The Internet-of-things in remote-controlled laboratories

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Abstract

In the South African education landscape, some of the schools have well-resourced science laboratories, while others are under-resourced. This has impacted on the quality of science education in under-resourced schools, resulting in a lower pass rate and poor Matric results. While under-resourced schools depend wholly on government funding because of the poor neighbourhoods they sit in, well-resourced schools are financed by parents in addition to government funds. The percentage of under-resourced schools is significant as it spans urban and rural areas, meaning that a large population of learners is affected by this status quo.

This research is about technology that can facilitate collaboration between under- and well-resourced schools so that under-resourced schools can have access to laboratory resources that are available in well-resourced schools. It is about using the Internet of Things (IoT) technologies in remote-controlled laboratories.

The proposed technology demonstrator in this research is specifically for facilitating a chemical reaction and incorporates IoT technologies including actuators, web cameras, sensors, RFID, and Arduino. The research contributes towards the concept of remote laboratories, specifically in the South African environment. It marries the concept of IoT into remote laboratory research. It is also a technology that replaces simulation as a very common technology in remote laboratories. The advantage of this technology is that it gives psychological presence to the learner.

Keywords Internet of Things, remote laboratory, actuator, Arduino, sensors, machine-readable code, education

1 Introduction

The Internet of Things (IoT) is likely to have a staggering impact on our daily lives and become an inherent part of areas such as electricity, transportation, industrial control, retail, utilities, management, healthcare, water resource management, etc. The IoT is what happens when everyday ordinary objects have Internet-connected microchips inside them. These microchips help not only keep track of other objects, but many of these devices sense their surrounding and report it to other machines as well as to the humans. This network covers all everyday objects such as watches,

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keys, household appliances, cars and buildings (Zhihao, 2011). When embedded with chips and sensors, these objects can think, feel and talk with each other. Together with the infrastructure of the Internet and mobile networks, these objects can communicate with humans and enable the humans to monitor and control them anytime, anywhere and enjoy their intelligent service.

Real time monitoring of water quality in the ocean through sensors connected to a buoy that sends information via the GPRS network, to the monitoring of computers being shipped around the world, and smart power grids that create conditions for more rational production planning and consumption will all be achieved via microchips implanted in objects that will communicate with each other. The use of technology to track objects, appliances, applications and even people is a fact of business for many companies. Using tags, sensors and chips paired with wireless technology, they are gathering loads of data about the location, status and other features of objects, ranging from a patient's whereabouts in hospital to cars backed up on the highway. Once connected though, there's the even bigger job of analysing information and getting it to the right recipients who can put it to use.

Some applications related to the IoT aren't new: toll collection tags, security access key cards, devices to track stolen cars and various types of identity tags for retail goods and livestock. More sophisticated tools such as embeddable chips, wireless Radio frequency identifier (RFID) readers, Global Positioning Systems (GPS) and cellular phone technology adapted to tracking are providing new forms of visibility. Other monitoring and tracking systems have more business uses such as solving or averting problems like sending cellphone alerts to drivers informing them that traffic is backed up at a particular exit ramp, and increasing efficiencies such as enabling a utility to remotely switch off an electric meter in a just-vacated apartment.

This research is about the architecture of a system that adopts the IoT technologies in the design of a remote-controlled laboratory. The remote laboratory supports a chemical reaction or experiment which can be viewed and manipulated by learners in remote sites. The IoT technologies that feature in this research are: machine readable identifiers, actuators, sensors, the Arduino, and a robotic arm. The next section of this paper is an overview of IoT technologies. The section thereafter is on the methodology and is followed by the proposed architecture of the system. At the end is a discussion section, followed by the conclusion.

2 The Internet of Things

This section is an overview of the IoT technologies adopted in this research.

2.1 Machine readable identifiers

An identifier is an alphanumeric string which allows an individual thing to be identified. As a machine-readable string for identification purposes, an identifier is usually machine-generated. Examples of machine-readable identifiers include bar-codes used as stock control and ID cards to give identifying data.

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2.1.1 RFID tags

A Radio frequency Identifier (RFID) reads information contained in a wireless device called a tag and provides a method to transmit and receive data from one point to another. RFIDs use radio waves to identify items. In contrast to bar codes, RFID tags can be read away from the line of sight. They track items in real-time to yield important information about their location and status. Early applications of RFID include automatic highway toll collection, keeping track of entire inventory, supply-chain management (for large retailers), pharmaceuticals (for the prevention of counterfeiting), and e-health (for patient monitoring). RFID tags are being implanted under the skin for medical purposes, e-government applications such as RFIDs in drivers' licences and passports and RFID-enabled phones are some of the applications. An important area of use for RFID is in the registration of goods transport data. Events can be registered along the entire transport route so that a shipment becomes transparent for the seller, purchaser and everyone involved in it. This can improve the planning and administration surrounding a shipment.

2.1.2 Bar codes

A bar code is an optical representation of machine-readable data and can be seen on the majority of products that are on sale in the retail industry to speed up the checkout process. These linear symbologies or so-called one-dimensional (1D) barcodes represent data in vertical parallel lines with varying space and line width (Bar code, 2011). A lesser well-known two-dimensional (2D) barcode or matrix code is also an optical representation resembling something like a crossword puzzle of even more machine-readable data and can normally be seen on larger packaging containers to assist with warehouse logistics and quality control.

Examples of matrix codes include QR Code, Data Matrix code and Semacode. QR Code (QR code, 2011) is derived from Quick Response as the creator intended to allow its contents to be decoded at high speed. QR Codes storing, for example, URLs appear in many places about any object a user might need information on. A user having a camera phone equipped with the correct reader software can scan the image of the QR Code causing the phone's browser to launch and redirect to the decoded URL.

A Data Matrix code (Data matrix code, 2011) is made up of a two-dimensional matrix code consisting of black and white square modules arranged in either a square or rectangular pattern. The information to be encoded can be text or raw data. The usual data size is from a few bytes up to 2 kilobytes. It can store up to 2335 alphanumeric characters. This is common on printed media such as labels and letters. The code can be read quickly by a scanner which allows the media to be tracked, e.g., on a parcel.

Semacode (Semapedia code, 2011) is machine-readable ISO/IEC 16022 data matrix symbols which encode URLs. It is primarily aimed at being used with cellular phones which have built-in cameras. A URL can be converted into a type of barcode resembling a crossword puzzle, which is called a “tag”. Tags can be quickly captured with a mobile phone’s camera and decoded with a reader application to obtain a web site address. This address can then be accessed via the phone’s browser.

2.2 The Arduino

The Arduino (Arduino, 2011) is an open-source electronics prototyping platform based on flexible and easy-to-use hardware and software. It is a single-board microcontroller, designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open hardware design for the Arduino board with an Atmel AVR processor and on-board input/output (I/O) support to facilitate programming and incorporation into other circuits. An important aspect of Arduino is the standard way that connectors are exposed, allowing the processor to be connected to a variety of interchangeable add-on modules (known as shields). The software is written in a C-like programming language. A boot loader on the board allows later changes to the software. The microcontroller on the board is programmed using the Arduino programming language (based on wiring). An Arduino-integrated development environment (similar to that used for the processing language) simplifies the development and debugging process. Arduino projects can be standalone or they can communicate with software running on a connected computer. The Arduino system easily interfaces with a computer via USB when programming is required.

2.3 Sensors

Sensors can be described as the’ eyes’, ‘ears’ and ‘skin’ of the virtual world. Sensors are physical devices that serve as state- and event-receptors of the real world and translate what they observe into a medium suitable for the virtual world of information technology. Without sensors, the virtual world will remain detached from what we as humans experience. Inputs received from sensors contribute to the creation, and maintenance, of a virtual world which to some extent represents the physical world. Examples of sensors include audio microphones, position sensing via the Global Positioning System (GPS), video cameras such as a web camera, and temperature sensors. An audio microphone is an electromechanical device designed to connect sound into an electric signal used in transmitting sound. A GPS is a radio navigation system that allows the user to determine their exact location. Satellites in orbit transmit precise signals, allowing GPS receivers to calculate and display accurate location, speed and time information to the user. A web camera is a video capture device connected to a computer network. It continuously monitors an activity and sends it to a web server for public viewing. A temperature sensor is a device that uses a sensing element to measure temperature external to the sensor.

2.4 Actuators

Actuators are the 'limbs', and 'vocal tract' of the virtual world. These physical devices enable the expression of the virtual world by enacting on the real world through things that inter alia light up, slide, rotate, vibrate, heat, and cool.

Exciting research is being conducted in the use of novel materials that act as sensors which are incorporated into everyday clothing. To compliment the sensors, small lights and buzzers are woven into the cloth to act as actuators. An example of how such devices can be incorporated in clothing is Buechley's Quilt Snaps (Buechley, 2006).

2.5 Robotic arm

A robotic arm is an example of an actuator and is used by computer processes to manipulate physical objects. The various linkages between arm sections enable the arm to reach a wide range of positions. A gripping mechanism at the end of the arm can grasp lightweight objects and release them when required.

3 Methodology

3.1 Aims and objectives

The purpose of this study is to integrate IoT technologies into education and specifically in the design of a remote-controlled laboratory. The objectives of the study were:

- Designing the architecture of the remote-controlled laboratory
- Producing prototype components of the system, i.e. the laboratory controller, the robotic arm and the sensors.

3.2 Procedure

A literature survey was conducted to establish a theoretical framework behind the system. The information collected was then utilised in the design of the architecture and the hardware components.

4 System overview

The envisaged system allows a remote operator access to a central, but geographically remote, laboratory. A user, or a group of users, use a co-located computer with appropriate software to access the remote laboratory (Fig. 1). The learner instructs the remote robotic arm to pick up previously-prepared vials and mix the contents. Progress- and the results of the experiments are observed using the web camera and values from the sensors that are displayed on the computer.

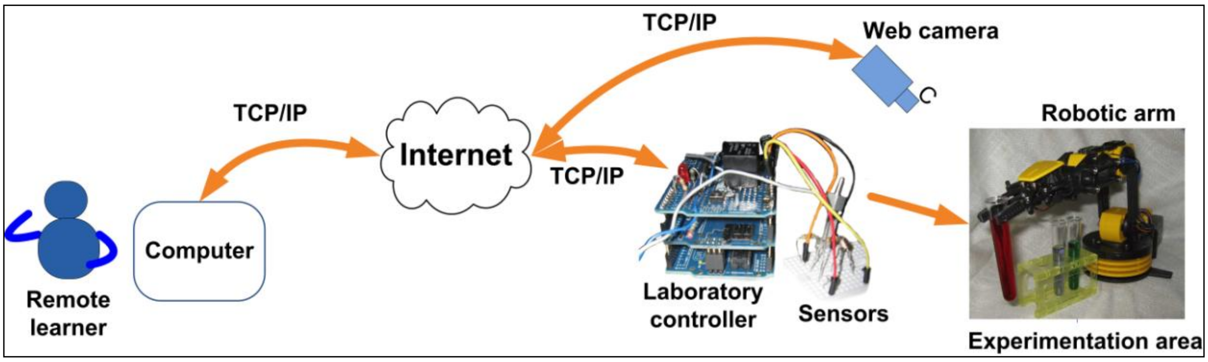

Figure 1. System overview

The system supports a chemical reaction between water and a chemical. Students remotely give instructions to actuators to pour the chemical and water into a beaker. Cameras in the well-resources laboratories send images of the experiment to the under-resourced laboratories. A sensor in the beaker sends the temperature from the chemical reaction at intervals to the remote student and the final colour of the contents of the beaker at the end is viewable using web cameras. Once the reaction stops, the actuator is instructed remotely to pick up the beaker and pour contents into a dropper. The student in the remote laboratory counts through the web camera the speed at which the drops move so as to measure viscosity of the liquid. RFID tags are incorporated in the remote laboratory to ensure that the correct chemicals are mixed.

The system consists of a remote laboratory, an internet connection, and a computer co-located with the user. Each of these components are described next.

4.1 Remote laboratory

The remote laboratory consists of a low-cost robotic arm (Fig. 2), the laboratory controller (Fig. 3), a web camera, and various objects and chemicals to be used in experiments.

Instructions received over the Internet are interpreted and acted on by the laboratory controller. The laboratory controller (Fig. 1) consists of a signal conditioning and actuator circuit, an Internet connection circuit, an Arduino (Igoe, 2007) microcontroller circuit, and various sensors. For example; the robotic arm may be instructed to mix the red and green vials. By observing the resultant colour (yellow), the learner has gained first-hand experience of mixing colours.

Figure 2: Robotic arm

Not only is a video stream made available to the learner, but sensor data is also returned by the remote laboratory. Sensor data include ambient light-levels, temperature levels, sound, and vibration.

Machine-readable identifiers are attached to the objects in the remote laboratory with the intended purpose of safeguarding the laboratory against abuse. Numerous identifiers are available for this purpose, including RFID (Sheng, 2009) and optical markers such as fiducials (Bencina, 2005) and QR codes (QR code, 2000).

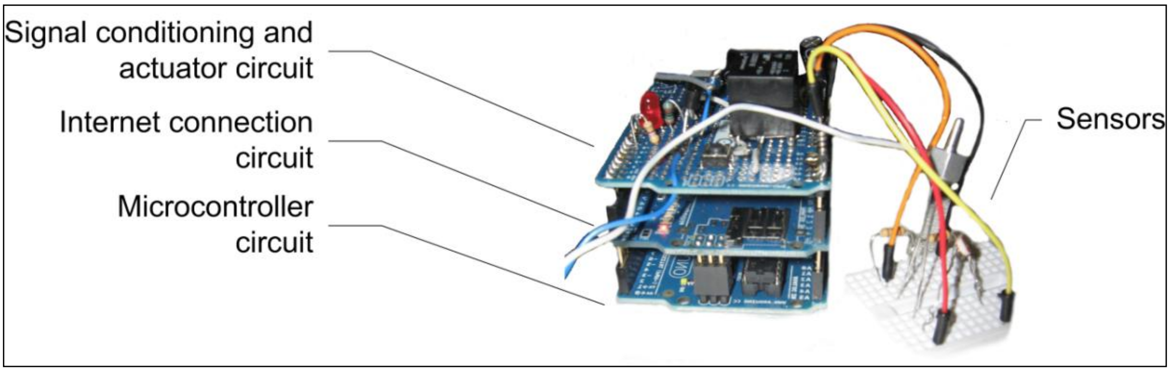

Figure 3: Laboratory controller

4.2 Internet

Instructions can be sent to the remote laboratory and sensor data plus a video stream can be returned to the learner by using the open standard TCP/IP protocol. If bandwidth is limited as anticipated in rural regions, the video stream can instead be replaced by still images that are updated at regular intervals.

Data and instruction are first routed to a service that can be accessed on the Internet before it reaches the destination. This service is part of the IoT. The purpose of this service is to ensure that the laboratory is not used beyond its designed capacity. Should this be detected, this service can either modify the commands to bring them in line with the laboratory's capacity and intended purpose, or the commands can simply be ignored.

4.3 Co-located computer

A computer running custom-developed software allows the learner to manipulate objects and chemicals in the remote laboratory. In addition, data from the remote sensors are made available to the learner using this interface.

5 Discussion

This research is a contributory effort towards enhancing science education in South Africa. In an economy in which education resources are unevenly distributed, resulting in unequal access to education, it is of vital importance to come up with innovative ways to mitigate the circumstances. By pairing schools with science laboratories with those without, learners from less-resourced schools can get the opportunity to experience psychological presence in laboratories, as opposed to a simulated environment.

IoT technology is already making an impact in other spheres of life all over the world. It should also be adopted to make an impact in education in South Africa. One of the requirements is that there should be a connection to the internet at least to enable access to remote laboratories. Unfortunately Internet connectivity does not cover all schools in South Africa currently. Efforts are in place to put in place broadband although this may take a little while longer.

Although the architecture proposed in this research is limited to a chemical laboratory situation, such customised systems can be designed for different aspects of the science curriculum. Although the system presented in this paper has not been implemented in full, some of the components are functional and in use in our own laboratory. We have yet to develop the user interface and also integrate the remote robotic arm with the laboratory controller.

6 Conclusion

This paper is about the architectural design of an education technology that marries IoT technologies into remote laboratory facilitation. In its current state it is customised to a chemical laboratory environment.

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