

## Design of Web-based Real-time Control Laboratory for Diversely Located Test Rigs

W. S. Hu \*. G. P. Liu\*. D. Rees\*.  
Y. L. Qiao\*\*

\*Faculty of Advanced Technology, University of Glamorgan, Pontypridd, UK (e-mail: whu@glam.ac.uk)

\*\*Institute of Automation, Chinese Academy of Sciences, Beijing, China

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**Abstract:** This paper introduces a four-layer structure for the global scale remote laboratory NCSLab (www.ncslab.net) which provides a unified interface for accessing the test rig diversely located. This structure is good for both expansion and maintenance. All the test rigs are classified into several sub-laboratories according to their functions rather than their locations. The user doesn't have to know their geographical locations. The user can use a single user ID and password to access all the test rigs in different locations just as they are all in one place. The remote lab also provides great flexibility for the users including remote tuning, remote monitoring and remote control algorithms. Most of the jobs done in a hands-on laboratory can be carried out in the remote laboratory.

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### 1. INTRODUCTION

Experimentation plays an important role in control engineering education. It can help students to experience the practical application of the knowledge they gain from the lectures. However, not all the educational Institutions can provide all the experimental test rigs their students needs. If these test rigs can be shared across Institutions, it would increase their utilizations and serve more students.

With the rapid development of the Internet and web technology, web-based laboratory becomes an economical solution to solve this problem. The design methods for various kinds of experimental instruments have been developed in the last few years, including DSPs (Hercog, 2005), PLL measurement (Burbidge, 2006), vibration measurements (Qin, 2004.) and linear systems (Viedma, 2005) etc. These laboratories provide good remote accessibility to the users.

However these laboratories only support a particular kind of instrument or require all the instruments to be located in one place. However, for geographically diverse Institutions to share their control experimental facilities, it is necessary to develop a new structure which supports different test rigs located in different places.

Peer-peer structures are proposed and implemented in the ALFA project (Alves, 2005) and Vienna University of Technology (Kerer, 2005) which support diversely located test rigs. However, peer-peer structure is good for expansion, but it is difficult to provide a unified interface because of the lack of a central server.

A three-layer structure is proposed in DEUSTO system (Carcia-Zubia, 2006) which is implemented in the University of Deusto. In that system, microservers are placed between the instruments and main server. The communications

between the instruments and the main servers are undertaken by the microservers via the Intranet. This distributed structure has the potential to support diversely located instruments. However, the microserver provides the direct TCP/IP services to the end users as well as the main server, which decreases the data flow between the microservers and the main server because the real-time data can be distributed to the users directly on the microserver layer. However, it also results in a big problem for concurrent access. The microsevers are normally based on cheap computers with limited capacities in order to reduce the cost. If too many users access a particular microserver simultaneously, it could overload the system easily.

To solve this problem, the microserver has to abandon the direct TCP/IP services and transfer all the data to the main servers where these data are distributed to the end users. It can keep the load on the microserver constant. The NCSLab originally used this structure. However, it also brings new problems. Firstly, this structure is not so efficient for a global scale remote laboratory. Consider a scenario that the main server is located in the UK and there are test rigs located in China. The data have to be transferred across the world to reach the server. Secondly, this structure is not good for expansion, if too many test rigs are connected to the server, the load on the main server could be very high and even cause system overload.

In order to design a world scale remote laboratory platform which provides a unified interface for different kind of test rigs located in different countries, a more complex structure has to be considered. The Networked Control System Laboratory (NCSLab) with four layer structure is introduced in this paper. It is located in University of Glamorgan and has already integrated six test rigs from four Institutions located in both UK and China.

## 2. STRUCTURE

As it is shown in Fig 1, the NCSLab adopts a four layer structure which consists of the test rigs, sub-servers, regional servers and the central server.

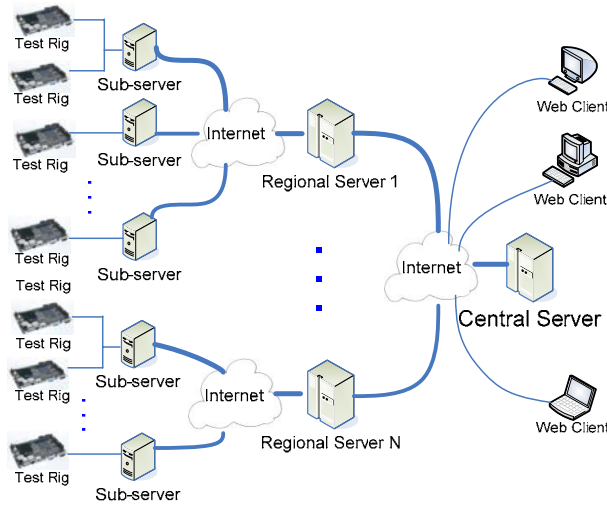


Fig. 1. The four-layer structure of the NCSLab

The sub-servers are placed locally with the test rigs. They collect the real-time data from the test rigs via the local network and then pass them to the regional servers where these data are stored in the regional server database. On the central server, non real-time information such as the users' details, the test rigs' details and help documents are stored in the central server database.

Both the regional servers and the central server provide direct TCP/IP services to the users, but the sub-servers have no direct communication to the users. They are only the bridge between the test rigs and the regional servers, so their loads can be kept constant even with concurrent access.

The regional servers are located in the places near their sub-servers. There are two regional servers deployed in the current NCSLab system. One is in the UK and the other is in China. All the sub-servers in UK connect to the UK regional server and all the sub-servers in China connect to the China one. The adoption of the regional server reduces the travel distance of the real-time data significantly. It is also good for future expansion. If some test rigs from other regions wants to join NCSLab in future, a new regional server can be deployed there.

The regional servers share most of the load on the central server. The main server only takes on the non time critical jobs such as user authorizations, test rigs management and providing the help documents for the users. The jobs such as distributing the real-time data are undertaken by the regional servers. If more test rigs join NCSLab, the more regional servers and sub-servers can be deployed to share the load.

### 2.1 Central server

The central server is the kernel of the whole NCSLab system. It provides the main web interface for the users. The central

server is the entry point for the users to enter the whole system where the user authorisation is undertaken. All the test rigs are also listed here. They are classified into server sub-laboratories. Their links to the corresponding regional servers are also provided. Following these links, the user's browser is redirected to the regional servers where the real time experiments are carried out.

The main server also keeps TCP/IP communications with every regional server, from which the status of every test rig is uploaded to the central server in real time. Fig 2 is the structure of the central server.

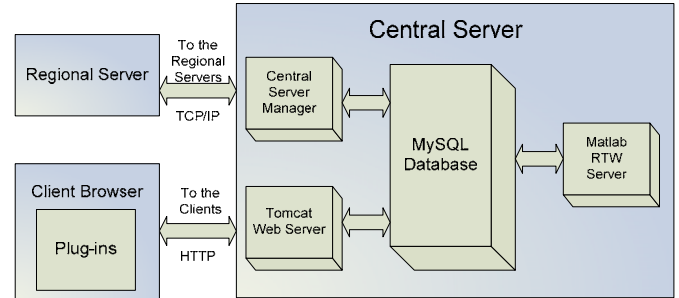


Fig. 2. The structure of the central server

#### 2.1.1 Tomcat web server

The web server for the NCSLab is based on Tomcat 5.5 which supports JSP/Servlet technology. It provides the web interface for the users to logon and access the remote laboratories. The interface includes plug-ins as well as web pages. These plug-ins are designed to provide dynamic interfaces for the clients to monitor the experiments results and adjust the control parameters. They are loaded automatically by the client's browser when the users logs on.

#### 2.1.2 Central Server Manager

The Central Server Manager is a Java program which keeps connections with the regional servers. It collects the status (for example, it is working or not; who has full control) of every test rig and stores them in the database.

#### 2.1.3 MySQL database

There is a lot of information that needs to be managed in the central server. All of them are stored in the MySQL database which is a free database solution with high reliability and good performance. The database is the central part of the main server. All the programs running in the central server derive or store data through the database. It works like a buffer which separates all other programs. Therefore, the use of the database not only simplifies the data management but also makes the structure more elegant.

#### 2.1.4 Matlab RTW Server

The Matlab RTW server consists of three parts: Matlab 7.1 with Simulink and RTW, ARM Linux GCC and an interface program RTW Assistant. Their relationship with the MySQL database is described in Fig 3.

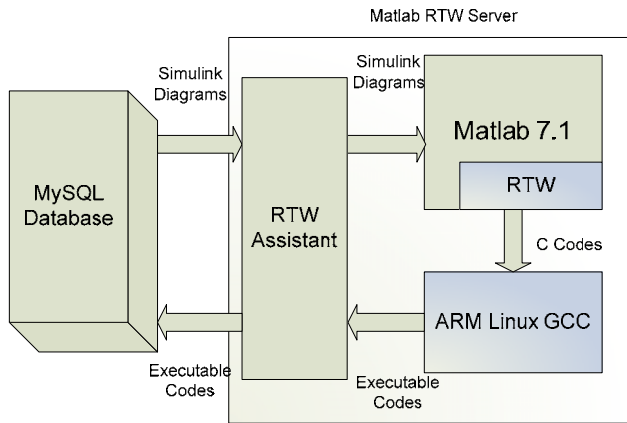


Fig. 3. The Matlab RTW Server

Matlab RTW can generate optimised ANSI C codes from control system blocks in Simulink. ARM Linux GCC, the special compiler version for embedded applications, can compile these C codes into executable programs. Therefore, based on this software, Matlab RTW Server for NCSLab is designed. The RTW assistant which is a Java program obtains diagrams from the database. The RTW transforms the diagram into C codes and ARM Linux GCC compiles these codes. The RTW Assistant sends the final executable program back to the database.

### 2.2 Regional server

The regional server has a similar structure with the central server. It consists of three parts, the Regional Server Manager, MySQL database and Tomcat web server which is shown in Fig 4.

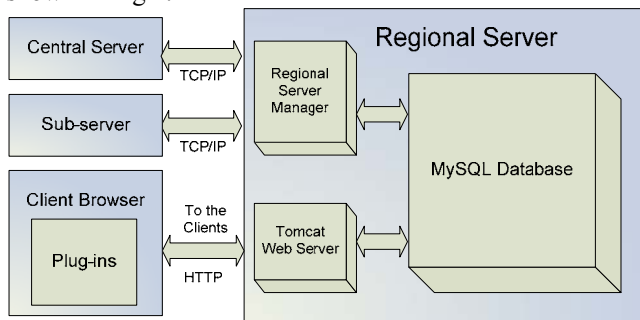


Fig. 4. The Regional Server

The Regional Server Manager is also a Java program which mainly has three tasks. Firstly it collects real-time data and images from the sub-servers and temporarily stores them in the MySQL database. Secondly, it keeps connections with the Central Server Manager updating the real time status of every test rigs. Thirdly, it passes the user's commands such as tuning the experimental parameters and changing the control algorithms to the sub-server layer.

Different to the central server database, the regional server database only stores temporary information such as experimental data and video images. This information is buffered in the MySQL database and then delivered to every user by the Tomcat web server.

The Tomcat web server on the regional server only generated the web pages for real-time experiments. Because all the configurations are stored in the central server database, the web server establishes a temporary HTTP connection with the central server to get the experimental configurations when these pages are being generated. This web page enclosed various plug-ins and Ajax (Mahemoff, 2006) scripts for the users to monitor the experimental process and tune the parameters.

### 2.3 Sub-server

There are two programmes running in the sub-server. The first one is the Sub-server Manager whose tasks are to pass the real-time data from the local test rigs to the remote regional server and deliver the commands from the regional server to the test rigs. The second one is the Video Image Collector which collects the real time images from the USB cameras, compress them into JPEG format and transfer them to the regional server.

The sub-server layer doesn't provide direct TCP/IP services to the end users. Therefore, no matter how many users access a certain test rig, the load on the sub-server can be kept constant. The computing capacities for the sub-servers don't have to be powerful. They can be properly chosen according to their constant loads.

### 2.4 Test rig

Test rigs are located throughout the world, but each of them is controlled by a similar control module. It is mainly based on a 32-bit ARM RISC microprocessor which is a cost-effective high-performance microcontroller solution for Ethernet-based systems. It is composed of a main board, an AD/DA board, a LCD board and an I/O board. The main board has a 32-bit ARM CPU (200MHz), 64M memory, a network port, and 2 USB ports. The AD/DA provides 12 analog-digital channels and 2 digital-analog channels.

Various real-time control algorithms can run on the control module. All the control algorithms for NCSLab are generated using Matlab Real-time workshop and GCC compiler. The operating system for the control module is embedded Linux. There is an algorithm receiver program running as a service which allows the users to change the control algorithm at any time. When a new algorithm is received, the service stops running the previous one and starts the new one. Because all control algorithms are generated by RTW, every control algorithms supports an unified monitoring interface, which enable the external programs such as NCSLab to monitor the internal parameters and signals via network.

As an example, Fig 5 is the magnetic levitation test rig in the University of Glamorgan. The device on the left hand side is the control module with a LCD; the right hand side is the test rig which is controlled by the control module.

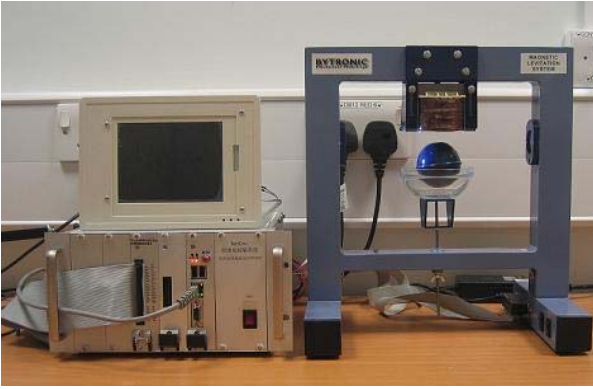


Fig. 5. Meglev test rig in University of Glamorgan

### 3. DESIGN

#### 3.1. Web interface

The web-based interface is written in HTML, JSP/Servlet, AJAX scripts, Flash and Java Applets cooperating together. It can be divided into two parts. One part of it runs on the central server and the other part is on the main server.

##### 3.1.1 Web interface on the central server

When a user logs on the NCSLab web address (<http://www.ncslab.net>), he connects the central server. The jobs such as the user authorization, experiment configuration and help documentation are undertaken by the central server.

Only authorized users can access the NCSLab. Before a user enters the laboratory, he must provide a valid user name and password. If he passes the user authorization, all the test rigs would be listed on the web pages. They are well catalogued by their functions. For example, all the water tank test rigs are classified into the water tank sub-laboratory. For every test rigs, the help documents are also available to the user. They help the user to understand the test rigs before he starts the experiment, which can reduce the possibility of making mistakes.

The user can choose the test rig he wants to access. Then he goes to the web pages for that test rig, where he can setup the experiment. All the parameters and signals can be listed in a tree structure, from which the users can choose which parameters he wants to adjust and which signals he wants to monitor during the experiment process. When he has finished the configurations, he clicks the "OK" button, and then the web page is redirected to the corresponding regional server where the real-time experiment is undertaken.

##### 3.1.2 Web interface on the regional server

The web interface for the real-time experiment is provided by the regional server. It is developed using Flash plug-ins, AJAX and JSP/Servlet together. Fig 6 is a snapshot for the networked predictive control (Hu, 2006) experiment on the servo test rig between China and UK. The servo plant is located in the University of Glamorgan, UK and the

controller is in CAS (Chinese Academy of Sciences), China. The two sides communicate through the Internet.

The chart for displaying the trend of the signals is developed based on Flash plug-ins. It keeps persistent connections with a Servlet running on the regional server. The Servlet gets real-time signals from the database and transfers them to the Flash. Based on these signals, the chart is displayed to the users on their browsers.

The tuneable parameters are also listed for the user. He can change the parameter by typing in the new value into the text box. After he clicks "Submit", this new value would be passed to the test rig through the Internet. This part is achieved by AJAX.

The NCSLab supports concurrent access to certain test rigs, but only a single user has full control (the right of tuning the parameters and changing the control algorithm) to that test rig at any one time. The users without full control can only watch the real-time experimental results. They can make no changes to the test rig. If they want to get full control, they must wait in a queue. The estimated waiting time is presented on the web interface when the user is waiting. When his/her time comes, the web will refresh itself and a new interface for full control will appear automatically. Once a user is granted full control of a test rig, they have about 30 minutes' experiment time.

#### 3.2. User-defined control algorithms

The NCSLab provides a few control algorithms (PID, LQG etc. for examples) for every test rig. The users can choose these algorithms. They also have the flexibility to design their own control algorithms.

The NCSLab provides a template file for every test rig. The template file which can be downloaded from the website encloses a sub-system which represents the mathematical model of the test rig. Based on this sub-system, the users can design their own control algorithms in Simulink. They can simulate their algorithms again and again until they are satisfied with the simulation results. Then the users can upload their simulation diagrams directly to the central server.

In Simulink, diagrams are stored in MDL format which is a text file with recursive syntax. The Servlet in the central server finds out the sub-system which encloses the mathematical model from the MDL file, and then replaces it with the physical module which links to the hardware (for examples, A/D, D/A and PWM generator). This modified MDL file is sent to the Matlab RTW Server, where the Simulink diagram is transformed into the executable code and stored into the database.

All the transformation procedures are transparent to the users. From their point of view, they only need to concentrate on the simulations in Simulink and then upload the simulation diagrams to the server. Then the server will generate the

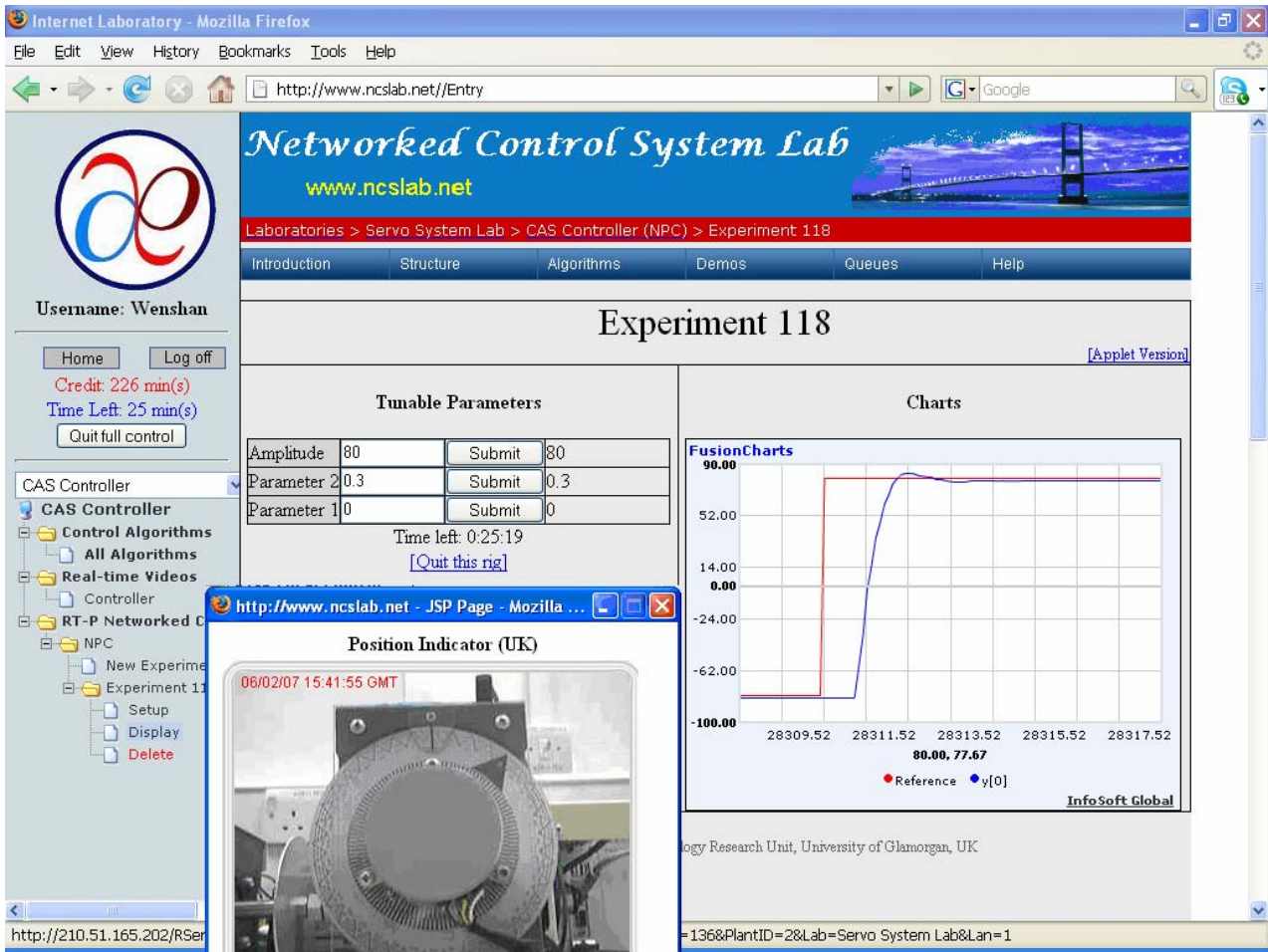


Fig. 6. Real time experiment

control algorithms automatically for them. There is no programming needed in the whole procedure. It is both flexible and convenient for the users.

After the user defined algorithm is generated, it is added into the algorithm list. When the user has full control, he can choose it and implemented it on the test rig.

### 3.3. Video system

In order to help the users to experience the real dynamic of the test rigs, a video system is developed in the NCSLab. On every sub-server, there is a Visual C++ video collecting program which obtains the Video frames from the USB cameras and compresses them into JPEG format. Then these JPEG images are sent to the regional server and temporarily stored in the MySQL database.

At the client side, a Java Applet is developed. It holds a persistent HTTP stream with the regional server getting the real-time video from the main server and displaying them in the user's browser.

## 4. IMPELEMENTATION

Currently, the central server is located in the University of Glamorgan UK. There are two regional servers deployed.

One is in the UK and the other is in China. There are six test rigs from both the UK and China which are integrated into the NCSLab so far. They are classified into three sub-laboratories by their characteristic rather than their geographical locations.

There are three sub-laboratories so far, the Servo Control Lab, Water Tank Lab and Meglev Lab. If a user wants to carry out experiments on a particular kind of test rig, he can search for it on the corresponding sub-laboratory. From the users' point of view, they don't have to know where the test rigs are geographically located. Actually, they can find what they want by going to the corresponding virtual laboratory.

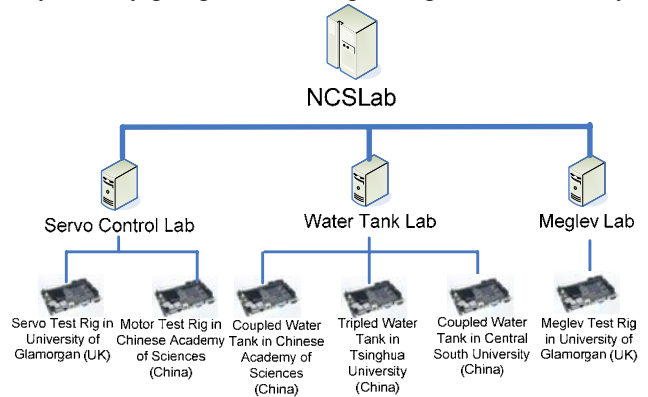


Fig. 7. The logic structure of the NCSLab

## 5. AN EXAMPLE

The user defined experiment on the servo control system in University of Glamorgan is selected as an example to illustrate how the users use the NCSLab to carry out experiment.

For the user defined experiment, the user needs to download the template file for the server control test rig. It can be found from the web site. The template encloses a sub-system which represents the mathematical model of the test rig identified as

$$G(s) = \frac{0.03868s^3 - 5.369s^2 - 97.34s + 13450}{s^3 + 169.8s^2 + 1730s + 159}$$

Based on this sub-system, the user can build his/her simulation diagram. Figure 8 is a sample example of PI control, in which the block "Servo Plant" is the sub-system. The user can work in Simulink and get simulation results.

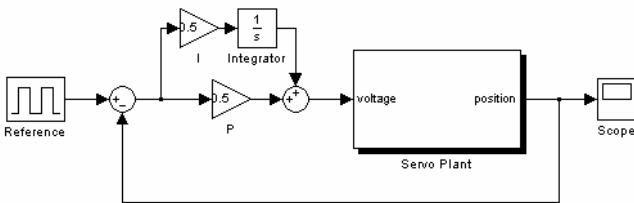


Figure 8. Simulation diagrams in Simulink

If the simulation results are satisfactory, the user can upload the diagram to the NCSLab server without any changes. At the server side, the mathematical model is replaced by the real physical plant and the modified diagram is compiled into the executable program. Then the user can select the newly generated user defined algorithm and implement it to the practical servo control test rig. Figure 9 is the comparison between the simulation result in Simulink and the practical experiment result in NCSLab. The left hand side is the result of the Simulation in Simulink. The right hand side is the real experiment result grabbed from the NCSLab. From the comparison, it is clear they are very close.

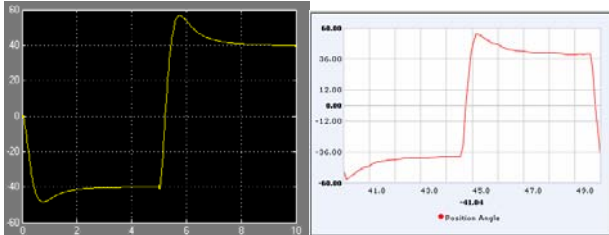


Figure 12. Comparison between the simulation in Simulink and experiment in NCSLab

## 6. CONCLUSION

This paper presents the four layer structure for the global scale web-based remote laboratory which provides a unified interface for accessing the test rigs geographically located in different places. It also gives the users great flexibility such as remote tuning, remote monitoring and remote control algorithms. Most jobs that can be done hands-on can also be realized in the NCSLab. The NCSLab has been running 24

hours a day, 7 days a week for over one year. Currently, there are six test rigs belonging to four Institutions from both China and UK already been involved and the open architecture enables more to join in the project in the near future.

With the rapid development of Ajax and Web 2.0 technologies, the functions of the Internet based applications become more and more powerful. Many applications that used to be achieved only on the computer desktops have now been successfully implemented on the Internet browsers. Therefore, based on these technology advancements, more research attention is going to be paid in the future on designing a friendlier and more desktop-like web based interface with better flexibility, accessibility and security.

## REFERENCES

- Alves, G. R., Ferrerira, J. M., Muller, D. Erbe, H. and Hine, N. (2005) Remote experimentation network-yidding an inter-university peer-peer e-service. In: *Proceedings of the IEEE international conference on emerging technologies and factory automation*. Vol. 2. pp. 1023-1030
- Burbidge, M. J. and Grout, I. (2006) Evolution of a Remote Access Facility for a PLL Measurement Course, In: *Second IEEE international conference on e-science and grid computing*, Vol 2. pp. 141
- Carcia-Zubia, J., Lopez-de-Inina, D., Orduna, P., Hernandez, U. and Trueba, I. (2006) Question and answers for designing useful weblabs. In: *International journal of online engineering*, Vol. 2.
- Hercog, D., Gergic, B and Matko, V. Remote Lab (2005) for Electric Drives. In: *Proceedings of the IEEE international symposium on industrial electronics*. Vol. 2. pp. 1685-1690
- Hu, W., Liu, G. and Rees, D. (2006) Design and implementation of networked predictive control systems based on round trip time delay measurement. In: *Proceedings of the 2006 American Control Conference*. pp. 674-679
- Kerer, C., Reif, G., Gschwind, T., Kirda, E., Kurmanowytch, R. and Paralic, M. (2005) ShareMe: Running a distributed systems lab for 600 students with three faculty memebers. In: *IEEE transactions on educations*. Vol. 48, pp. 430-437
- Mahemoff, M., (2006) *Ajax design patterns*. O'Reilly Media, Inc. Sebastopol, USA
- Qin, S., Bo, L. and Liu, X. (2004) Development of the networked virtual instrument lab for vibration measuring based on Microsoft. NET. In: *Proceeding on American control conference*. Vol. 2. pp. 1286-1289
- Viedma, G., Dancy, I. J. and Lundberg, K. H. (2005) A web-based linear-systems iLab, In: *Proceeding on American control conference*, vol. 7, pp. 5139-5144
- Gallardo, S., Barrero, F., Toral, S. L., Duran, M. J. (2006) eDSPLab: A remote-accessed instrumentation laboratory for digital signal processors training based on the Internet. In: *32nd annual conference on IEEE industrial electronics*. pp. 4656-4661