Voice Driven Virtual Assistant Tutor in Virtual Reality for Electronic and Electrical Engineering Remote Laboratories

Intelligent Systems Research Centre, Ulster University, Derry, Northern Ireland
mj.callaghan@ulster.ac.uk

Abstract. The first generation of affordable consumer virtual reality headsets and related peripherals are now available. Question-Answering (QA) systems and speech recognition/synthesis has improved dramatically over the last decade. Virtual assistants, based on speech-based services are growing in popularity and can be used in a range of diverse application areas. This paper explores the practical use of virtual reality, IOT and voice driven virtual assistants in remote laboratories to facilitate visualization of electrical phenomena and to tutor students; guiding them through each stage of an experiment; presenting supplementary teaching resources when requested; accessing, controlling and configuring instrumentation and hardware and providing feedback with summative and formative assessment. The re-purposing of existing teaching material for use in an immersive environment with a virtual assistant is shown and the limitations and opportunities offered by the approach taken and the technologies used are discussed. The process of integrating test instrumentation, the board under test, a switching matrix and additional teaching resources into virtual reality using IOT is discussed and the inclusion of virtual assistants described. Two case studies of practical working examples of remote laboratories in virtual reality with a virtual assistant tutor are demonstrated and the viability and long-term opportunities for the use of virtual reality and virtual assistants in the context discussed.

Keywords: Virtual Reality, IoT, Automatic Question-Answering (QA) systems, speech recognition and synthesis, virtual assistants, voice user interface practical laboratories.

1 Introduction

Affordable consumer virtual reality headsets and peripherals are increasingly common driven by advances in video game technologies and related hardware [1]. Automatic Question-Answering (QA) systems and speech recognition/synthesis functionality and accuracy has improved dramatically over the last decade allowing the use of voice interactions to automate and organize complicated tasks and directly answer domain specific questions using natural language and have the potential to revolutionize human
interactions with devices and data [2,3]. Virtual assistants, based on speech-based services are growing in popularity and are now entering the mainstream. These services come with a set of built-in capabilities and allow the creation and addition of new abilities e.g. the Cortana Intelligence suite provides a development environment and distribution ecosystem which includes IoT where developers can publish and distribute their voice based applications with functionality to connect devices to cloud based services [4]. These flexible, highly functional development environments and backend architectures allow the use of voice enabled services in a range of diverse application areas including education, industrial and home automation. Practical virtual and remote laboratories engineering laboratories for undergraduate students are evolving driven by the availability of more affordable instrumentation, hardware kit, internet growth, new types of interfaces/front ends and a move towards student-centered pedagogies [5].

This paper explores the use of virtual assistants in remote electronic and electrical engineering virtual reality laboratories to tutor students; guiding them through experiments; presenting supplementary teaching resources when requested; accessing, controlling and configuring test instrumentation and hardware and providing feedback through summative and formative assessment. Two case studies and practical working examples of voice driven virtual assistants are demonstrated based on the enhancement of an existing remote laboratory and teaching resources for fundamental electronic and electrical engineering circuits suitable for the first year of an undergraduate degree. The process of integrating test instrumentation, the board under test, a switching matrix, additional teaching resources, an IoT hub and two types of virtual assistants into an immersive virtual reality environment is discussed.

Section II of this paper provides an overview of the Cortana Intelligence suite and the creation of voice user interfaces using the Microsoft Bot framework. Sections III, IV and V discusses challenges related to the re-purposing of an existing laboratory for voice interactions and virtual reality and provide practical example of this process and explore deeper integrations. Section VI presents the conclusion and possible future work in this area.

2 Creating voice user interfaces using the Microsoft Bot framework and the Cortana virtual assistant

The Microsoft Bot framework is part of the Cortana intelligence range of cloud based services and provides a set of tools to create, deploy and publish conversational bots across a range of channels and interaction modes including text and voice. The Cortana personal assistant is a speech-enabled channel in the framework that can send and receive voice messages using cloud based voice recognition and speech synthesis capabilities based on natural language processing (NLP) algorithms [6]. It is integrated into Microsoft Windows 10, can be installed as an app on Android and iOS devices and is available in smart speaker format on Harman Kardon Invoke hardware devices [7]. Cortana is capable of processing a range of voice commands and user interactions and can be used as a home automation hub to access and control smart devices. When operating in default mode the Cortana assistant continuously listens to all speech in its
general vicinity and responds/becomes active when it detects the use of a “wake word”. The voice command interactions detected after activation are sent to the cloud for processing through LUIS (Language Understanding Intelligent Service) and relevant responses generated (Figure 1). Third party developers can create voice user interfaces/Bots that extend the capabilities of Cortana. These are called using an invocation name which is a key word used by the end user to initiate a set of voice interactions/responses with Cortana and the developed/connected services or hardware devices.

The voice interactions and responses are defined by an interaction model (Figure 2) which manages communications between the parties involved using an intent schema, sample utterances and entities [8]. Intents are the core functionality of your skill and are a list of common actions your skill can accept and process. Entities are parameters or values passed with an intent. Sample utterances specify the spoken words and phrases users can say to invoke intents.

<table>
<thead>
<tr>
<th>Action</th>
<th>Voice User Interaction (Interaction model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make a request</td>
<td>User says, “Ask Cortana to open practical engineering laboratories”</td>
</tr>
<tr>
<td>Collect more information from the user</td>
<td>Cortana replies “Which laboratory?” and then waits for a response.</td>
</tr>
<tr>
<td>Provide required information</td>
<td>User replies, “Series Parallel laboratory.”</td>
</tr>
<tr>
<td>User request in completed</td>
<td>Cortana initializes Series Parallel laboratory and responses “Welcome to laboratory one, the Series Parallel…”</td>
</tr>
</tbody>
</table>

Fig. 2. Interaction model for Cortana Skills kit
Re-purposing a remote laboratory for voice/virtual reality

The architecture of a typical online laboratory allows the user, located in a separate geographical location, to access, control and conduct experiments remotely. The hardware control element is usually facilitated by the use of GPIB (General Purpose Interface Bus) or similar communication standards connected to a switching matrix allowing test instrumentation and experimental boards to be selected, connected and configured during experiments. The lab(s), related teaching resources, test instrumentation and the circuit board under test are accessed through the web using a client/server approach [9, 10]. The approach taken for this project was to reuse most of the existing local control protocols and add a Raspberry Pi running Microsoft Azure IoT (Figure 3). This facilitated interactions and communications between the physical laboratory, the Cortana/LUIS/Bot framework and the client user interface which is an application created in the Unity games engine for the Oculus Rift/touch controllers and allows remote access to and control of the remote laboratory through Virtual Reality [11]. In practical terms this process involved creating a bot service in the Azure portal, enabling the Web-Chat/Cortana channels and extending the functionality/range of understanding of these channels using LUIS. Communications with the Unity Virtual Reality front end was through the Microsoft Azure IoT stack/Raspberry Pi using UDP.

Fig. 3. Re-purposed laboratory with Cortana intelligence services
4   Series Parallel experiment with Virtual Assistant Tutor in Virtual Reality

The experiments in the existing online remote laboratories are focused on first year undergraduate level electronic and electrical engineering and cover topics ranging from series/parallel to oscillator circuits. The Series Parallel experiment was selected to develop a prototype using a virtual assistant tutor in virtual reality with circuit phenomena visualization to explore the viability and challenges of this type of approach (Figure 4).

<table>
<thead>
<tr>
<th>Laboratory</th>
<th>Objective/circuit</th>
<th>Theory</th>
<th>Learning outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab 1</td>
<td>Solve for R1 given Vr2,R3 to get value Vo</td>
<td>( V_o = \frac{R_{eq} \times V_o}{R_{eq} + R_1} )</td>
<td>Parallel and series circuits. Equivalent resistance. Circuits and current flow.</td>
</tr>
</tbody>
</table>

Fig. 4. Series Parallel game based laboratory for undergraduate engineering students

The Series Parallel experiment employs a game and time based approach where using the formulas provided for equivalent resistance \((R_{eq})\), voltage out \((V_o)\) and the current values of input voltage \((Vin)\) and resistors \(R2/R3\) the students have to calculate the correct value of resistor \(R1\) to achieve the given target output voltage \((Vo)\). A score is then awarded based on how close the calculated value was to the target value of \(V_o\) and the time taken to complete the calculations. When the laboratory is in progress, the game user interface/client communicates with the underlying hardware, switching matrix and instrumentation and connects the selected value of resistor \(R1\) to physically complete the circuit [12]. Using this experiment as a starting point, a structured series of interactions suitable for a voice driven experience which included an overview of the laboratory, access to help, remote control and configuration of instrumentation and circuits and assessment with feedback to the student was created (Figures 5 + 6).

The web based user interface was removed and the teaching material and related resources re-purposed for use in an immersive 3D environment built in the Unity games engine and using the Oculus Rift/touch virtual reality headset and peripherals. A virtual laboratory environment was created to host the experiment and designed to facilitate the visualization of electrical phenomena (Figure 7). The physical layout of the Series Parallel circuit was recreated at “room scale” to allow the student to explore individual circuit components and related voltage and current values. The virtual laboratory contains a series of feedback panels which were synchronized with the Cortana virtual assistant to provide additional/complementary information to the student i.e. an overview of the circuit to solve, instructions on how to approach the experiment, an interface to select and connect individual components, written feedback from Cortana, a live streaming webcam showing the physical circuit and instrumentation in the real world lab and formative/summative when the lab was completed.
Fig. 5. High level overview of user interactions and hardware communication
<table>
<thead>
<tr>
<th>TASK</th>
<th>INTENT NAME</th>
<th>CORTANA PROMPT</th>
<th>UTTERANCES</th>
<th>HARDWARE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Cortana app</td>
<td>app.launch</td>
<td>Welcome to laboratory one, the Series Parallel circuit. This session will help you to understand the operation of series parallel resistor networks. You will also learn about equivalent resistance. I have initialised the hardware and we are ready to begin. When you are ready, you can ask for your objectives, by saying, what are my objectives? Or you can say leave to exit the program.</td>
<td>What are my objectives. Leave.</td>
<td>Initialise hardware and circuit board(s) based on experiment selected</td>
</tr>
<tr>
<td>Provide overview of experiment selected</td>
<td>help</td>
<td>For this laboratory, you need to solve for the value of resistor R1 to achieve the required target output voltage Vout. I will provide the values of the input voltage Vin, resistor R2 and resistor R3 and the value of the output voltage Vout. From these values, you can calculate the required value of resistor R1. When you are ready to start, please say ready to start. Or you can ask for some formulas to help you solve the circuit by saying formula please. Or you can say leave to exit the program.</td>
<td>Ready to start. Formula please. Leave.</td>
<td></td>
</tr>
<tr>
<td>Offer context specific help</td>
<td>selectFormula</td>
<td>Do you require the formula for the voltage out or the formula for the equivalent resistance?</td>
<td>Voltage out. Equivalent resistance.</td>
<td></td>
</tr>
<tr>
<td>Provide context specific help</td>
<td>provideFormula (equivalent resistance)</td>
<td>Equivalent resistance is equal to the product of resistor R2 multiplied by resistor R3, divided by the sum of resistor R2 plus resistor R3. The value is in ohms. When you are ready to start, please say ready to start. Or you can ask for more formulas to help you solve the circuit by saying formula please.</td>
<td>Ready to start. Formula please.</td>
<td></td>
</tr>
<tr>
<td>Provide context specific help</td>
<td>provideFormula (voltage out)</td>
<td>The value of the voltage out is calculated by multiplying the equivalent resistor, R equivalent by the value of voltage Vin. Then dividing the product by the sum of the values of R equivalent and resistor R1. When you are ready to start, please say ready to start. Or you can ask for more formulas to help you solve the circuit by saying formula please.</td>
<td>Ready to start. Formula please.</td>
<td></td>
</tr>
<tr>
<td>Prompt to provide correct value of R1 to achieve target value of Vout</td>
<td>readytoStart</td>
<td>The value of the input voltage Vin, is 5 volts, the value of resistor R2 is (valueR2) ohms and the value of resistor R3 is (valueR3) ohms. Now please state the value of resistor R1 to achieve the target output voltage of (valueVout) volts. There are 4 options available for the value of resistor R1 which are 1000, 1500, 2200 and 3300 ohms.</td>
<td>(First) ohms. (State value of R1 in ohms) Set input voltage, select and physically connect values of R2 and R3</td>
<td></td>
</tr>
<tr>
<td>Complete circuit and calculate score</td>
<td>circuitComplete</td>
<td>I have connected resistor R1 with the value of (resistance) ohms and completed the circuit. The output voltage is (voltage) volts and your score is (score).</td>
<td>Restart. Leave. Physically connect selected value of R1. Read Vout</td>
<td></td>
</tr>
<tr>
<td>Provide feedback</td>
<td>feedback</td>
<td>Feedback on the score and on how to increase the score achieved is then given to the student based on the target value of voltage out and the calculated values of voltage out.</td>
<td>Restart. Leave. Reset hardware</td>
<td></td>
</tr>
</tbody>
</table>

Fig.6. Interaction model for Cortana Series Parallel experiment
Fig. 7. High level overview of the virtual reality laboratory environment

The student starts the lab/interactions by launching the Virtual Reality Unity application on the PC and using the invocation name to begin the engagement process with Cortana. This initializes the remote hardware, circuits and instrumentation (Figure 8).

Fig. 8. Remote hardware, circuits and instrumentation and virtual reality user interface
Cortana then welcomes the student to the laboratory, provides an overview of the experiment and sets out their objectives (Figure 9). It guides the student through the laboratory with a series of voice prompts, underpinned and complemented by the supporting material on the feedback panel e.g. help provision and formulas for equivalent resistance and voltage out.

The student is then asked to physically select and connect the correct resistor value using the Oculus Touch controllers to bias the circuit and achieve the required output voltage (Figure 10). When the resistor is connected virtually it is also connected physically through the switching matrix. Visual feedback is provided on the hardware camera panel which shows a live feed of the multi-meter in the physical lab (Figure 11).

Fig. 9. Lab welcome, initialization and overview

Fig. 10. Using Oculus Touch to connect resistors in virtual environment
Cortana provides the student with summative and formative feedback i.e. an overall score and a context related summary on how well they completed the experiment and areas of improvement if needed. The student can use the touch controllers to navigate and explore the virtual circuit further e.g. relative voltage drops and current flow through each of the individual components (Figure 12).
5  Deeper integration with Unity using Cognigy AI

The previous demonstration used the Microsoft Bot framework and Cortana as the virtual assistant. However, the current iteration of the Bot framework does not have a SDK for the Unity games engine. Cognigy AI offers a cross-channel voice and chat user interface with a deep Unity integration through its platform [13]. Figure 13 provides a high level overview of the Cognigy integration in Unity. The plugin/extension works by using the computer microphone to record the student's voice/input which is then parsed to text. The extracted text is sent to a Cognigy bot (as a flow) and associated with an intent. The intent processes the request and sends the response/action to complete back to Unity which then carries out any required actions and provides audio feedback to the users (Figure 14). The integration streamlines the development process and provides a better overall user experience.

Fig. 13. Cognigy integration in Unity
6 Conclusion and future work

This paper explored the feasibility of using virtual assistants, voice user interfaces and virtual reality in campus based engineering laboratories to tutor and assess students. Practical case studies were presented based on the modification of an existing remote laboratory where a virtual reality front end with virtual assistants were added. The working examples shown demonstrated how this approach could be used to guide a student through an experiment, providing supplementary teaching resources and help when requested while accessing and controlling remote test instrumentation and hardware. It also demonstrated how voice user interfaces integrated into a virtual reality environment could be used for summative and formative assessment and to provide feedback to students. This area of research is set to grow rapidly as virtual assistants, consumer virtual reality and related peripheral devices become mainstream driven by
low cost consumer hardware and cloud based services. Future work on this project will focus on developing formal, structured approaches to the creation of virtual assistant/voice user interfaces/virtual reality environments for engineering laboratories, extending the approach to all of the practical experiments discussed previously, investigating how this approach could be integrated with existing and widely used remote laboratory infrastructures and frameworks and exploring possible uses of these technologies to improve accessibility and access to teaching resources for students with disabilities.

7 References