1 Client Software

1.1 Framework of the client software

The client software has three main functions, through this APP users can create a new project, load an old project and analyse the existed data. The Framework is shown in Illustration 4.4 below:

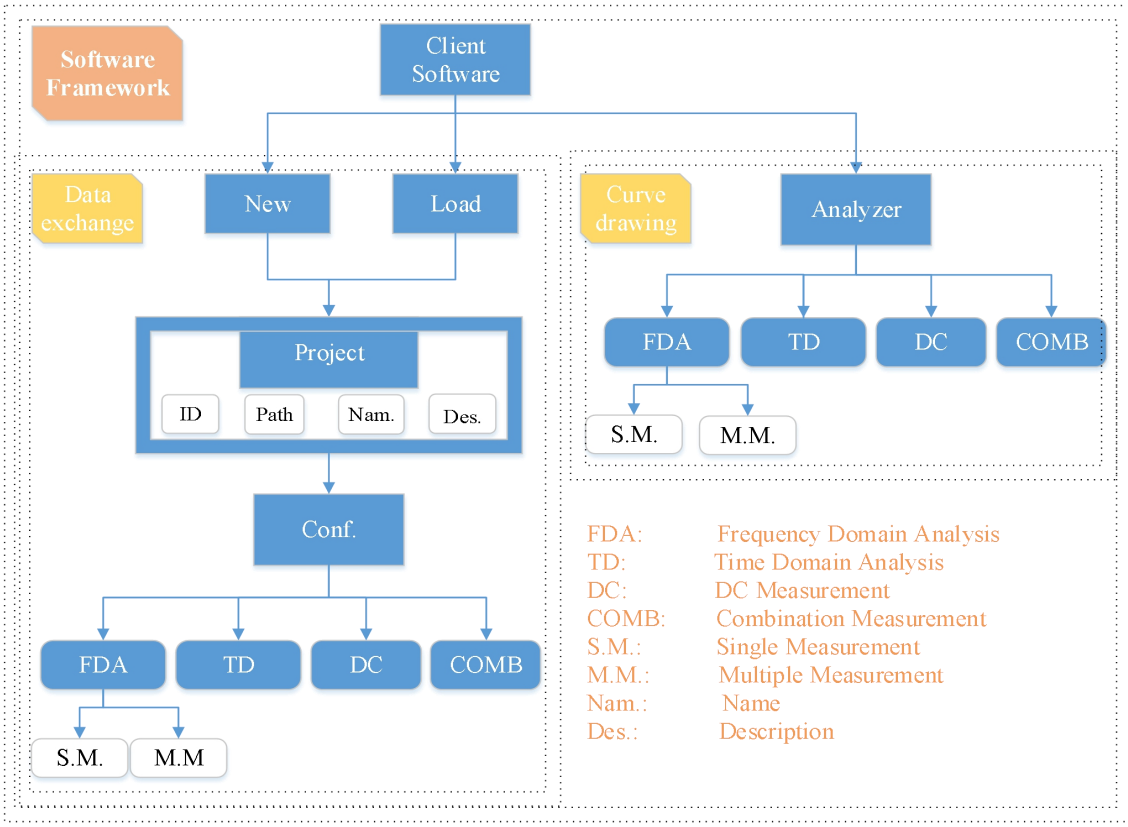


Illustration 4.4 The Framework of the client software

There are four attributes in a project. When users create a new project, the system opens a new form as Illustration 4.5 named “NewProject”, in this form, users can input the Project Name, Folder Path, and Description for the project. Simultaneously, the system automatically creates an ID number for the project, which is used by Web Server, MCU and client software to identify it.

In the Folder Path, a Folder with the Project Name is created. The folder also has four folders, FDA, TD, DC, and Comb, which are used to store the data of an experiment and pictures of curves. The details will be introduced in the 4.6 File System.

When users select the project (New Project or Load Project), they should select the parameters for COM and Sever, then connect with microcontroller by serial port and Web Server by Wi-Fi to ensure communication. After that, four models, Frequency Domain Analysis (FDA), Time-domain Analysis (TD), DC Measurement (DC), and Combination (Comb), can be selected by users.

If the users select Data Analyzer, they can plot the curves of FDA, TD, DC, and Comb from historical data.

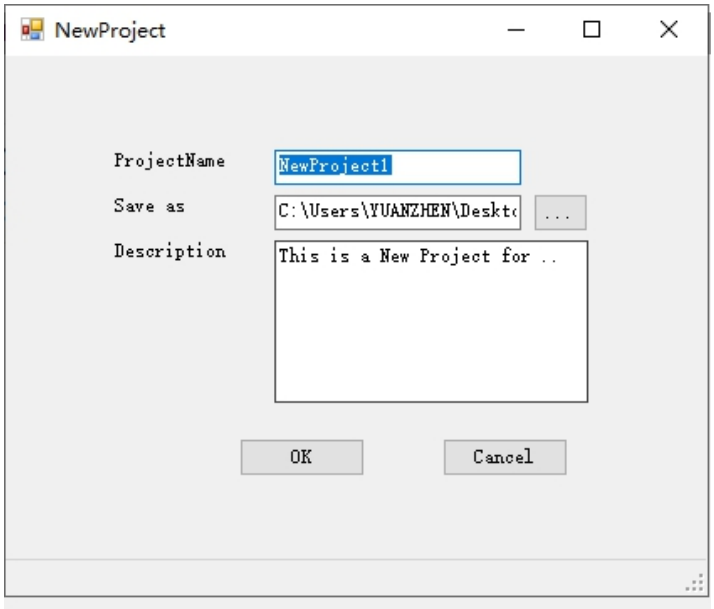


Illustration 4.5 The Form, NewProject: Makeup of ProjectName, SavePath and Description

Each model has a start and a stop button: when users click the start button, the client Application will send parameters to the MCU, and then the experiment starts. When a user clicks the stop button, the experiment will be stopped right away.

The following Illustration 4.6 describes the processes of the client Application:

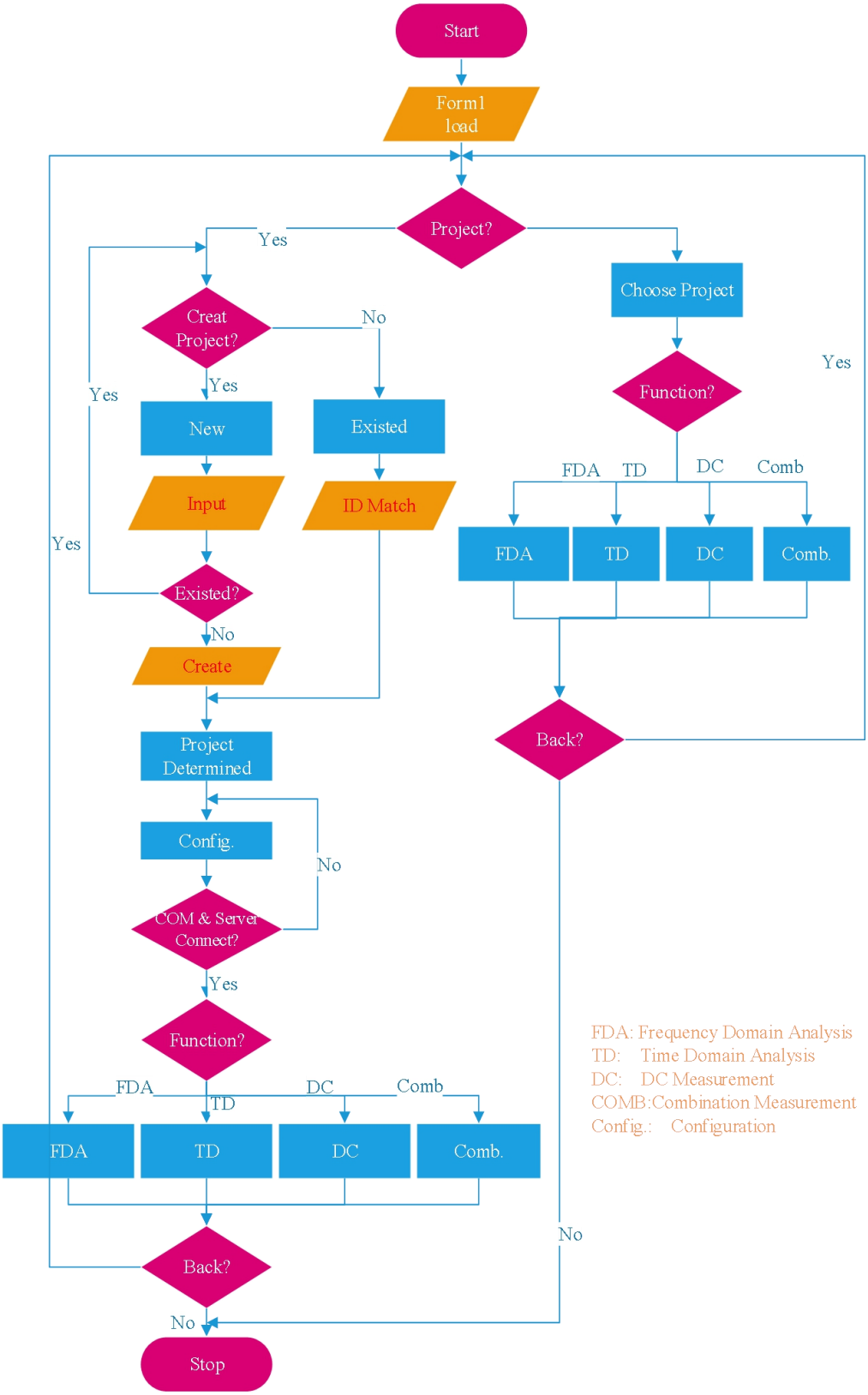


Illustration 4.6 The Flow Chart of the client software

1.2 Configuration

In the interface of Configuration, there are two main parts, Serial COM and Server Configuration, they are shown in Illustration 4.7 below:

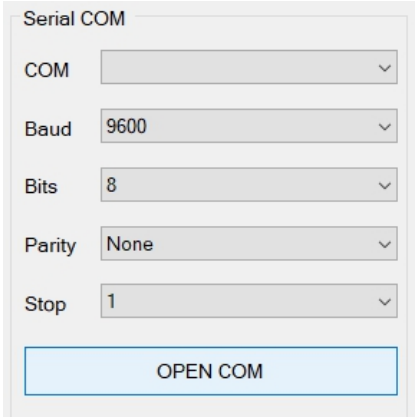


Illustration 4.7 Serial COM

To communicate with the MCU successfully, this client Application was adapted to a serial port, this port has four attributes as shown in Illustration 4.7, which are COM, Baud, Bits, Parity, and Stop. In this system, the parameters are:

Baud: 100000 Bits: 8 Parity: None Stop: 1

For the connection between the software and the MCU, there are three statuses for them in Sheed 4.3.

Sheed 4.3 Status of MCU and software

Connect	MCU	Message
Successful	unused	MCU is already!
successful	working	MCU is busy!
unsuccessful	\	False COM!

When the client Application connects with the MCU successfully and MCU is unused, the message box will show “MCU is already!”;

Conversely, when the client Application connects with the MCU successfully but the MCU is working, the message box will show “MCU is busy!”;

When the client Application connects with the MCU unsuccessfully, the message box will show “False COM!”.

Due to the Web Server’s successful communication, this client Application used TCP protocol. This Web Server has two attributes as **Illustration 4.8**, IP Address, Port.

Here the parameter are:

IP Address: http://192.168.191.1 Port:8080

Thus, when the client Application connects with Web Server successfully, the message box will show “connect server successfully”.

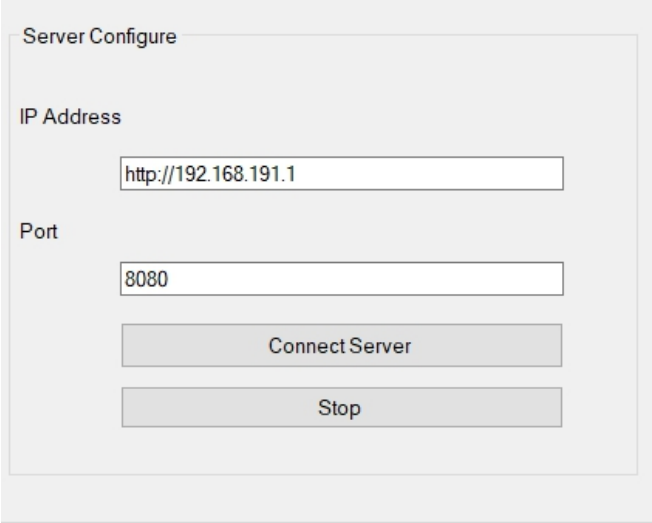


Illustration 4.8 Server Configuration

1.3 Frequency domain Analysis

In this Interface, users can operate two areas, AC Control as Illustration 4.10 and Experiment Control as Illustration 4.11, and view the Real-time curve plot zone as Illustration 4.12. This function can show the Bode plot includes Amplitude-Frequency

curve and Phase-Frequency curve, as well as the Nyquist plot. Below Illustration 4.9 is the data flow of FDA.

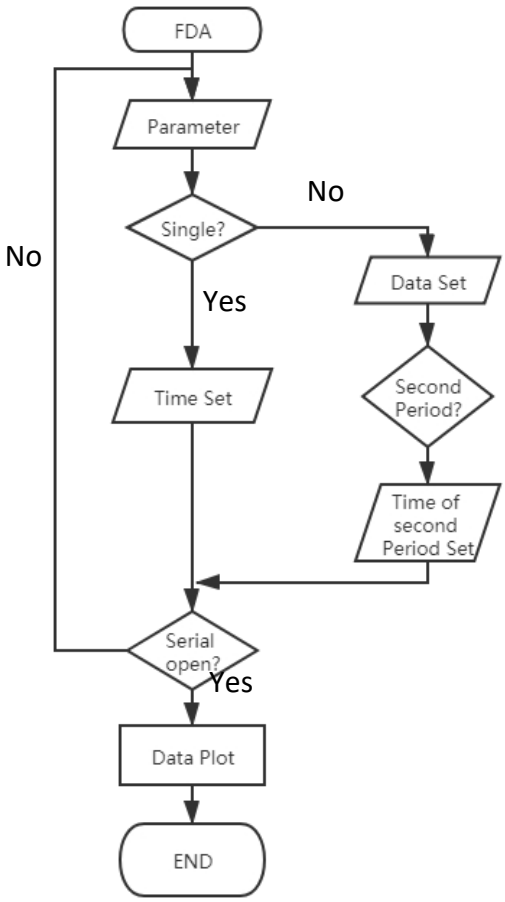


Illustration 4.9 Data flow of FDA

1.3.1 AC Control and Experiment Control

In this section, users can set the parameters for Sweep Frequency, Amplitude, ODR (output data ratio), RTIA, DFT, and Sweep Points. Illustration 4.10 is the UI, and Sheed 4.4 shows the range of the parameters.

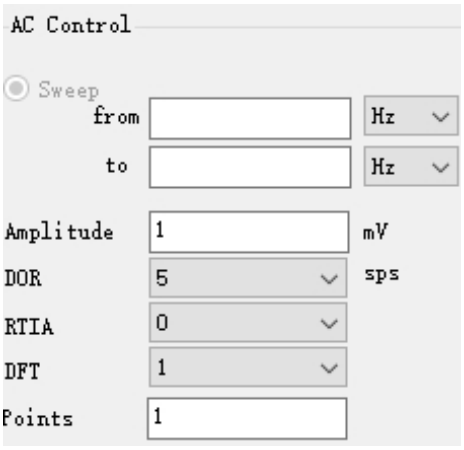
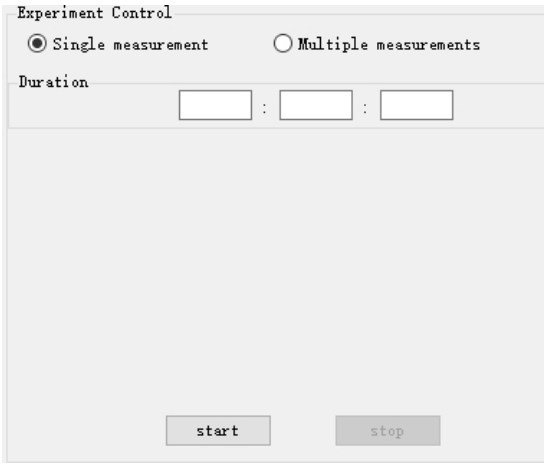


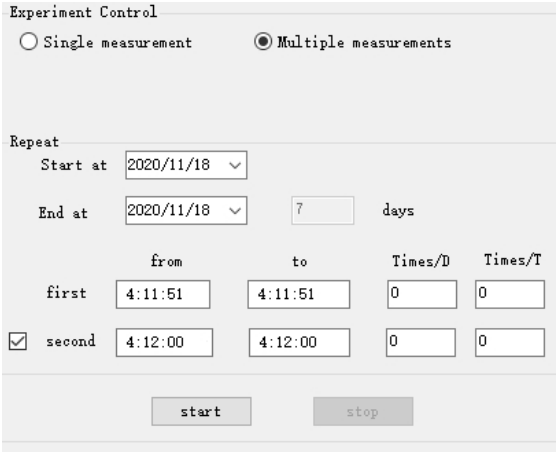
Illustration 4.10 AC Control of FDA

Sweep from	<200kHz
to	<200kHz
Amplitude	<607 mV
ODR	1-200 sps
RTIA	0-8
DFT	0-12

Sheed 4.4 Range of the parameters



(a) Single Measurement



(b)Multiple Measurement

Illustration 4.11 Experiment Control of the FDA:

(a) Single Measurement, and (b) Multiple Measurement

In the part of Experiment Control, users can select two models, Illustration 4.11(a) Single measurement and Illustration 4.11(b) Multiple measurement, Sheed 4.5 Range of the parameters in Experiment Control shows the Range of Single/Multiple Measures :

Single measure	**Multiple measure**	**Duration**	**Start Datum**	**End Datum**	**Repeat days**	**From**	**to**
True/False	False/True	<86400	year/month /day	year/month /day	1-7	Hour:Minute :Second	Hour:Minute :Second
repeat (Times/ Period）	**repeat (Times/Cycle）**	**Second Period**	**From**	**to**	**repeat (Times/ Period）**	**repeat (Times/ Cycle）**	
0-5	0-5	true/false	Hour:Minute: Second	Hour:Minute: Second	0-5	0-5	

Sheed 4.5 Range of the parameters in Experiment Control

The parameters in Illustration 4.10 and Illustration 4.11 are listed below:

Sweep from: Start frequency of the experiment.

to: Stop frequency of the experiment.

Amplitude: The peak-peak voltage of the input signals.

ODR (Output data ratio): The Acquisition rate of the ADC (Analog-to-Digital Converter).

RTIA (Trans resistance amplifier): As the output signal is current in microamperes, a trans resistance amplifier is used to convert the current into voltage and amplify the signal, so as to test the signals more efficiently.

DFT (Discrete Fourier transform): The number in the textBox is the N of components in the formula 4-2:

$$\hat{x}[k] = \sum_{n=0}^{N-1} e^{-i\frac{2\pi}{N}nk} x[n], k = 0,1,..., N-1. \qquad \text{formula 4-2}$$

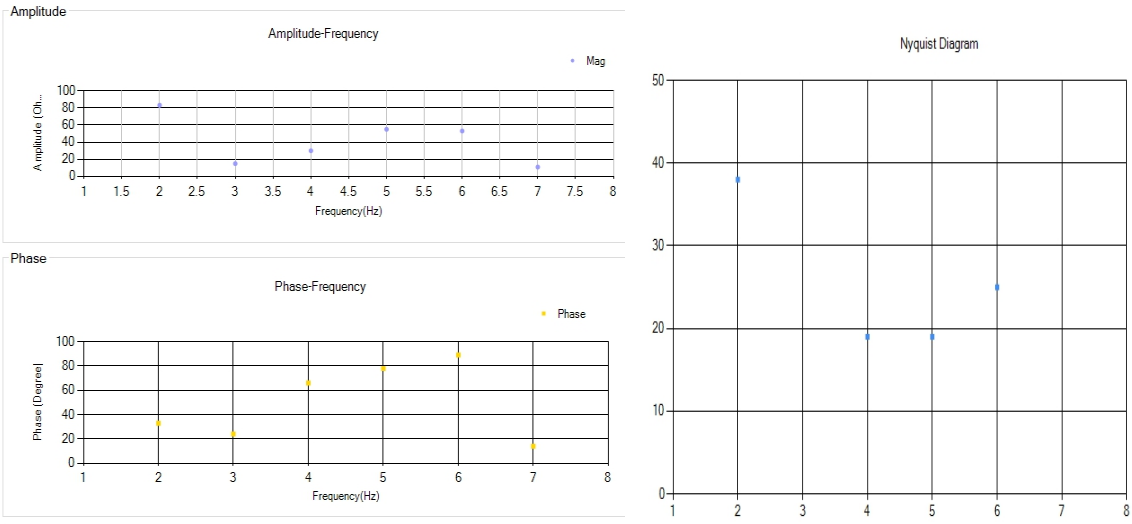
Points: The number of points in a curve.

Single Measurement: This measurement is only needed to set the duration time for the experiment and the duration time is not too long, mostly 5 minutes.

Multiple Measurement: Before setting of the parameters, the users should give the start date and stop date, but the difference of dates can not be more than seven days. Moreover, this measurement can be divided into two periods: At the first period, the start time and stop time are necessary, then the users can select the number of repeat times per period and per cycle. The repeat times per period should be less than 1 time/hour and the repeat times per cycle should be less than 5 times, which means for the 1 time per hour, the software can plot a maximum of 5 curves.

When the users want to continue the experiment after a short pause, they can check checkBox and set the parameter as the first period. But the stop time should not be more than 24 hours.

1.3.2 Plot Zone



(a) Bode plot (b) Nyquist plot

Illustration 4.12 Plot zone: (a) Bode plot (b) Nyquist plot

The plot zone is shown in Illustration 4.12, and Real-time curves will be drawn in the plot zone. Users can store curves (graphs), Amplitude-Frequency curve is named as “bode_amp.png”, Phase-Frequency curve named as “bode_pha.png”, Nyquist curve named as “Nyqst.png”. All of the pictures are saved in FDA folder, when the pictures are saved, the message box will show “you have stored this picture”.

1.4 Time domain Analysis

In this Interface, operations are similar to Frequency domain Analysis, but in Time Domain Analysis, users can only select a Single measurement. Users can also operate two areas, AC Control as Illustration 4.14 and Experiment Control as Illustration 4.12 (a), and also view the Real-time curve plot zone as Illustration 4.15. Moreover, the following Illustration 4.13 is the data flow of TD.

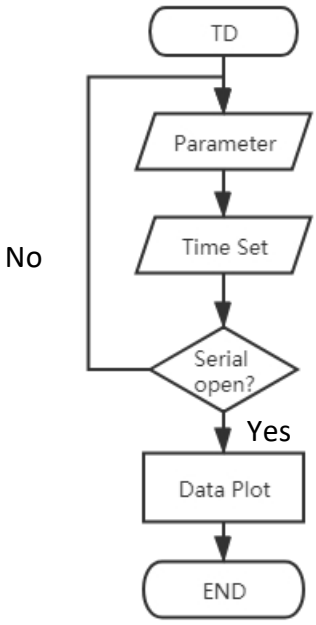


Illustration 4.13 Data flow of TD

Here, the frequency is fixed, so the textbox after “Frequency” is to set the initialisation frequency. The settings of other parameters are the same as Frequency Domain Analysis and its Single Measurement.

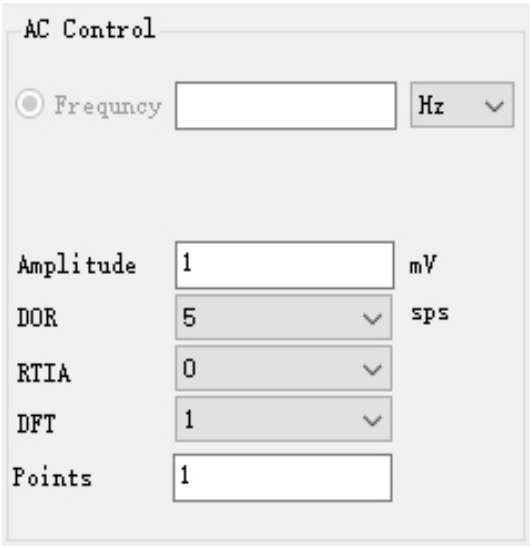


Illustration 4.14 AC Control of TD

Frequency	<200 kHz
Amplitude	<607 mV
ODR	1-200 sps
RTIA	0-8
DFT	0-12
Sweep points	0-200
Single Measurement	TRUE
Duration	<86400

Sheed 4.6 Range of the parameters in TD

Sheed 4.6 is the range of the parameter of AC Control parameter. Also, the Experiment Control of TD is the same as FDA Illustration 4.11 (a).

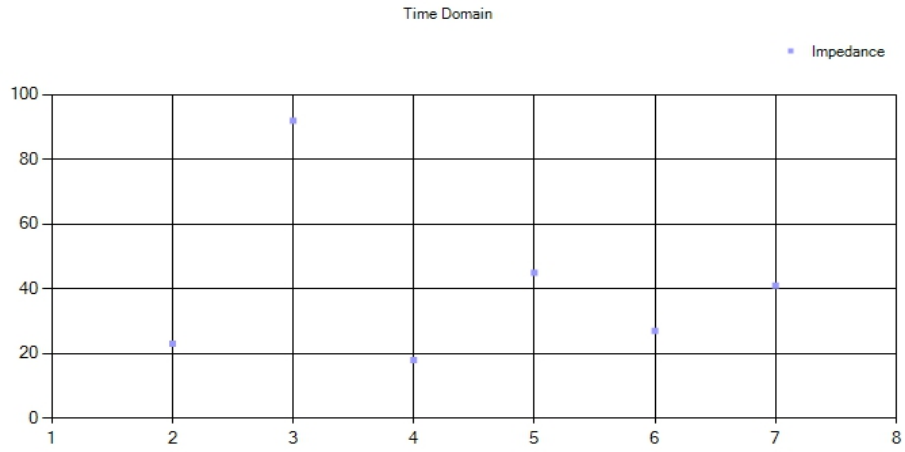


Illustration 4.15 Plot zone: Time-Impedance curve

In the Illustration 4.15 Plot zone: In the Time-Impedance curve, the chart displays the relationship between time and Impedance. Users can also store curves, Time-Impedance curve is named as “TD_Wave.png”. All of the graphs are saved in

the TD folder. When the grapha are saved, the message box will show “you have stored this picture”.

1.5 DC Measurement

In this Interface of the DC Measurement, there are two parts that users can operate, namely, DC Control as Illustration 4.17 and U-I-R as Illustration 4.18, and observe the Real-time curve plot zone as Illustration 4.19. Besides, the data flow of the TD is shown in Illustration 4.16.

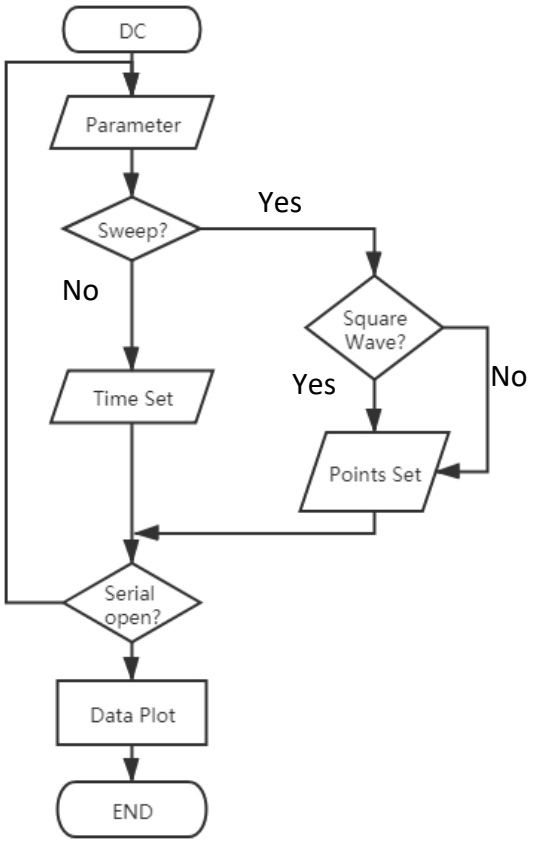


Illustration 4.16 Data flow of DC

The settings of the parameters are shown below:

Start at: The start voltage of the input signals

Amplitude: This is the maximum voltage of the input signals: Square wave ,Triangle wave or a fixed voltage.

There are two models for the input signals:

Sweep: Select the shape of the input signals, Square wave or Triangle wave at first, set the amount of the points in a wave by moving the slide.

Duration: Set the time of duration and the times of measurement during the time.

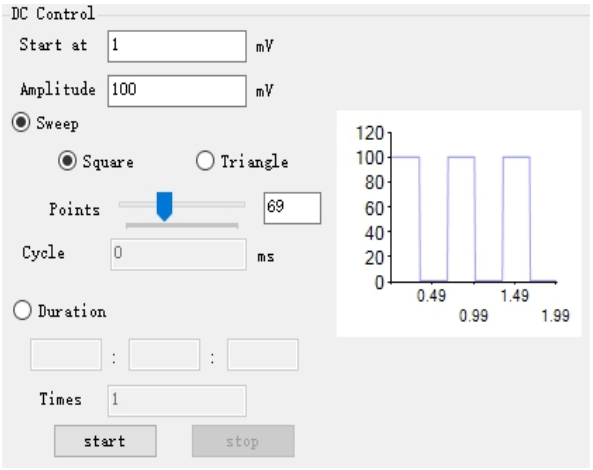


Illustration 4.17 DC Control of DC

Start at	<607 mV
Amplitude	<607 mV
Sweep	TRUE/FALSE
Square	TRUE/FALSE
Triangle	FALSE/TRUE
Sweep points	0-200
Duration	FALSE/TRUE
Duration Time	<86400
repeat	0-5 times

Sheed 4.7 Range of the parameters in DC

This part also has two models, the Sweep model and the Duration model. Before users select the model, they should set the start voltage and peak voltage. The Sheed 4.7 is the range of the parameters in the DC.

Sweep model: At first, users should select Sweep waves (Square wave or Triangle wave), then set the sweep points. In the right chart of the Illustration 4.17, users can preview the wave, and know the wave's Cycle.

Duration model: Users can set the time from 0 second to 86400s, but mostly not more than 5 min, and they can set repeat times for each Measurement.

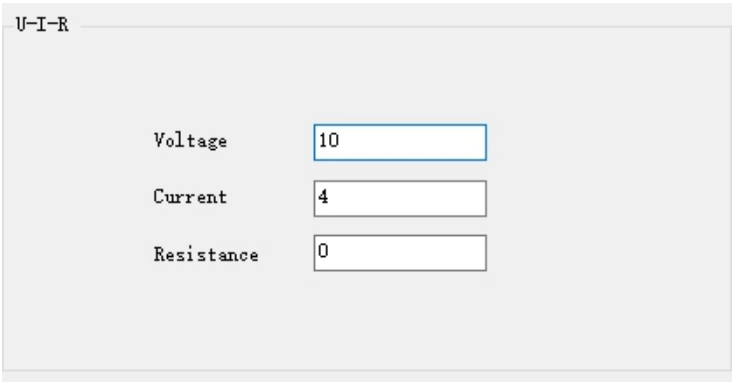


Illustration 4.18 Real time data (Voltage, Current, Resistance)

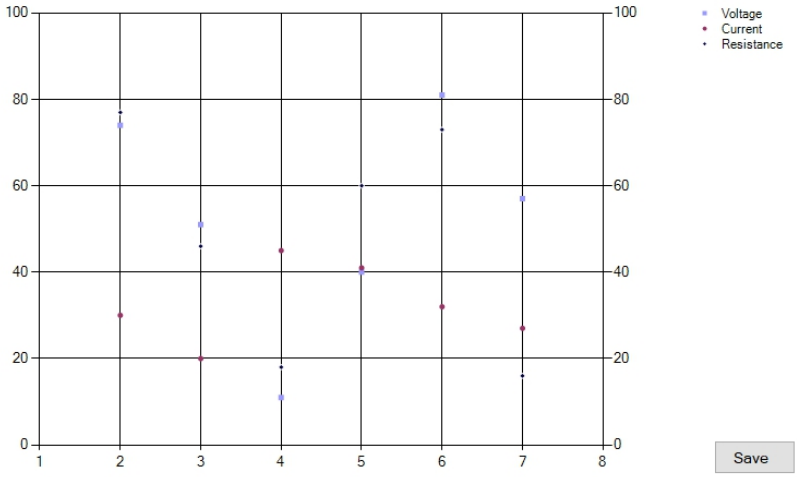


Illustration 4.19 Real time curve (Voltage, Current, Resistance)

Illustration 4.18 Real-time data (Voltage, Current, Resistance) shows the Real time status of Voltage, Current, Resistance.

And Illustration 4.19 Real-time curve (Voltage, Current, Resistance) shows the Real time curve of Voltage, Current, and Resistance in a graph.

Users can also store these curves here, the U-I-R curve is named as "U_I_R_Wave.png". All of the graphs are saved in the DC folder. When the graphs are saved, the message box will show "you have stored this picture".

1.6 Combination Measurement

In the Combination Interface, there are three steps: AC Control as Illustration 4.21, DC Control as in Illustration 4.22(a), Temperature Measurement as in Illustration 4.22(b). The plot zone is the same as FDA, in Illustration 4.12, and the data flow of this part is described in Illustration 4.20

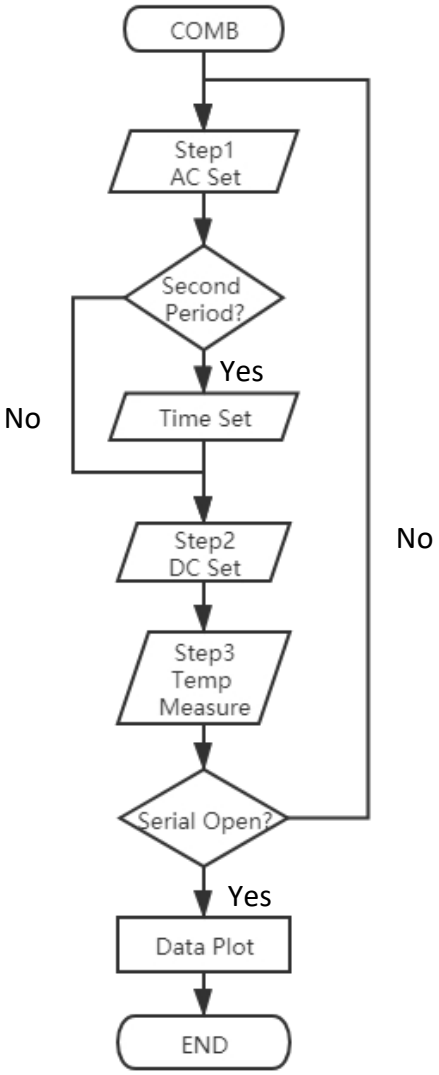


Illustration 4.20 Data flow of Combination Measurement

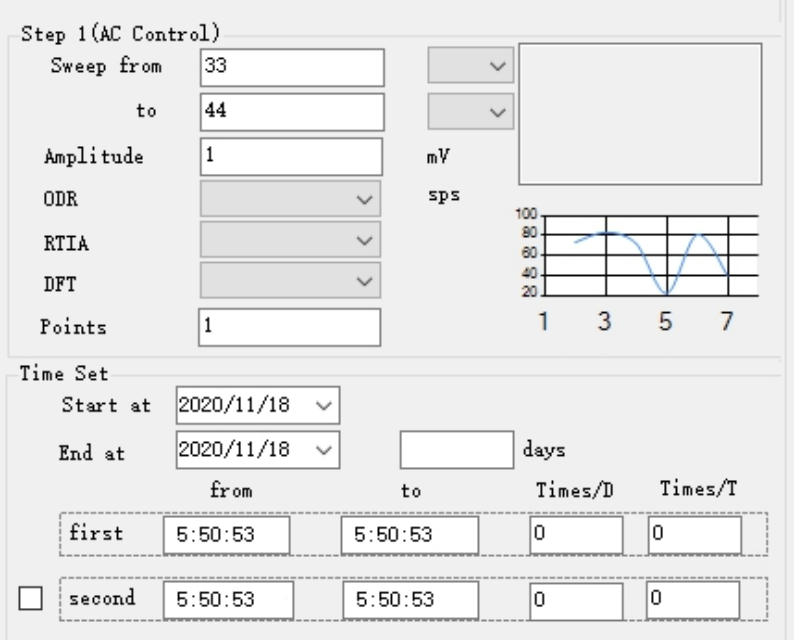


Illustration 4.21 Step1(AC Control) and Time Set

Sheed 4.8 Range of the Parameters in Step1 of AC Control in Comb

Sweep from	<200kHz
to	<200kHz
Amplitude	<607 mV
ODR	1-200 sps
RTIA	0-8
DFT	0-12
Sweep Points	0-200

In the step 1, the user operates the same as Multiple measurements in the FDA. Also. The right textBox and Chart can show the temperature of experiment. Sheed 4.8

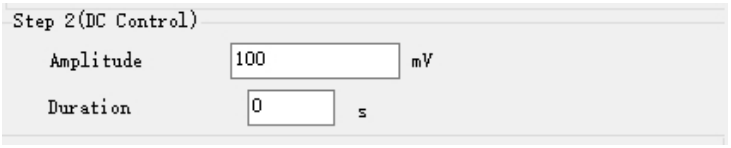
shows the range of the AC Control and Sheed 4.9 shows the range of the Time Set in the Combination measurements.

Sheed 4.9 Range of the Parameters in Step1 of Time Set in Comb

Start Datum	**End Datum**	**Repeat days**	**From**	**to**	**Repeat (Times/Period）**
year/month/day	year/month/day	1-7	Hour:Minute:Second	Hour:Minute:Second	0-5
Repeat (Times/Cycle）	**Second Period**	**From**	**to**	**repeat (Times/Period）**	**repeat (Times/ Cycle）**
0-5	true/false	Hour:Minute:Second	Hour:Minute:Second	0-5	0-5

As Illustration 4.22 shows: In the step 2, users need to set the peak amplitude of the DC signal and the duration time , which is always very short, often as 30-60s. This operation is to energize the electrode so that the silver electrode undergoes a chlorination reaction to generate a silver chloride electrode [Eas00]. The method is shown in Illustration 4.23. Furthermore, the chemical equation of this chemical equation is shown in the formula 4-3.

In the step 3, users have only to choose if the experiment measure temperature or not.



(a) Step 2

(b) Step 3

Illustration 4.22 Step2 and Step 3 of Combination Measurement

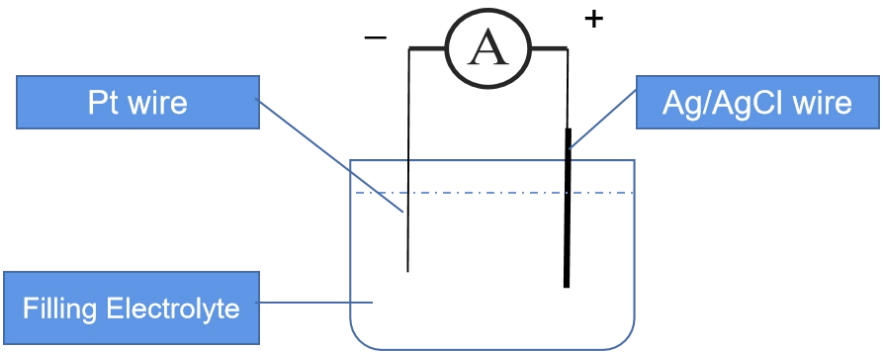


Illustration 4.23 Generating of Ag/AgCl Electrode

$$AgCl(s)+Ag(s)+e^{-} \leftrightarrow Ag(s)+e^{-}+Cl^{-}+Ag^{+}$$ formula 4-3

The plot zone of Combination is the same as the FDA as in Illustration 4.12, and users can also store curves, Amplitude-Frequency curve as the FDA experiment.

1.7 Data Analyzer

When users select Data Analyzer, this system will show the data from the .txt file in the selected project. The following Illustration 4.24 is the menu of the Data Analyzer.

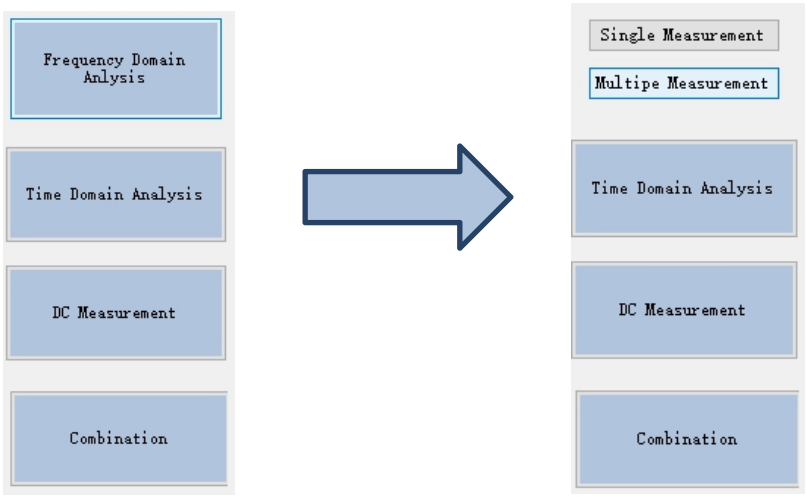


Illustration 4.24 The menu of Data Analyzer

The FDA also hat two models: Single Measurement, and Multiple Measurement. Furthermore, these plot zones are the same as the plot zones of the experiment. In this function, the users can simultaneously load more than one project, but the data of the project can not be too large.

1.8 Other areas

1.8.1 Main menu

When users click the File, they can see a drop list as Illustration 4.25

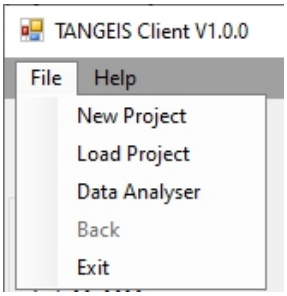


Illustration 4.25 Drop list of Main menu

The main menu contains New project, Load Project, Data Analyzer, Back, Exit and Help. Once users select a function like New project, Load Project or Data Analyzer,

“Back” and the other two function can not be used. Only when the experiments are stopped, can users select “Back”and then can select all the functions again. “Exit” can shut the client Application down. “Help” shows an introduction to the client software.

1.8.2 Time Display

Illustration 4.26 Time Display

Illustration 4.26 can always show time, when the users click this block, the software will send actual time to the MCU, to correct its system time.

1.8.3 Data Received Area

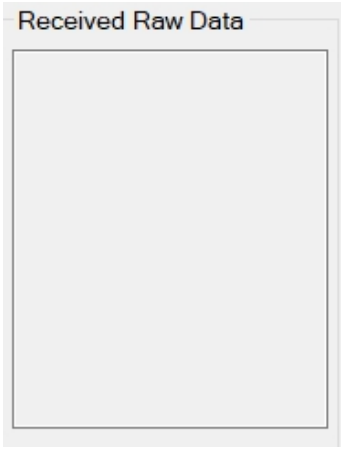


Illustration 4.27 Data Received Area

This Textbox in Illustration 4.27 shows the raw data from the MCU and the experiment’s conditions.

1.8.4 Download Button

Illustration 4.28 Download Button

If the user selects “load project”, this green arrow button as in Illustration 4.28 will appear on the top left of the form. When this button is clicked, the user can obtain the historical data from the Web Server.

2 Web Server

This server is programmed by Node.js and consists of two parts: ID match, and Data receive.

2.1 Before Running

The Server is based on Node.js, so before running it, the computer needs to install JDK: Download:https://www.oracle.com/java/technologies/javase-downloads.html

Node.js:Download: https://nodejs.org/en/download/

Npm(Node.js Package Manager): In command Prompt input: $ npm install npm@latest -g

Express: In command Prompt input: $ npm install -g express-generator

2.2 Running of Server

As the users create a new project, the ID number will be generated automatically. So when they connect to the server, the ID number will be sent to the IT, then creates a folder named by this number as in Illustration 4.29. If the folder already exists in the file system, the server can directly match the ID number and receive the data.

Illustration 4.29 Folder named by ID number

After the connecting with the server, it can receive the data as Illustration 4.29 and publish those data in the file “EIS.html”, and then the users can use the Front-End (Website and Mobil Device) in 4.5 Front-End (Website and Mobil Device) to observe the process at http://192.168.192.1.

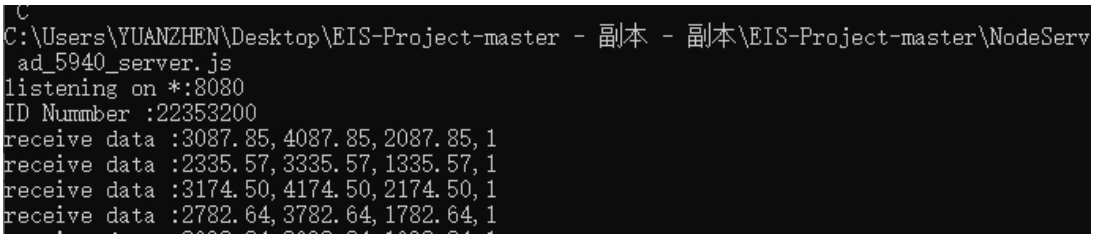


Illustration 4.30 Data receive

3 Front-End(Website and Mobil Device)

The opposite of the Web Server, the Website and Mobil Device (like a smart phone or tablet) are regarded as the client in the system. This front-end is programmed in Html5 and Java Script. Illustration 4.31 shows the four functions in the menu that match the client software’s primary function.

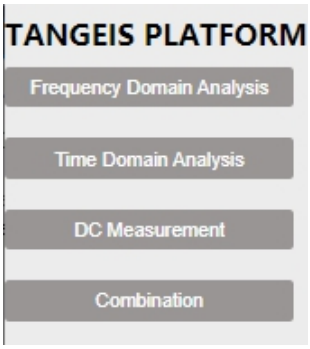


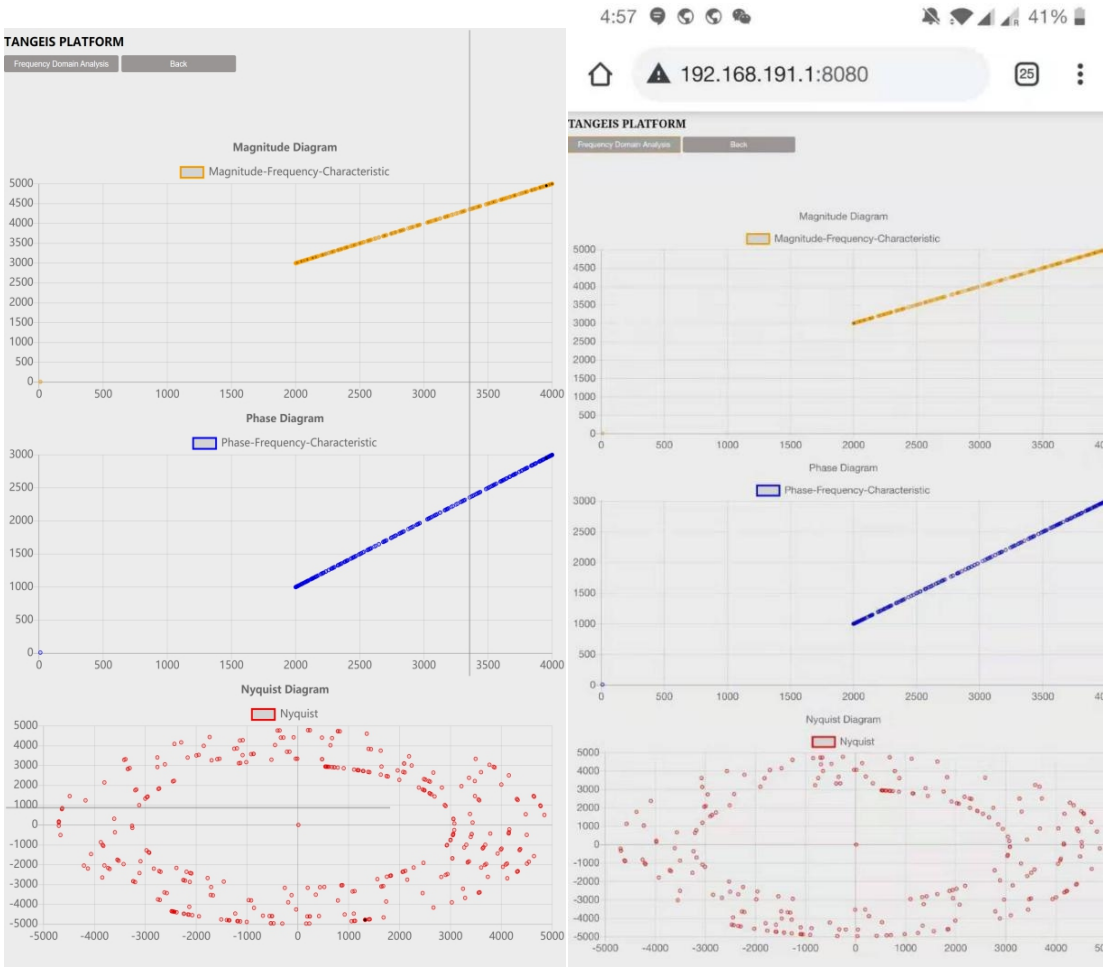
Illustration 4.31 Menu of the front-end

And the following Illustration 4.32 shows the EIS result in the browser of a PC (a) and a Smart phone (b).

And the input signals are in theformula 4-4 :

$$y_1 = 3000 + 1000 * \sin(2 * 3.14 * i * 1000),$$
$$y_2 = 4000 + 1000 * \sin(2 * 3.14 * i * 1000),$$
$$y_3 = 2000 + 1000 * \sin(2 * 3.14 * i * 1000).$$

formula 4-4



(a) In PC

(b) In Smart phone

Illustration 4.32 Testing results of front-end (a) in PC (b) in Smart phone

4 File System

To categorize and store experimental data, this system has established a file system for this purpose. The file system is divided into two parts: one part is in the client software, which collects the data and experimental parameters in the form of .txt. The other part is in the Web Server, and this part is only used to store the data from the MCU.

When the user creates a project, the ID_Information.txt will simultaneously be created. This document stores the ID Number, Project Name, Save path and Description of the project. The following Illustration 4.33 is an example of the ID_Information.txt.

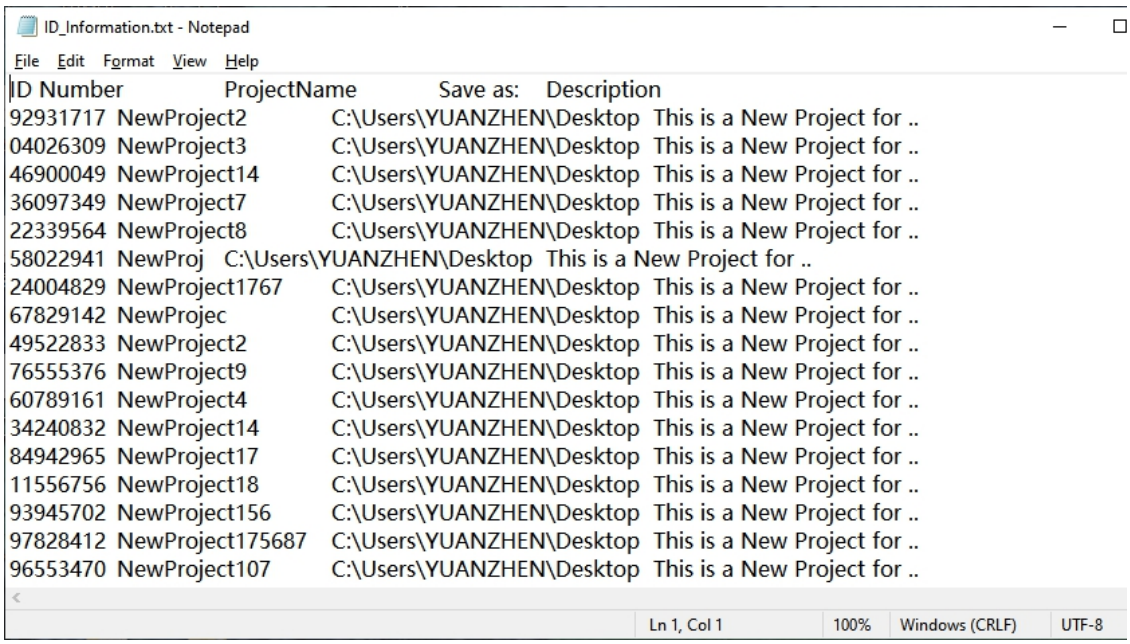


Illustration 4.33 Example of ID_Information.txt

4.1 File system in client software

The NewProject1(ID 22353200) is used as the example, and this project includes four sub-folders and a ReadMe.txt (as Illustration 4.34 shown): FDA, TD, DC, and Comb.

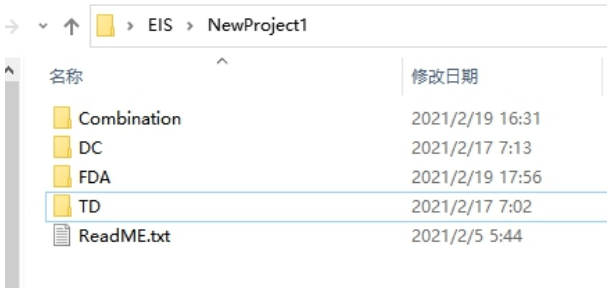
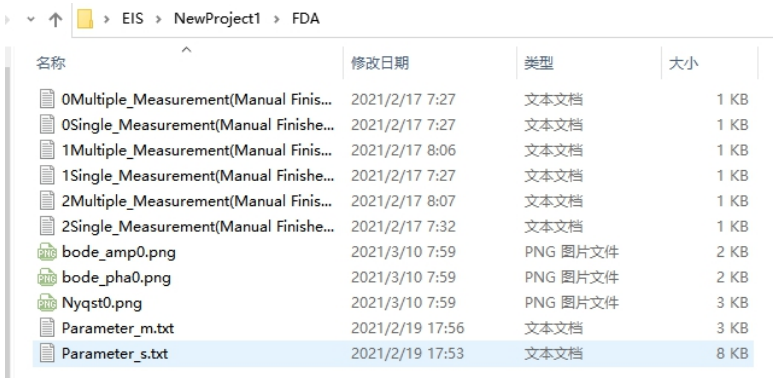
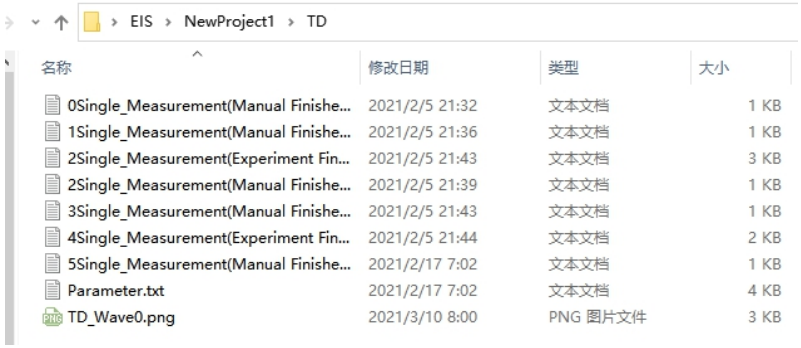


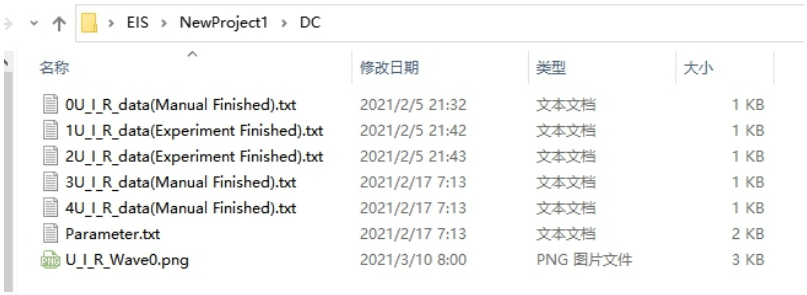
Illustration 4.34 Folder of NewProject1



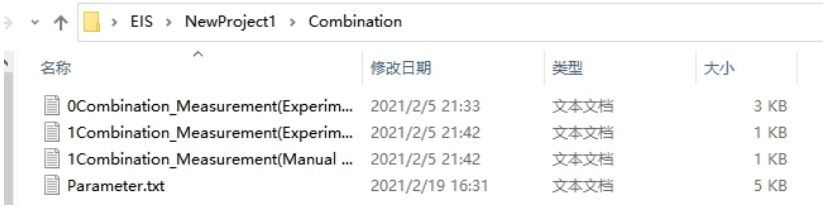
(a)



(b)



(c)



(d)

Illustration 4.35 Sub-folders of NewProject1: (a)FDA (b)TD (c)DC (d)Comb

When the experiment finishes, the data will be stored in the .txt with the message “Experiment Finished”. If the users stop the experiment before it finishes, the data are saved with “Manual Finish”. The pictures of the curves are also saved from the figure in those sub-folders as in 3.3 Client Software previously mentioned. Additionally, the parameters are saved in Parameter.txt when the experiment starts. Illustration 4.35 is an example of the DC in NewProject1:

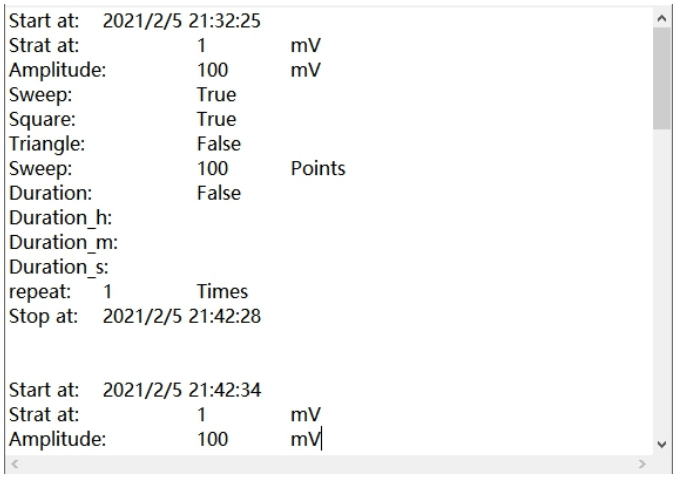


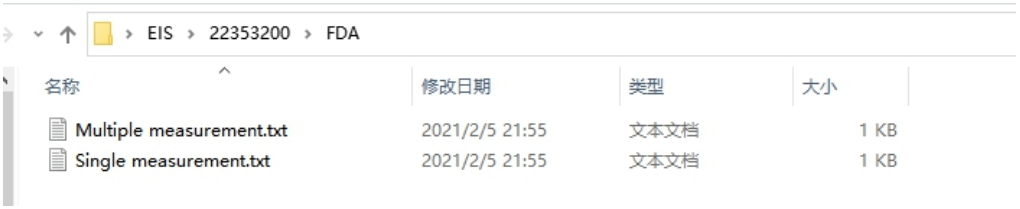
Illustration 4.36 Parameters of DC in NewProject1

In Illustration 4.36, this Parameter.txt shows that the first experiment started at 2021/2/5 21:32:25 and stopped at 2021/2/5 21:42:28, and the values between the two time points are its parameters.

4.2 File system in Web Server

The File system in Web Server is relatively simpler than it in client software. Here, the project is named the ID number (22353200) and includes four sub-folders. Illustration 4.37 shows the folder of 22353200 :

Illustration 4.37 Folder of 22353200(NewProject1)



(a)

(b)

(c)

(d)

Illustration 4.38 Sub-folders of 22353200(NewProject1): (a)FDA (b)TD (c)DC (d)Combination

This file system stores only the experimental data without the parameters. The client software system can then download those data from the Web Server, but then the new .txt will not cover the documents in the software's folders. Thus, the user can obtain historical data and compare them with exited data.