LED_TYPE    WS2811
#define COLOR_ORDER GRB
CRGB leds[NUM_LEDS];
#define UPDATES_PER_SECOND 100
#define NOTE_C4  262
#define NOTE_G3  196
#define NOTE_A3  220

CRGBPalette16 currentPalette;
TBlendType    currentBlending;

extern CRGBPalette16 myRedWhiteBluePalette;
extern const TProgmemPalette16 myRedWhiteBluePalette_p PROGMEM;

int melody[] = {
  NOTE_C4, NOTE_G3, NOTE_G3, NOTE_A3
};

int noteDurations[] = {
  6, 12, 12, 6
};
```

```
void play(int *melody, int *noteDurations, int num) {
  for (int note = 0; note < num; note++) {
    int noteDuration = 3000 / noteDurations[note];
    tone(8, melody[note], noteDuration);

    delay(noteDuration * 1.30);
  }
}



void setup() {
    delay( 3000 ); // power-up safety delay
    FastLED.addLeds<LED_TYPE, LED_PIN, COLOR_ORDER>(leds, NUM_LEDS).setCorrection( TypicalLEDStrip );
    FastLED.setBrightness(  BRIGHTNESS );

    currentPalette = RainbowColors_p;
    currentBlending = LINEARBLEND;
    // initialize digital pin 13 as an output.
      pinMode(A5, OUTPUT);// Set A5 as OUTPUT
      pinMode(5, INPUT); // Use digital pin 5 as output port

}

void loop()
{
    ChangePalettePeriodically();

    static uint8_t startIndex = 0;
    startIndex = startIndex + 1; /* motion speed */
```

```
    FillLEDsFromPaletteColors( startIndex);
    play(melody, noteDurations, sizeof(melody) / sizeof(int));//Play the music

    FastLED.show();
    FastLED.delay(1000 / UPDATES_PER_SECOND);
    int D2Sig = digitalRead(5);// read pin 5 signal

        if (D2Sig == 1)
        {
            /* code */
            digitalWrite(A5, HIGH);   // atomize



        }
}

void FillLEDsFromPaletteColors( uint8_t colorIndex)
{
    uint8_t brightness = 255;

    for( int i = 0; i < NUM_LEDS; i++) {
        leds[i] = ColorFromPalette( currentPalette, colorIndex, brightness, currentBlending);
        colorIndex += 3;
    }
}

// There are several different palettes of colors demonstrated here.
//
```

```
// FastLED provides several 'preset' palettes: RainbowColors_p, RainbowStripeColors_p,
// OceanColors_p, CloudColors_p, LavaColors_p, ForestColors_p, and PartyColors_p.
//
// Additionally, you can manually define your own color palettes, or you can write
// code that creates color palettes on the fly.  All are shown here.


void ChangePalettePeriodically()
{
    uint8_t secondHand = (millis() / 1000) % 60;
    static uint8_t lastSecond = 99;


    if( lastSecond != secondHand) {
        lastSecond = secondHand;
        if( secondHand ==  0)  { currentPalette = RainbowColors_p;         currentBlending = LINEARBLEND; }
        if( secondHand == 10)  { currentPalette = RainbowStripeColors_p;   currentBlending = NOBLEND;  }
        if( secondHand == 15)  { currentPalette = RainbowStripeColors_p;   currentBlending = LINEARBLEND; }
        if( secondHand == 20)  { SetupPurpleAndGreenPalette();             currentBlending = LINEARBLEND; }
        if( secondHand == 25)  { SetupTotallyRandomPalette();              currentBlending = LINEARBLEND; }
        if( secondHand == 30)  { SetupBlackAndWhiteStripedPalette();       currentBlending = NOBLEND; }
        if( secondHand == 35)  { SetupBlackAndWhiteStripedPalette();       currentBlending = LINEARBLEND; }
        if( secondHand == 40)  { currentPalette = CloudColors_p;           currentBlending = LINEARBLEND; }
        if( secondHand == 45)  { currentPalette = PartyColors_p;           currentBlending = LINEARBLEND; }
```

```
        if( secondHand == 50) { currentPalette = myRedWhiteBluePalette_p; currentBlending = NOBLEND; }
        if( secondHand == 55) { currentPalette = myRedWhiteBluePalette_p; currentBlending = LINEARBLEND; }
    }
}

// This function fills the palette with totally random colors.
void SetupTotallyRandomPalette()
{
    for( int i = 0; i < 16; i++) {
        currentPalette[i] = CHSV( random8(), 255, random8());
    }
}

// This function sets up a palette of black and white stripes,
// using code.  Since the palette is effectively an array of
// sixteen CRGB colors, the various fill_* functions can be used
// to set them up.
void SetupBlackAndWhiteStripedPalette()
{
    // 'black out' all 16 palette entries...
    fill_solid( currentPalette, 16, CRGB::Black);
    // and set every fourth one to white.
    currentPalette[0] = CRGB::White;
    currentPalette[4] = CRGB::White;
    currentPalette[8] = CRGB::White;
    currentPalette[12] = CRGB::White;

}
```

```
// This function sets up a palette of purple and green stripes.
void SetupPurpleAndGreenPalette()
{
    CRGB purple = CHSV( HUE_PURPLE, 255, 255);
    CRGB green  = CHSV( HUE_GREEN, 255, 255);
    CRGB black  = CRGB::Black;

    currentPalette = CRGBPalette16(
                                   green,  green,  black,  black,
                                   purple, purple, black,  black,
                                   green,  green,  black,  black,
                                   purple, purple, black,  black );
}

// This example shows how to set up a static color palette
// which is stored in PROGMEM (flash), which is almost always more
// plentiful than RAM.  A static PROGMEM palette like this
// takes up 64 bytes of flash.
const TProgmemPalette16 myRedWhiteBluePalette_p PROGMEM =
{
    CRGB::Red,
    CRGB::Gray, // 'white' is too bright compared to red and blue
    CRGB::Blue,
    CRGB::Black,

    CRGB::Red,
    CRGB::Gray,
    CRGB::Blue,
```

```
    CRGB::Black,


    CRGB::Red,
    CRGB::Red,
    CRGB::Gray,
    CRGB::Gray,
    CRGB::Blue,
    CRGB::Blue,
    CRGB::Black,
    CRGB::Black
};
```

Human detection subsystem test codes

```
const int trigPin = 12;
const int echoPin = 10;
long duration;
float distance;


void setup() {
  // put your setup code here, to run once:
  pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
  pinMode(echoPin, INPUT); // Sets the echoPin as an Input
  Serial.begin(9600);


}


void loop() {
  // put your main code here, to run repeatedly:
  // Clears the trigPin
```

```
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  // Sets the trigPin on HIGH state for 10 micro seconds
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  // Reads the echoPin, returns the sound wave travel time in microseconds
  duration = pulseIn(echoPin, HIGH);
  // Calculating the distance
  distance = duration * 0.034 / 2;
  // Prints the distance on the Serial Monitor
  Serial.print("Distance: ");
  Serial.println(distance);
   delay(2500);

}
```

Spray subsystem test codes

```
/*
  Demo code for grove  atomization.

*/

// the setup function runs once when you press reset or power the board
void setup() {
    // initialize digital pin 13 as an output.
    pinMode(A5, OUTPUT);// Set A5 as OUTPUT
    pinMode(5, INPUT); // Use digital pin 5 as output port
}

// the loop function runs over and over again forever
void loop() {
    int D2Sig = digitalRead(5);// read pin 5 signal

    if (D2Sig == 1)
    {
        /* code */
        digitalWrite(A5, HIGH);   // atomize


    }
}
```

System test codes

```
#include <FastLED.h>


#define LED_PIN     4
#define NUM_LEDS    12
#define BRIGHTNESS  64
#define LED_TYPE    WS2811
#define COLOR_ORDER GRB
CRGB leds[NUM_LEDS];


#define UPDATES_PER_SECOND 100


#define NOTE_G3  196
#define NOTE_A3  220
#define NOTE_C4  262
#include "Seeed_SHT35.h"



/*SAMD core*/
#ifdef ARDUINO_SAMD_VARIANT_COMPLIANCE
#define SDAPIN  20
#define SCLPIN  21
#define RSTPIN  7
#else
#define SDAPIN  A4
#define SCLPIN  A5
#define RSTPIN  2


#endif
```

```
SHT35 sensor(SCLPIN);

const int trigPin = 12;
const int echoPin = 10;
long duration;
float distance;

CRGBPalette16 currentPalette;
TBlendType    currentBlending;

extern CRGBPalette16 myRedWhiteBluePalette;
extern const TProgmemPalette16 myRedWhiteBluePalette_p PROGMEM;


int melody[] = {
  NOTE_C4, NOTE_G3, NOTE_G3, NOTE_A3
};

int noteDurations[] = {
  6, 12, 12, 6
};

void play(int *melody, int *noteDurations, int num) {
  for (int note = 0; note < num; note++) {
    int noteDuration = 3000 / noteDurations[note];
    tone(8, melody[note], noteDuration);

    delay(noteDuration * 1.30);
```

```
  }
}

void setup() {
    delay( 1500 ); // power-up safety delay
   FastLED.addLeds<LED_TYPE, LED_PIN, COLOR_ORDER>(leds, NUM_LEDS).setCorrection( TypicalLEDStrip );
   FastLED.setBrightness(  BRIGHTNESS );

   currentPalette = RainbowColors_p;
   currentBlending = LINEARBLEND;

  pinMode(trigPin, OUTPUT); // Sets the trigPin as an Output
  pinMode(echoPin, INPUT); // Sets the echoPin as an Input
  pinMode(5, OUTPUT);
  pinMode(6, OUTPUT);
  Serial.begin(115200);
  delay(10);
  Serial.println("Serial start!!");
  if (sensor.init())
  {
    Serial.println("sensor init failed!!!");
  }

  Serial.begin(9600); // Starts the Serial communication
}

void loop() {
  // Clears the trigPin
  digitalWrite(trigPin, LOW);
```

```
delayMicroseconds(2);
// Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
// Reads the echoPin, returns the sound wave travel time in microseconds
duration = pulseIn(echoPin, HIGH);
// Calculating the distance
distance = duration * 0.034 / 2;
// Prints the distance on the Serial Monitor

Serial.print("Distance: ");
Serial.println(distance);
u16 value = 0;
u8 data[6] = {0};
float temp, hum;
if (NO_ERROR != sensor.read_meas_data_single_shot(HIGH_REP_WITH_STRCH,
&temp, &hum))
{
  Serial.println("read temp failed!!");
  Serial.println("   ");
  Serial.println("   ");
  Serial.println("   ");
}
else
{
  Serial.println("read data :");
  Serial.print("temperature = ");
  Serial.print(temp);
  Serial.println(" ℃ ");
```

```
  Serial.print("humidity = ");
  Serial.print(hum);
  Serial.println(" % ");

  Serial.println("   ");
  Serial.println("   ");
  Serial.println("   ");
}

if (distance < 100) {
  Serial.println("Human Detected!");
  digitalWrite(6, LOW);
  digitalWrite(5, HIGH);//power the motor
  play(melody, noteDurations, sizeof(melody) / sizeof(int));//Play the music
  SetupTotallyRandomPalette();
  FillLEDsFromPaletteColors( 0);
  FastLED.show();

}
else {
  digitalWrite(5, LOW);
  digitalWrite(6, HIGH);//close
  Serial.println("Nobody!");
  TurnoffPalette();
  FillLEDsFromPaletteColors( 0);

  FastLED.show();
}
```

```
}

void SetupTotallyRandomPalette()
{
   for( int i = 0; i < 11; i++) {
      currentPalette[i] = CHSV( random8(),random8(), random8());    }
}

void TurnoffPalette()
{
   for( int i = 0; i < 11; i++) {
      currentPalette[i] = CHSV(0, 0, 0) ;   }
}

void FillLEDsFromPaletteColors( uint8_t colorIndex)
{
   uint8_t brightness = 255;

   for( int i = 0; i < NUM_LEDS; i++) {
      leds[i] = ColorFromPalette( currentPalette, colorIndex, brightness, currentBlending);
      colorIndex += 3;
   }
}
```

Appendix Ⅳ: Detailed Results

Microcontroller composition

The basic composition and functions are listed below:

1. CPU (Central Processing Unit): CPU plays a core role in the microcontroller. The reception and execution of all operating instructions of the microcontroller, various control functions and auxiliary functions are all carried out under the management of CPU.

2. Register: There are two kinds of registers in the microcontroller, RAM (Random access memory) and ROM (Read-Only Memory). RAM is used to store intermediate data when the program is running, and its storage content is lost after power failure. The data stored in the ROM will not be lost after the power is off and could still be read after the power is turned on.

3. Input/Output (I/O) interface: The input/output interface circuit refers to the connection channel between the CPU and external circuits, related control circuits, and personal computers. In general, the level and data format of external devices are not compatible with the CPU. Only through the bridging function of the I/O interface can the information transmission and communication between the external devices and the CPU be realized.

4. Counter/Timer: In the application of the microcontroller, it is often necessary to count external events through a counter. The timer realizes the function of timing by counting the standard clock pulses inside the microcontroller. Each time a clock pulse comes, the counter increases by one, and the accumulated value represents the passage of time.

5. System bus: The above-mentioned CPU, registers, and counter/timers are connected to each other through the address bus, the data bus, and the control bus. Connected to the external devices through an I/O interface in the end.

Selection process

Table 17 shows the evaluating scores of 3 different power source. The score is from 1-5, the larger the score, the better the performance, and the total score is calculated in the end.

Table 17 The evaluating score table

Scoring aspects	Pneumatic linear actuator	Hydraulic linear actuator	Electric linear actuator
Overload automatic protection	3	4	2
Start with load	2	4	3
Self-locking function	1	5	5
Stroke adjustment	1	5	5
Output force	1	3	5
Cost	1	3	5
Control methods	2	3	5
Size	1	3	5
Total score	12	30	35

The total score in the table shows that the electric linear actuator is the best selection for this project.

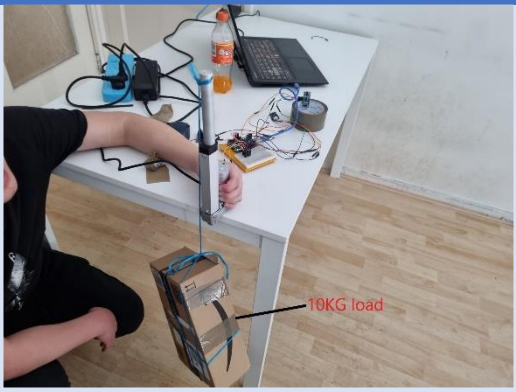
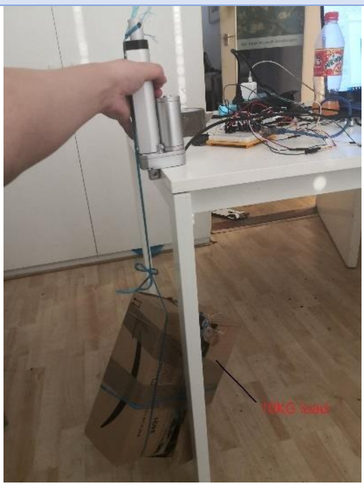
Lifting subsystem test results

Table 18, Table 19 shows the detailed test results of lifting subsystem.

Table 18 Test results (No load)

Tested items	Result
Response of lifting motor (lifting end state)	
Time of lifting process	12.3 seconds
Stroke distance	9.8cm
Response of lifting motor (dropping end state)	
Time of falling process	12.0 seconds

Table 19 Test results (load=10KG)

Tested items	Result
Response of lifting motor (lifting end state)	
Time of lifting process	11.8 seconds
Stroke distance	9.8cm
Response of lifting motor (dropping end state)	
Time of falling process	12.2 seconds

Decoration subsystem test results

Figure 39 shows the test results of decoration subsystem.

Figure 39 LED Module test results

Spray subsystem test results

Figure 40 shows the test results of spray subsystem.

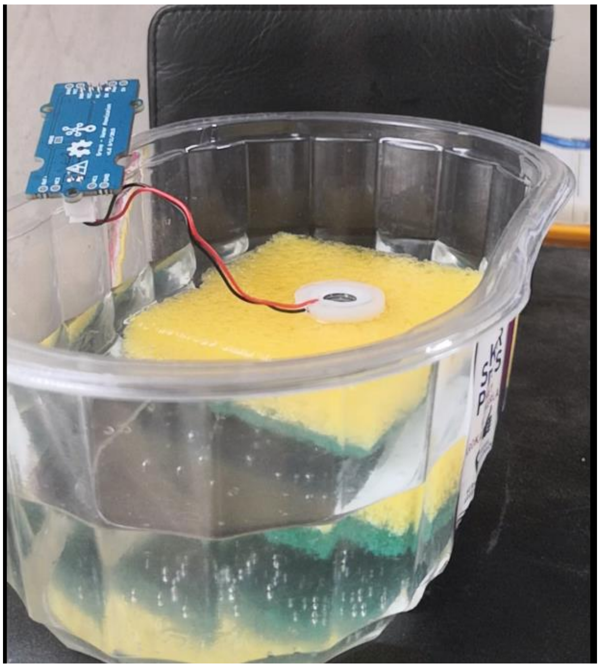


Figure 40 Water atomization module test results

Human detection subsystem test results

Table 20 shows the tested results of human detection subsystem.

Table 20 Test results of human detection subsystem.

Test scenarios	Exact distance	Test distance	Error $= \frac{\lvert Test\ disdance - Exactdance \rvert}{Exact\ distance} * 100\%$
0°	100CM	92.3CM	7.7%
	80CM	75.0CM	6.3%
	60CM	55.9CM	6.8%
	40CM	37.7CM	5.8%
	20CM	18.7CM	6.5%
30°	100CM	93.5CM	6.5%
	80CM	75.2CM	6.0%
	60CM	54.3CM	9.5%
	40CM	36.7CM	8.2%
	20CM	19.2CM	4.0%
-30°	100CM	94.4CM	5.6%
	80CM	73.2CM	8.5%
	60CM	56.4CM	6.0%
	40CM	36.2CM	9.5%
	20CM	18.2CM	9.0%

System test results

The detailed test results of system in different scenarios are listed below:

1. Human standing at 1M-2M position (exceed the set detection range)

Figure 41 shows that when a human is standing outside the preset detection range of the system, the lifting subsystem and decoration subsystem are kept shut down, the upper shell is closed, and there is no music or light.

Figure 41 System test result 1

2. Human standing at 0M-1M position (inside the set detection range)

As shown in Figure 42, when a human is standing inside the preset detection range(0-1M) of the system, the lifting subsystem was activated, the upper shell was lifted to the preset position. In the meantime, the decoration subsystem played the programmed music and the LED module changed the color automatically. When a person was standing in the detection range, the lifting subsystem kept the upper shell open, and the decoration subsystem continued to play music and change the light color.

Figure 42 System test result 2.

3. Humans leave the system (exceed the set detection range)

When a person leaves the set detection range, the lifting subsystem dropped the upper shell. the decoration subsystem stopped playing music and turned off the LED (shown in Figure 43).

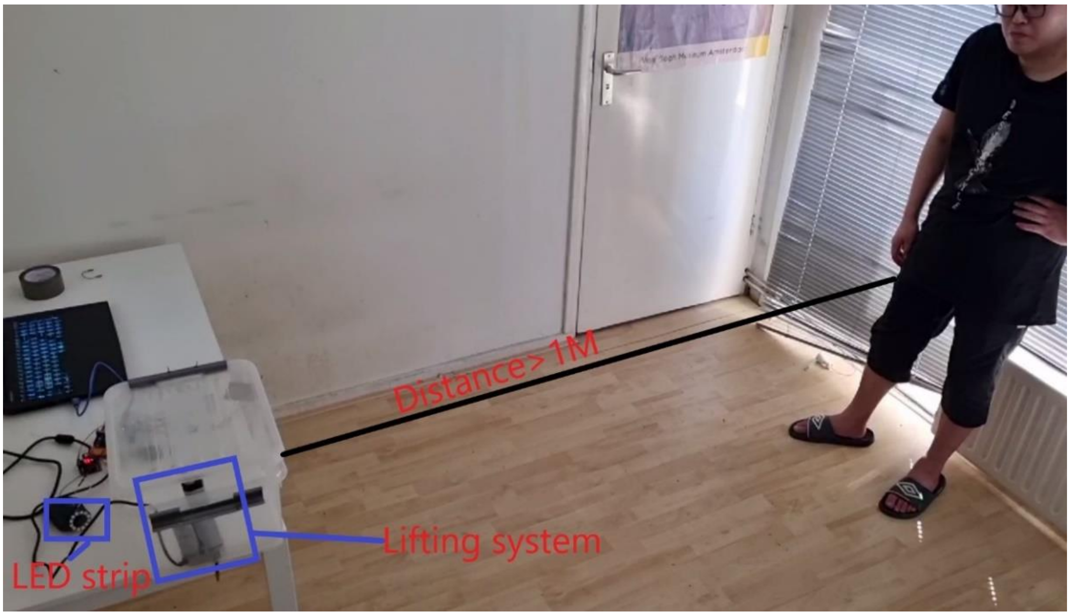


Figure 43 System test result 3.

Figure 44 shows the response of the spray function.

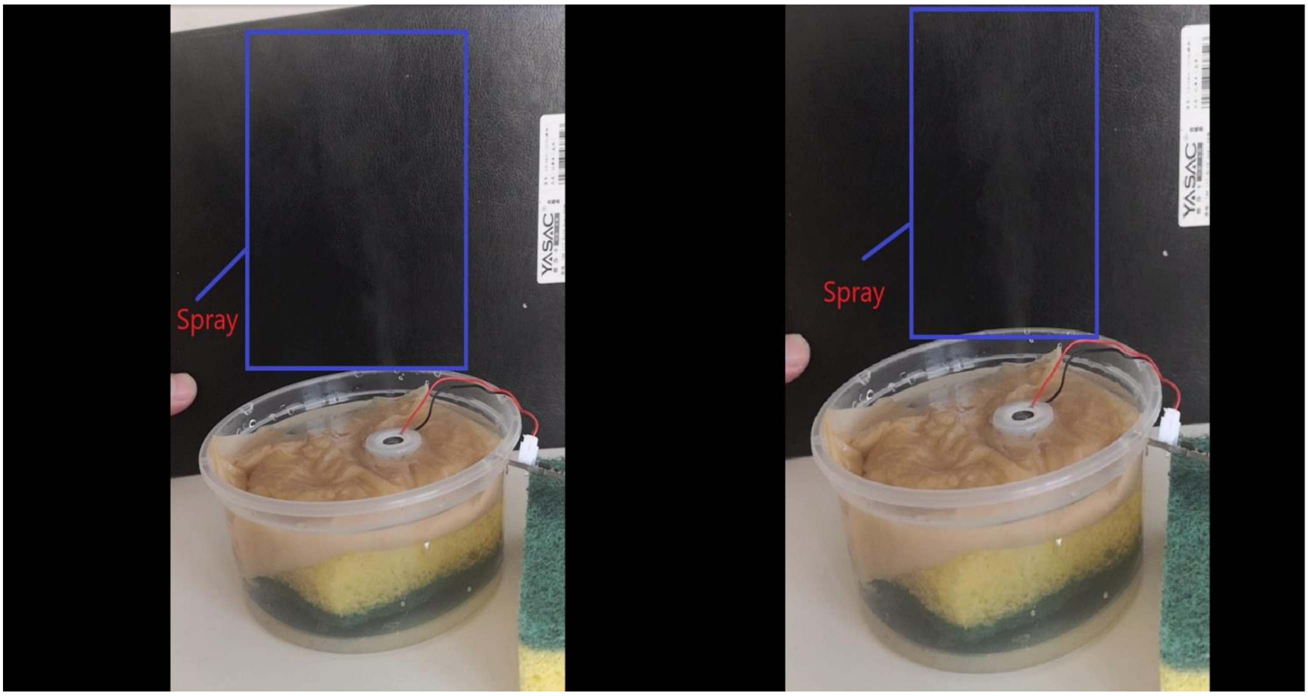


Figure 44 The response of the spray subsystem

Table 21 listed the other tested items and results in the system test.

Table 21 System test result 4

Tested items	Results
Time of lifting process	12.4 seconds
Stroke distance	10.8CM
Opening Angle	51°
Time of dropping process	11.6 seconds

Appendix Ⅴ: System cost and selected components

Arduino Uno Rev3

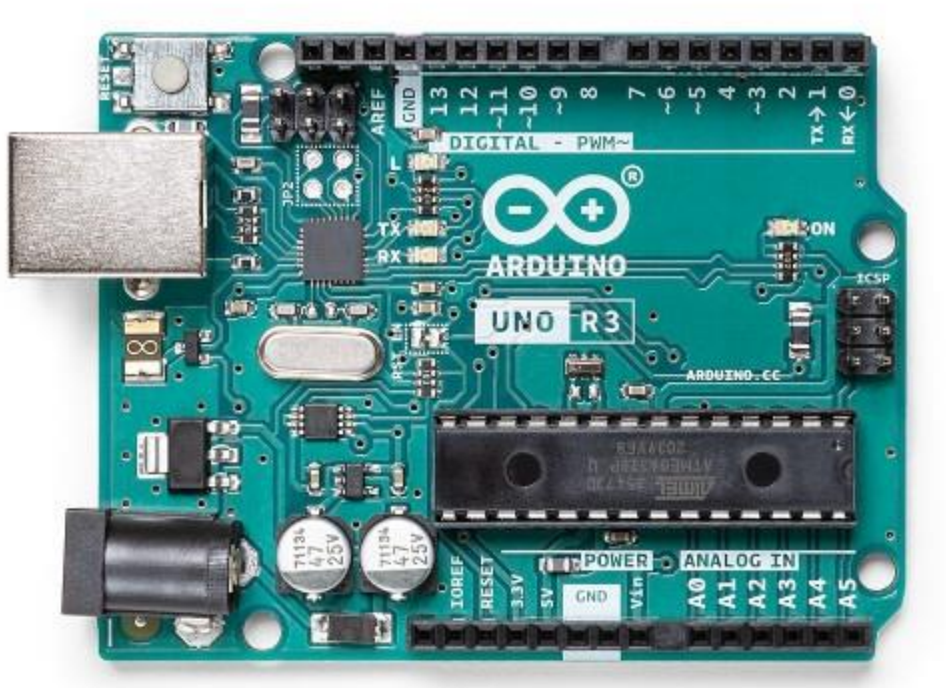


Figure 45 Arduino Uno Rev 3

Technical specifications:

Table 22 Technical specifications of Arduino Uno Rev3

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

Supplier: https://store.arduino.cc/arduino-uno-rev3

Electric linear actuator JSP005

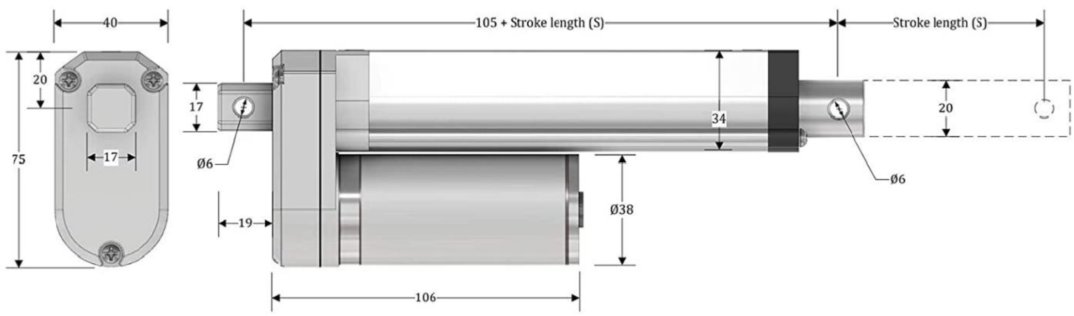


Figure 46 Electric linear actuator JSP005.

Technical specification:

Table 23 Technical specifications of electric linear actuator JSP005.

Brand Name	Justech
Color	White
Material	Aluminum
Protection level	IP54
Operating voltage	DC 12V
Operating current	0-4A
Rated power	20W
Load capacity	750N/160LBS

Retracted length	205MM
Stroke length	100MM
Speed	10MM/S

Supplier: https://www.amazon.com/Justech-Actuator-Industrial-Agricultural-Machinery/dp/B07W8N8X22

Optional suppliers:

https://www.linak.nl/producten/?gclid=Cj0KCQjwxdSHBhCdARIsAG6zhlX6yVnW6en6iu-gO4IkiIKxiFzj2PjpVqKRsy5Rci9Y3RSqW8lBJEQaAk1wEALw_wcB

https://wuxijdr.en.made-in-china.com/?gclid=Cj0KCQjwxdSHBhCdARIsAG6zhlW4vWM3lCymJ9ecE335ZEBTucrXyRKAG22b_ueJYEmg8-80HLKq6W4aAsJ5EALw_wcB

Power supply module L298N

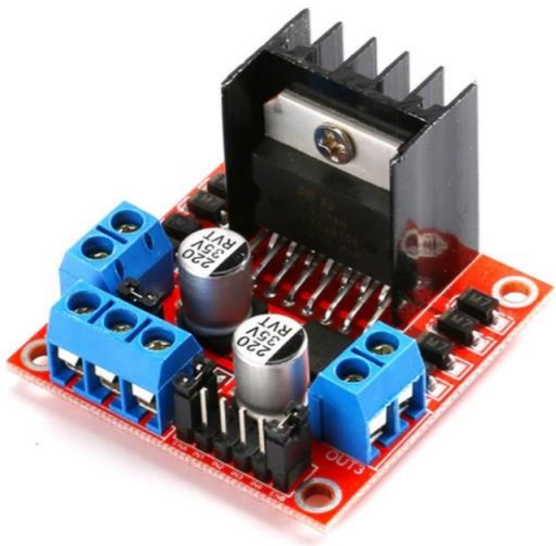


Figure 47 L298N motor driver.

Technical specification:

Table 24 Technical specifications of motor driver L298N

Power supply voltage	5V DC
Type	L298N
Motor voltage (supply to motor)	5 – 35V
Motor current	2A
Dimensions	43 x 43 x 27 mm

Supplier:

https://tecvoordeel.nl/product/l298n-motor-driver-module/?gclid=Cj0KCQjwxdSHBhCdARIsAG6zhlUiopj9Wd51n6SRDU3pdy06J1kqjZydt1V8mva45eooozyqZuQrcKkaAuEYEALw_wcB

Arduino Speaker

Figure 48 Arduino speaker.

Technical specification:

Table 25 Technical specifications of Arduino speaker.

Coil Resistance	8Ω
Sound Level	85dB
Rated Power	1W
Lead Length	150mm
Cone Material	Mylar
Dimensions	36 (Dia.) x 4.6mm
Diameter	36mm
Height	4.6mm

Supplier:

https://nl.rs-online.com/web/p/miniature-speakers/1176044/?cm_mmc=NL-PLA-DS3A-_-google-_-PLA_NL_NL_Passive_Components_Whoop-_-(NL:Whoop!)+Miniature+Speakers-_-1176044&matchtype=&pla-333378419216&gclid=Cj0KCQjwxdSHBhCdARIsAG6zhlUmvhEHsJbOM9u6JT6SKAvNrslUV5Z4gXnS-GrFV-GeGfUJmQ0qa68aAie6EALw_wcB&gclsrc=aw.ds

WS2812B LED strip

Figure 49 WS2812B LED strip

Technical specification:

Table 26 Technical specifications of Arduino speaker.

Operating Voltage Range	3.3 - 5V
LEDs	4 with 3mm diameter
LEDs Mounting holes	1W
Dimensions	Inside diameter: 36mm [1.41in] Outside diameter: 50mm [1.97in]

Supplier:

https://www.az-delivery.de/nl/products/kopie-von-rgb-led-ring-ws2812-mit-12-rgb-leds-5v-fuer-arduino?_pos=3&_sid=97c2eddcb&_ss=r#description

Grove-Water Atomization Module

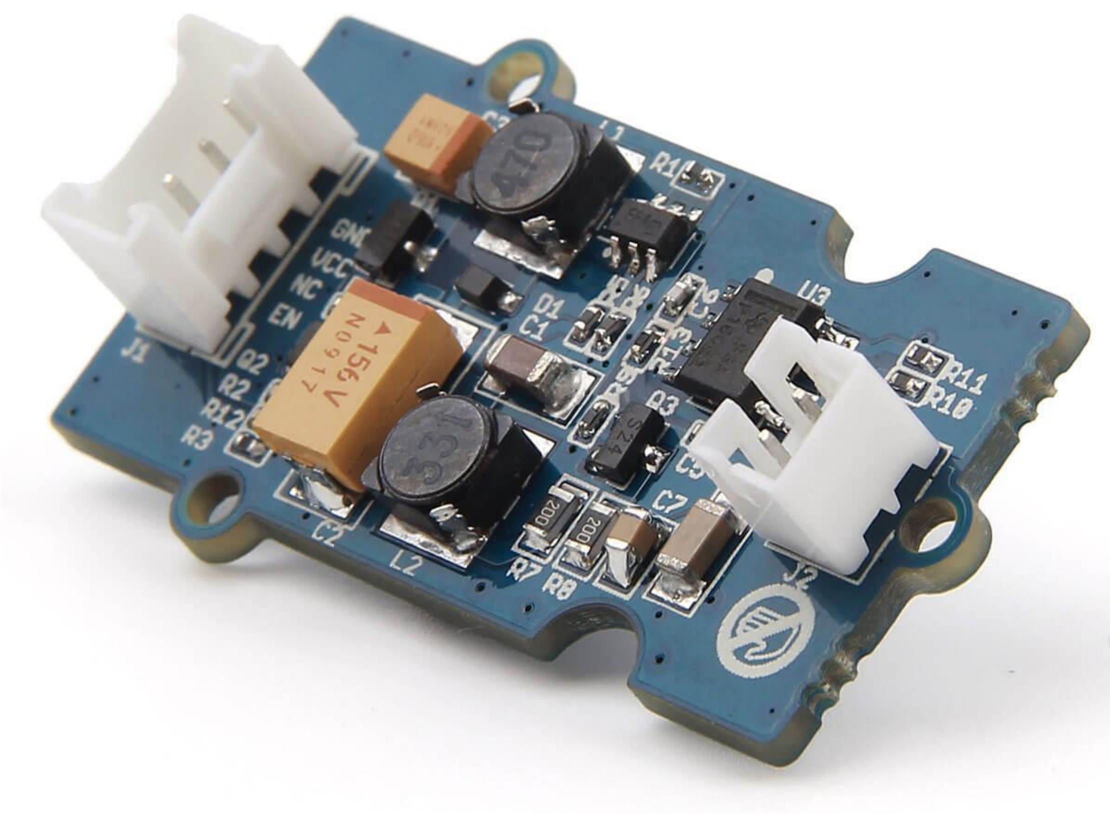


Figure 50 Grove-Water Atomization Module

Technical specification:

Table 27 Technical specifications of Arduino speaker.

Working voltage	5V
Ripple voltage (maximum power)	100mV
Maximum power	2W
Maximum output voltage	+65 V (+/-5 V)
Working frequency	105 ± 5 kHz
Chip	ETA1617 NE555

Supplier:

https://secure.reichelt.nl/nl/nl/arduino-grove-ultrasone-waterverstuiver-v1-0-eta1617-grv-o2-atomiz-v1-p191218.html?&nbc=1

Ultrasonic Sensor HC-SR04

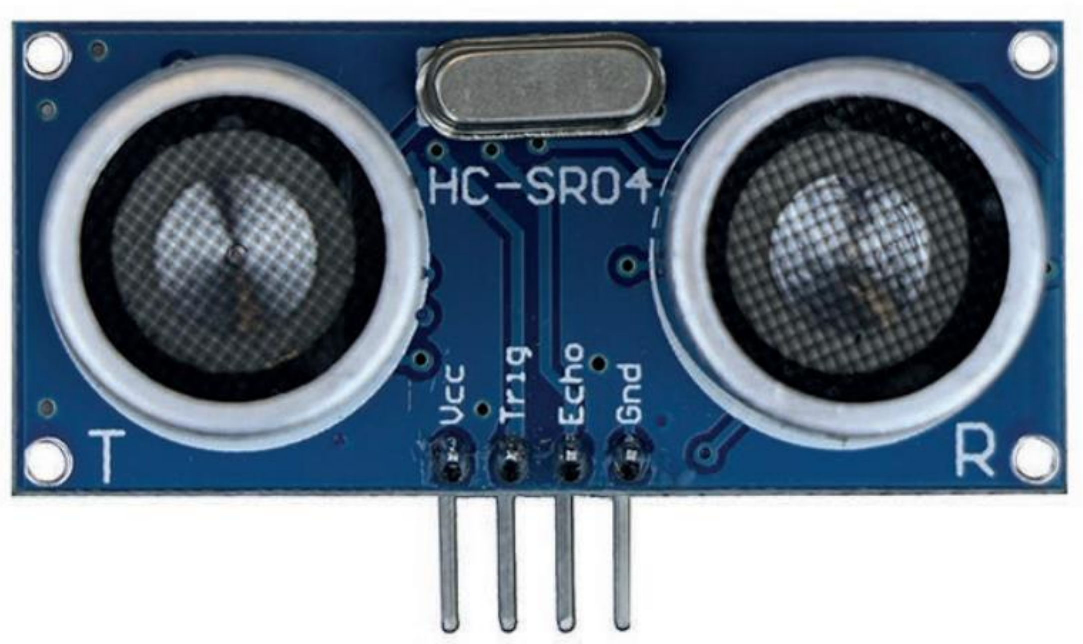


Figure 51 Ultrasonic Sensor HC-SR04

Technical specification:

Table 28 Technical specifications of Arduino speaker.

Working Voltage	DC 5 V
Working Current	15mA
Working Frequency	40KHz
Detect Range	2CM-4M
Measuring Angle	-30°-30°
Trigger Input Signal	10uS TTL pulse
Echo Output Signal	Input TTL lever signal and the range in proportion
Dimension	45*20*15mm

Supplier:

https://nl.rs-online.com/web/p/bbc-micro-bit-add-ons/2153181/

System cost

Table 29 lists the total cost of building an automatic mussel display system prototype, the quantity and cost of each component are included.

Table 29 The system total cost

Component	Quantity	Unit price
Arduino Uno Rev3	1	20.00€
Electric linear actuator JSP005	1	38.99€
L298N motor driver	1	4.39€
Arduino speaker	1	4.34€
WS2812B LED strip	1	4.79€
Spray system: Grove water atomization module	1	9.14€
Ultrasonic Sensor HC-SR04	1	2.30€
Total cost amount		83.95€