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Research paper

Development of Internet of Things Optical Sensor based on Surface Plasmon Resonance Phase Interferometry

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Abstract

This paper demonstrates the integration between an Internet of Things platform and an optical sensor based on surface plasmon resonance (SPR) phase interferometry. The optical sensing system starts when the liquid containing the heavy metal is flowing through the top surface of a glass prism. A laser is turned on and a motor can sweep from 0 to 90 degrees initially. Data is collected by a photodiode sensor. The SPR angle is determined where the reflectivity of light falls to the minimum level. The motor rotation is then fixed at the SPR angle. Self-mixing interferometry is applied by reflecting back the light from laser using a piezo actuator. The resulting phase difference is measured, and the concentration of heavy metal can be determined using virtual instrument (VI). VI consists of control of the optical sensing system which is built in LabVIEW software and installed in a host computer. A web page is created based on the VI using Web Publishing Tool which allows user to monitor the data collected from the optical sensor by entering the URL address in the Internet Explorer from the client computer. Keysight BenchVue software is used to monitor and control the function of oscilloscope. The result of this project is an optical sensor capable of sensing different concentration of heavy metals in which the real-time data collected from it can be monitored remotely using computer and smartphone.

Keywords: *BenchVu; LabVIEW; Internet of Things; Optical sensor; Real-time monitoring;*

1. Introduction

Internet of Things (IoT) is started by Kevin Ashton in 1999 (“That â€™ Internet of Things â€™ Thing” 2010). It connects devices and humans to create a smart world in which the physical, digital and virtual focus to build a smart environment [1]. IoT sparks off the revolution of technology in various fields such as transportation, industries, cities and others. It allows access to information not only “whenever” and “where ever” but also using “whatever” by “whomever” through any “path” and “service”.
IoT is believed as the next mega trend which will happen in the next few years. IoT will achieve its “plateau of productivity” by about the mid-2020s [2]. Mark Uncapher, the director of Fiber Optic Sensing Association reported that the sensor technology is the linchpin of IoT and fiber optic sensing could contribute a huge opportunity. IoT based sensors are able to detect and deliver the parameters in real time through software in electronic devices which can be at anywhere.

IoT system is built by four main layers which are the device layer, network layer, support layer and application layer. In the device layer, devices such as the sensors, actuator and gateways are used to collect readings from sensors for the coming processes. The network layer provides transportation to the processing places while the support layer provides generic and specific services such as storage in the form of database management system and cloud-computing system. Fig. 1 shows the summary of the four main layers of IoT system.

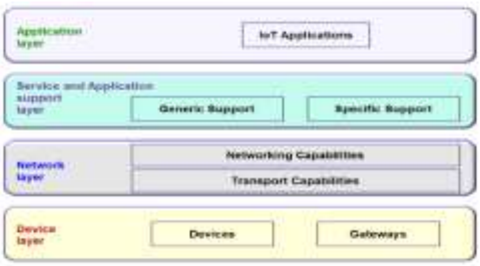

Fig. 1 : Main layers of the IoT system

Wireless communication technology plays an important role in the IoT system, especially the wireless sensor network (WSN). Basically, WSN can be described as a network of small sensors communicating with each other using radio signal for measuring physical world [1]. WSN sensors are small, durable and cheap which can be deployed in smallest objects for any environment. This integration will become the main evolution in WSN.

LabVIEW or Laboratory Virtual Instrument Engineering Workbench is a platform and building environment for visual programming language using "G" language from National Instrument [3]. The engineering software is different from other programming languages [4]. It allows users to visualize the outcomes by creating unique engineering user interface. By reducing the complexity of programming and simplifying the hardware integration for engineering applications, users can obtain data from the hardware easily.

BenchVue is a software product from Keysight which is simple to connect, control instruments and automate test sequences to ease the development phase [5]. Controlling the test devices in the software does not require any form of programming while data visualization eases the users in the testing processes. Automatic testing using Test Flow in the front panel saves time in data collection and test development. The data collected can be exported in various formats.

Surface plasmon resonance (SPR) is an optical technique which uses the sensitivity of surface plasmon polariton created at the interface of metal-dielectric to the refractive index for measuring the adsorption of the interface and the deposition of thin film. SPR is an important optical bio-sensing technology due to its real-time, label-free and non-invasive characteristics [6]. Furthermore, quantitative real-time analysis for label-free detection for biology and chemical samples can be achieved by SPR sensor with high level of sensitivity.

The SPR angle is affected by the characteristics of metal layer, wavelength of incident light and refractive index of medium. The refractive index is sensitive to temperature; hence, measurements have to be conducted at defined temperature. However, the refractive index is not affected by the density of medium [7]. SPR phase interferometry has higher performance than normal SPR in terms of sensitivity in optimum configuration [8].

Interferometry is an analytical technique used for measuring difference, small shift and surface deviation to analyze the light absorption [9]. Self-mixing interferometry can produce an interferometry sensor in which the laser is both the source and detector. This technique is often used in gas laser, quantum cascade laser and solid-state laser [10].

2. Methodology

This project is divided into two main parts; the SPR phase interferometry optical sensor system and the development of IoT system. The sensor part requires hardware setup whereas the development of IoT system involves software.

The sensor system is built using LabVIEW software. A photodiode is connected to a power meter (PM100USB) and a motor driver (CR1-Z7) is used to move the photodiode for a certain range of angles. To establish the connection, the devices' serial number is registered in the virtual instrument (VI) before the control can take place.

The motor driver sweeps the motor from 0 to 90 degrees. This process is to determine the surface plasmon resonance angle of the sample being measured. The SPR angle is defined as the reflectivity of light from the laser falls to minimum.

Web Publishing Tool is used to create a web page written in Hypertext Markup Language (HTML) for system. HTML turns normal texts into a hypertext Uniform Resource Locator (URL) address using Hypertext Transfer Protocol (HTTP) which is created for the web page. HTTP transfers the hypertext page from host to the client. The URL address created will consist of the protocol used, the host name and the file name. The web page can be visited by using a web browser in the client computer. The data obtained from the sensor can be monitored in real-time and remotely.

A piezo controller activates the piezo actuator at 75Hz to set up the self-mixing interferometry. This induces a difference in phase when the motor is at the SPR angle. An oscilloscope is used to measure the phase difference between the initial self-mixing signal and the self-mixing signal at the SPR angle. The oscilloscope can communicate with the host computer using Keysight BenchVue for PC software. This software allows user to monitor and control the oscilloscope directly without pressing the physical buttons on the device itself.

Smart devices such as smartphones and tablets serve as the client while the computer serves as the host. BenchVue Mobile app is installed in client device to set up the connection between host and client. The connection requires both the host and client to be connected to the same local network (behind the same corporate firewall)

The host is assigned a private IP address to ensure the connection is within the user's private space without letting it directly exposed to the Internet. Entering the IP address of the host and the password or scanning the QR code is required to prevent others from accessing the instruments without the user's knowledge. With wireless connection, real-time monitoring and controlling remotely can be achieved by the client. Fig. 2 shows the setup of the system used in this study.

Fig. 2: Setup of the system

3. Results and discussions

3.1. Power sensing thorlabs PM100USB system

Power meter (PM100USB) is connected to the host computer via Visual Instrument Software Architecture (VISA). Communication in block diagram of power sensing system is built using drivers. Table 1 shows the drivers used and its functions for the power meter.

Table 1: Drivers and functions for the power meter

Driver	Function
Set Wavelength	Set the wavelength in nanometer
Set Average Count	Set the average count for measurement value generation
Measure Power	Obtain power readings from instrument

The power sensing system is first built in virtual instrument (VI) using LabVIEW software. The block diagram is then compressed in the form of icon to be used as a sub-VI in the overall integration system for IoT based optical sensor as seen in Fig. 3. Fig. 3 shows that the icon consists of three terminals; an input and two outputs. The input (purple) represents the terminal connected to a constant which is the serial number of PM100USB power meter or the number of the USB port connected to it. One of the outputs (pink) represents the terminal connected to the function “Table” where the measurement of intensity of light is recorded in it. The last output (orange) is the terminal connected to the function “Waveform Chart” in which the graph of light intensity against time is generated. These table and graph can be observed at the front panel of the VI.

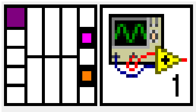

Fig. 3: Icon for power sensing system

3.2. Self-mixing interferometry

Self-mixing interferometry is used in the optical sensor system where the laser beam is reflected at the reflective tape placed at the surface of piezo actuator. The reflected light creates interference with the light from the laser. This causes changes to the laser electrical and optical properties.

The averaging for the waveform is obtained by selecting the “Acquire” and “Averaging” functions on the oscilloscope. This process calculates the average of a series of waveform and eliminates the noise of the repeating signal. The resulting waveform has frequency resolution similar to the original with additional vertical resolution. Fig. 4 and 5 show the waveform before and after averaging, respectively.

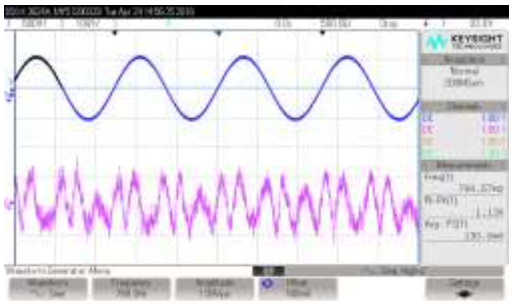

Fig. 4: Waveform before averaging

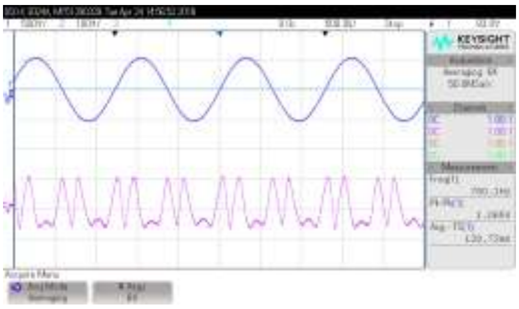

Fig. 5: Waveform after averaging

3.3. Overall system of IoT based optical sensor

A new virtual instrument (VI) is built in LabVIEW software for the development of the overall system of IoT based optical sensor. The icon for power sensing system is used as a sub-VI in the VI which includes the control for both the power meter and the motor driver for automated control of the IoT optical sensor system.

Fig. 6: Front panel of the overall system

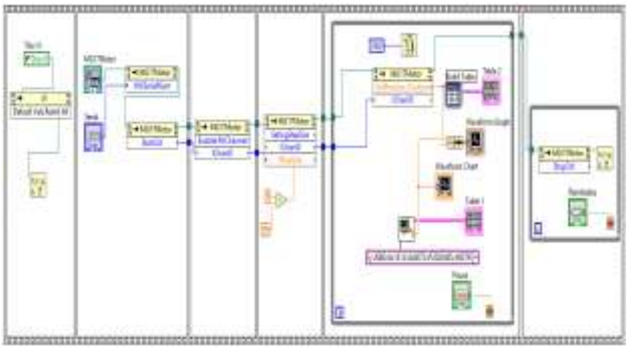

Fig. 7: Block diagram of the overall system

“Flat sequence” structure is used in the overall system as shown in Fig. 6. Fig. 7 shows the block diagram built that consists of five sub-diagrams or frames in which the operation is executed according to the sequence from left to right. Data leaves each of the frames when the frames are finished executed.

The VI is always in “default” mode every time a new measurement takes place. When the optical sensor system started, all the previous collected data and plotted graph are erased. This is done by introducing the “VI server reference” function at the beginning of the block diagram.

The next step is to establish the connection of the motor driver and the computer by registering the serial number. “StartCtrl” functions to start the APT control to communicate with the motor driver. Parameters are set from the APT control including the “Jog Step Size”, “Min Pos” and “Max Pos”. “Jog Step Size” sets the step size for every rotation of the motor. The minimum and maximum positions of the motor rotation are fixed by “Min Pos” and “Max Pos”.

The last frame includes “StopCtrl” to stop the ActiveX control. A “Close Reference” function is used to end the reference. It frees up the memory dedicated by LabVIEW for the reference.

The VI for overall system of IoT based optical sensor is published as a web page using the Web Publishing Tool in LabVIEW. “Embedded” mode is chosen to embed the front panel of the VI to allow clients to monitor and control the front panel remotely. “Start Web Server” is selected as to start the web server.

The web page consists of the VI is written in HTML. Structural semantics such as the document title, header and footer are created. All these features are displayed in the resulting web page. A preview function is available to preview the web page before publishing it.

The local directory (C:\Program Files (x86)\National Instruments\LabVIEW 2017\www” is selected to save the web page in the host computer. The web page created is named as Main.html. As the result, a URL address (http://192.168.1.4:8000/Main.html) is formed starting with the protocol used (http), following by the host computer name (192.168.1.4:8000) and ending with the file name (Main.html). Fig. 8 shows the web publishing tool used in this study.

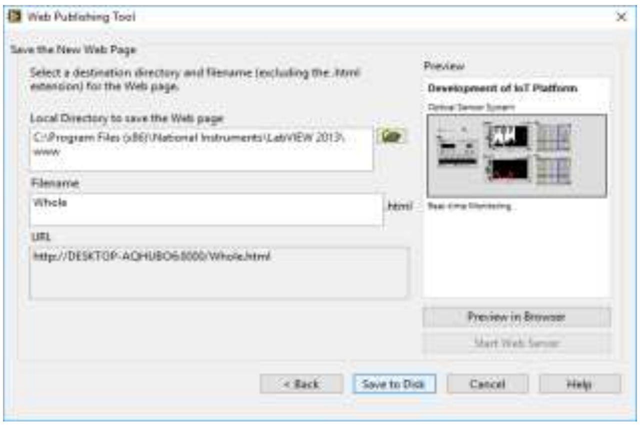

Fig. 8: Web Publishing Tool

The URL address created is entered in the web browser of the client computer. In this project, Internet Explorer is chosen as it can support the plugin used by LabVIEW in publishing the web page. After loading finishes, the front panel of the VI for overall system of IoT based optical sensor is displayed. Data collected from the sensor is displayed when the VI is run by the host computer. Fig. 9 shows the web page of the overall system.

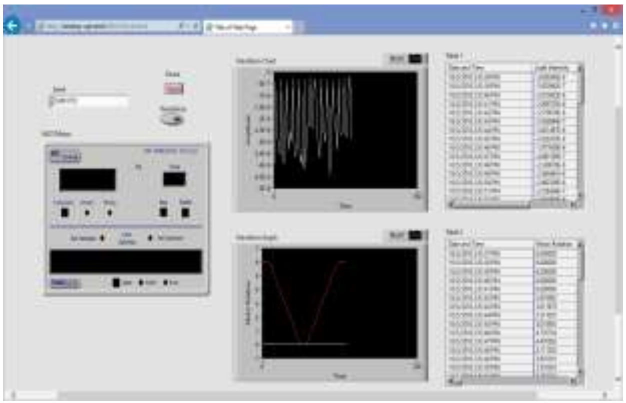

Fig. 9: Web page of the overall system

An oscilloscope is used to measure the phase difference between the self-mixing signals before and after the motor is rotated to the SPR angle. The IoT platform to control the device is developed using Keysight BenchVue for PC software. The oscilloscope is connected to the host computer using USB cable. An icon consisting of the oscilloscope model name and serial number is displayed at the bottom right of the software when the model is supported by the software and the connection is setup successfully.

The "BenchVue Oscilloscope" app is installed to enable communication and control of the oscilloscope. The icon is double-clicked to start the communication between the host computer and the oscilloscope. BenchVue allows real-time monitoring directly from the oscilloscope. The functions of the oscilloscope can be controlled in the software directly. Fig. 10 shows the waveform in BenchVue for PC.

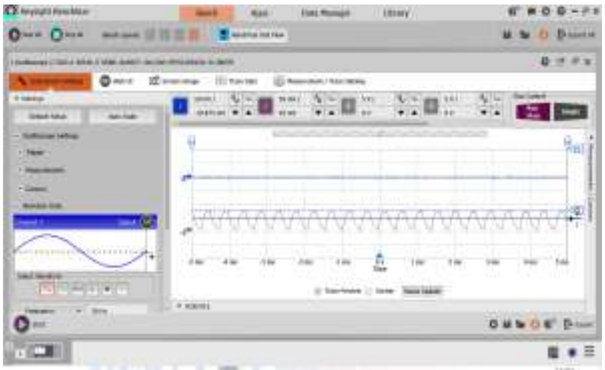

Fig. 10: Waveform in BenchVue for PC

Keysight BenchVue for PC allows sharing of data and control between computers and smart devices. The connection is established by enable the mobile access in the setting of the software. The computer serves as the host while the smart device is the client. BenchVue Mobile app is installed in the smart device for the connection of both devices.

BenchVue Mobile is launched in the client device. Both the host and the client must have access to the Internet in which they should share the same local network. IP address and the password of the host is entered to setup the communication between host and client as seen in Fig. 11. Scanning the QR code (Fig. 12) of the host which can include the password, from the client device eliminates the need to enter the previous information. These steps ensure that the client is connected to the correct host before sharing of information begins.

Fig. 11: IP address and password

Fig. 12: QR code of host computer

The instruments connected to the host computer will be listed in the BenchVue Mobile app as shown in Fig. 13. The oscilloscope model DSO-X 3024A is selected to start the connection between the app and the oscilloscope. This will allow direct control and real-time monitoring using the BenchVue Mobile.

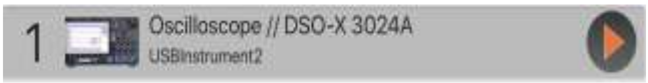

Fig. 13: Oscilloscope listed in BenchVue Mobile

The waveforms displayed in the normal oscilloscope screen, BenchVue for PC software in host computer and BenchVue Mobile app (Fig. 14) in client device are having the exactly the same parameters. This means that the connection and data sharing is established between all the three devices.

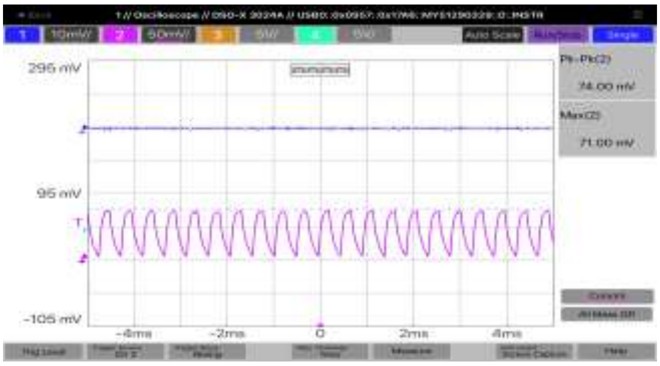

Fig. 14: Waveform in BenchVue Mobile

The access in Keysight BenchVue for PC software is disabled when the communication with the client device is in process. This is to allow full control by only one side for preventing interruption. Pressing the physical buttons at the oscilloscope will interrupt both the access from host computer and client devices. To resume the access in host computer, the user has to select the “Take Back Control with PC” function in the Keysight BenchVue for PC software from the host.

4. Conclusion

This project reports on optical sensor based on surface plasmon resonance (SPR) phase interferometry integrated with Internet of Things (IoT) platform. The sensor developed in this project is capable to measure different concentration of different types of heavy metals which allow real-time monitoring and control of the system from distance. The IoT platform is developed using LabVIEW and Keysight BenchVue. Web Publishing Tool in LabVIEW is used to create a web page written in HTML language. The web page uses HTTP as the protocol and an URL address is generated. The web page is visited from the client devices which can be a smartphone or tablet using Internet Explorer for real-time monitoring and control the optical sensor system. Keysight BenchVue is used to set the computer connected to the oscilloscope to be the host. The mobile access setting is configured to allow the sharing of data to the client. The integration of IoT platform and optical sensor results in a simple, user-friendly and portable sensor. Future developments for this project include the auto-detection of the SPR angle in the VI built for overall system. The integration of Keysight BenchVue graphical user interface in the web page created may also ease the user in monitoring and controlling the IoT optical sensor.

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