Developing a Cloud Robotics Infrastructure for a Humanoid Robotic Teaching Assistant

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This project investigates the use of robotics in the classroom as a way to encourage interactivity amongst students. Building on work by the author that looked at the use of technology to add additional feedback mechanisms to the classroom, this work will describe a software framework for the Nao robot that allows a robotic teaching assistant placed in the classroom to act as a proxy for students, using input they provide via a smartphone/tablet application to show student reaction to the lesson and to ask questions. This paper begins this work by describing a prototype system demonstrating robot network connection functionality and a cloud based architecture for robotic control. This infrastructure can be built on to enable artificial intelligence interactions with robots in a variety of settings, such as assistant positions in corporations, or within an educational setting. Through experimental testing, this infrastructure will be assessed for its affect in the classroom and on the use of a robot as a teaching assistant. The proposed outcome of the work is a greater understanding of how robotics can be used to support a general set of classroom activities, beyond those conducted in the traditional computer science classroom.

Introduction

Robotics is an area of intense interest currently, with humanoid robots emerging that can mimic the behaviour of humans much more accurately than ever before. This provides an opportunity to conduct research on how robots might help individuals with robotic assistance and skill development in areas as diverse as business, information technology, and education.

As the 21st century moves on, consumer grade, pre-built anthropomorphic robots designed to complete human-like tasks are becoming more common. For instance, Nao (pronounced *now*) is an autonomous, programmable humanoid robot developed by Aldebaran Robotics, a French company headquartered in Paris. Nao robots have been used for research and education purposes in numerous academic institutions worldwide and, as of 2015, over 7,000 Nao units are in use in more than 50 countries, according to Aldebaran (see https://www.ald.softbankrobotics.com/).

Whilst many projects with Nao are conducted locally, the field of Cloud Robotics is growing and could be applied to Nao (and eventually to other robots) for robotic assistance purposes. Cloud computing technologies enable robot systems to be endowed with powerful capability whilst reducing costs by offloading processing to computers in the cloud. Humans can also delegate tasks to robots remotely through networks, and Artificial Intelligence in the cloud can be applied to enhance the autonomous actions of the robot. This provides an excellent platform to develop a cloud-driven, autonomous robotic assistance model applicable in a variety of different areas.

For instance, with the recent announcement by the Queensland State Government that robotics should become core in all classrooms in 2016 (see http://advancingeducation.qld.gov.au), consideration needs to be given on how this technology might fit into the classroom. One option is that robotics be taught as part of the curriculum, but what if robotics could be used more directly to support teaching activities in the classroom? Specifically, what if a robot could be used to provide direct assistance to the teacher, serving as both a proxy for students as well as a teacher's aide? This proposed research project will look to answer these research questions and other questions relating to the use of a robot as a semi-autonomous robotic assistant driven by a cloud infrastructure.

This paper begins this work by describing a prototype system demonstrating robot network connection functionality and a cloud based architecture for robotic control. This infrastructure can be built on to enable artificial intelligence interactions with robots in a variety of settings, such as assistant positions in corporations, or within an educational setting. The proposed outcome of the work is a greater understanding of how robotics can be used to support a general set of classroom activities, beyond those conducted in the traditional computer science classroom.

Background

Robotics, especially the use of commercial robots in a classroom setting, is a new field that is still being established and explored. Whilst the use of robots in the classroom has been gazetted as one of the priorities of the Queensland state government, little work has been done on how these robots might fit into the everyday lives of students.

Like the introduction of the iPad before it, it's important that robotics not be relegated to a single block of *robotics time*, but rather integrated into the curriculum for all relevant coursework, including English, Mathematics, Social Science and other areas. Also important is the need for the pedagogy to come before the technology - teachers need to see the value in robotics to teach other concepts, otherwise it will not be used. One of the best ways to do this is to introduce reasons for the robot to be used in the general classroom – this implementation of a robotic teaching assistant is one such initiative.

Although robotics in the classroom is not a particularly new concept (Benitti, 2012), it has been acknowledged in recent years that the approach to the use of robotics in the classroom can sometimes be quite narrow (Rusk, Resnick, Berg & Pezalla-Granlund, 2008). Whilst robots are becoming increasingly common, with papers already being written on how best to use them in class (Weilemann, Brune & Meyer, 2016), the functionality of many of these initiatives currently seems to be focussed mainly on the use of robots to teach computer science, basic robotics and other STEM concepts (Eguchi, 2016).

In fact, it can be quite difficult to find papers that cover other uses of robotics in the classroom, with even recent publications considering the use of robotics to teach areas such as arts and music to be supplementary to its use in the STEM area (Miller & Nourbakhsh, 2016). Despite this, some studies are starting to emerge of situations where robots have been used in a more general context in the classroom (Causo, Vo, Chen & Yeo, 2016). However, even within these studies, specific choices are still being made as to how the robot might be used.

A common choice of robot in many classroom activities is the Nao robot produced by Aldabaran robotics, headquartered in Paris (https://www.ald.softbankrobotics.com/en/cool-robots/nao). The Nao robot is used in many countries, and is reported as often being used in the university classroom, where student interaction with a robot can be more sophisticated than in a primary or secondary setting (Mubin, Stevens, Shahid, Mahmud & Dong, 2013). Nao has also been reported as a good robot for social conversations with students (Jokinen & Wilcock, 2014), and is often used in the study of interaction with students with autism, due to the anthropomorphist nature of the robot allowing for a more confident approach from students (Tapus, Peca, Aly, Pop, Jisa, Pintea & David, 2012).

The capabilities of the Nao robot suggest that it might be able to participate successfully in classroom activities as a teaching assistant, assuming it can complete the common tasks of a teaching assistant. Harris & Aprile (2015) conducted a study in 2015 at regional schools in QLD, speaking to 27 teacher aides and 6 administrative staff. Through this study, they identified the common tasks completed by a TA based on their own experience, the top 4 of which are outlined in Table 1.

Based on these previous studies, this project will look at expanding the use of robotics beyond STEM education and into the general classroom. Using Nao as a case study due to his humanoid form, this project will investigate how robots can be used to more effectively serve as a proxy for students in the classroom, asking questions and providing the teacher with important feedback.

Table 1. Top 4 Teaching Aide Tasks (Harris & Aprile, 2015)

Task responsibilities	Percent of Sample
Working with small groups of students on academic tasks (e.g. reading, maths, word study, science)	100%
General classroom support for students and teachers	100%
Administrative duties for teachers (e.g. photocopying gathering resources, data entry, filing, setting up activities)	96%
One-on-one support for ascertained students with disabilities	67%

Experimental Design

This pilot project will look at the use of robotics in the classroom as a way to encourage interactivity amongst students. Building on work by the author (Cowling & Novak, 2012) that looked at the use of technology to add additional feedback mechanisms to the classroom, this work will begin by developing a software framework for a NAO robot named Boris (provided through an industry partnership with ACME Robotics), that allows a robotic teaching assistant placed in the classroom the ability to act as a proxy for students, evaluating their reaction to the lesson through input they provide via a smartphone/tablet application and mirroring that reaction through body language and non-verbal cues for the teacher.

The robot will also be able to act as a proxy for the students, taking questions via the app and reformatting these to query the teacher about content of the course. Finally, during tutorial and workshop sessions, the robot will serve as an autonomous guide, answering frequently asked questions by the students and providing the teacher more time to spend on other aspects of the class.

To begin this project, initially a developer was recruited (funded by ACME Robotics) to investigate how an infrastructure can be developed to support control of Nao through the cloud. To enable this, the project looked at the following:

1. Connect the robot, using WIFI, to a cloud based server for the purpose of receiving instructions from the server and responding to the human audience.

2. Create a way for a handheld mobile device (iPad, iPhone or Android device) using WIFI, to send instructions to the cloud based server for retransmitting to the robot.

The idea was to design a modular system that could be gradually expanded as the robot developed more functionality. To this end, the developer started by creating a set of instructions that could be used for the robot to communicate with the cloud. The initial aim was to develop a simple set of beginning instructions that would just allow the core functionality of the teaching assistant, specifically allowing the robot to connect to the cloud, and allowing students to ask questions directly without disturbing the class. Functionality was also added to provide a way for students to ask urgent questions, and also to allow students to give some rudimentary feedback on how they felt about the class delivery.

Due to the functionality of the Nao robot, it was decided to develop the on-robot components of the architecture using Python code built into the existing Choregraphe IDE provided by Aldebaran. For the server side components, an Amazon Web Instance was used running Linux, Apache and PHP, and code was written in PHP to provide a responsive web interface for students.

Each of these components will be described in more detail below, starting with the robotic assistant instruction set.

Robot Assistant Instruction Set (RAIS)

A basic instruction set was developed for communication with Boris, with the students being able to use the PHP interface to interact with the system, and the system then generating source files with the instructions in them for download to Boris. The set of instructions used took the form of a simple three character 'op-code' followed by a set of parameters specific to that op-code. Each instruction is listed on its own line in the command file and followed by a semi-colon, allowing for easy separating of the instructions when they are downloaded by the robot. The choice of a three character op-code allows for 17,576 different possible instructions, providing ample room for scalability of the features of Boris in the future. In addition, instructions were chosen to be as generic as possible, with a view to complex behaviours being modelled with a sequence of instructions rather than a single complex instruction. Table 2 outlines each of the initial instructions developed for the robot and their parameters.

Table 2. Robotic Assistant Instruction Set Commands

Command	Description
MVE	Moves the robot. Parameters for this instruction are: W - Forward; S - Stop; A - Left; D - Right; Q - Turn Left; E - Turn Right; X - Stop
SET	Used by the Lecturer only. "SET:Timer=X" where X is the number of seconds. Designed to set / configure many different variables for testing purposes.
SPK	Appends question to the list of questions. Lecturer can decide when questions will be answered by touching buttons on the robots forehead. Questions will be added to the questions database.
SPN	Speak now. Used for when asking urgent questions, the question will not be saved in the database.
RES	Response from student. Student can click on the smile and crying face image where robot would then either nod its head or yawn. More responses can be added and format used is "RES:fun" or "RES:bored". Will be used in the future to aggregate an average response from the class and reflect in the robots 'mood'.

Robot Action Framework

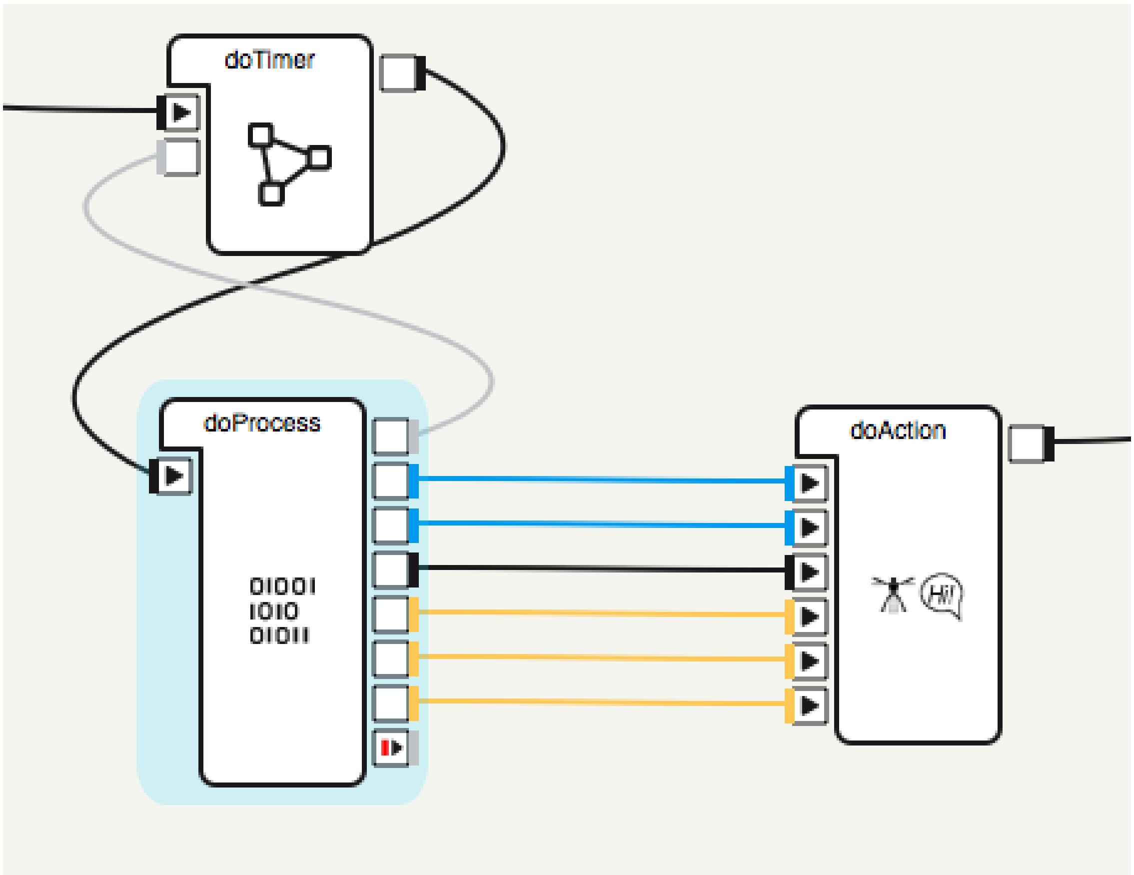

Figure 1 - The overall program in Choregraphe

Once the instruction set was developed, code was written for the robot to interpret these instructions. The code was written using Choregraphe as the IDE with underlying Python code, and the main Aldebaran framework used was ALProxy, required for using Nao proxy commands such as speech, movement, camera and more. This framework is enabled by calling specific parameters for movement, speech etc. using the ALProxy method within the Phython code. Figure 1 shows the overall program as written in Choregraphe, with details of each module described in more detail below.

The first module, *doTimer* is used to set HTTP Request time and execute *doProcess*. Specifically, data is read from the instruction file downloaded from the server using **urllib2** and passed to doProcess to determine what instructions the robot will carry out.

doProcess then takes the content from the server and strips out the instructions and examines them, identifying what the robot will need to do based on this instruction file.

Finally, the *doAction* method is called accordingly by *doProcess* once content from the server is stripped / examined to allow the robot to execute the instructions it has been given. For example, a command to move forward would call **self.motion.moveTo(0.1, 0, 0)** using the ALMotion parameters of the ALProxy framework, whereas a command to speak would call **self.tts.say()** method using the ALTextToSpeech parameter of the ALProxy framework.

Finally, it should also be noted that the robot also has the ability to take videos and pictures of the audience. Whilst this is not currently built into the instruction set, actions are contained in the Choregraphe code to allow this to be added, with an ALVideoDevice being used to create a camera proxy that can then collect and save images in the PNG file format.

Server Side Programming

Finally, the last piece of the architecture is the server side code that generates the webpage that students see to ask a question and interact with the robot, and then takes these questions and adds them to the instruction file that the robot can download.

Currently, the mechanism to allow this is quite simple, with students presented with a simple webpage with a text box and submit button to ask their question. Once they ask a question and press the submit button, their question is written to the instruction file by the PHP server code and the robot then retrieves this file periodically. Figure 2 details a simple example for writing these questions to the file (note that the files used are called Boris because that is the name of the robot being used in this example).

Robot and Server (speaking a question)

1. User connects to server IP address from browser
2. User click walk and browser send GET request to index.php?do=s
3. Server: If ‘sAsk.php’exists, writes “SPK<question>” to the file
4. Robot: Checks “http://serverIP/boris.php” every 1 second
    a. Server (boris.php): Checks ‘sAsk.php’ and if content is not empty, send contents to Boris. Then deletes ‘sAsk.php’ content. File is locked before reading and deleting content.
5. Robot: Receives content from server. (In this case ‘SPK:<question>’)
    a. Since content starts with ‘SPK:’ calls speak function.
    b. <question> is added to the queue for the robot to ask when prompted by the lecturer

Figure 2 – Robot & Server Code Sequence

Bringing it Together

Using these three pieces, we can now bring together a fully functioning robotic assistant prototype. An interface was developed for students to provide input to the robot, and the robot was set up in a classroom and connected to the network. An introductory speech was written for the robot, and refined to ensure that he was understandable, and code was written to allow this speech to be launched from the robot. To go along with this presentation, the robot was also given a set of slides to present from, with the progression controlled by the lecturer. Figure 3 shows this lecture.

Figure 3 – Boris Giving an Introductory Lecture

In addition to the original question asking interface, a queue system was also developed to collate all the student questions and allow them to be addressed one at a time. From the student interface perspective this was identical to that described above, but within the robot, it required a more complex set of instructions that allowed him to identify when a question was received and also allowed the lecturer to approach the robot and get it to provide multiple questions in sequence. Figure 4 shows the question asking web interface.

Figure 4 – The Student Question Asking Interface

In the classroom, these changes were embodied by the robot raising its hand briefly for each question as it arrived, and the lecturer then being able to use the buttons on the head to indicate they were ready to answer questions, as well as navigate through the questions one at a time. A basic recording functionality was also added to record answers to the questions, with a view towards adding later functionality that allowed students to replay questions with the robot outside of the lecture environment. Figure 5 shows this recording facility in the web interface

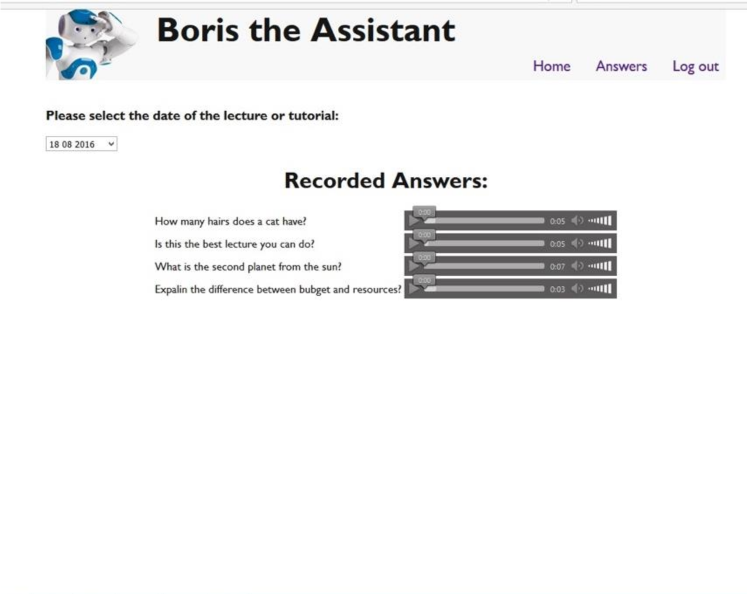

Figure 5 – Question Recording Facility

Student feedback from this initial test was good, and has since been used to make updates to the software used on the Nao robot. In addition, feedback was generally positive, with students reporting that the robot helped them feel more comfortable in the classroom. Figure 6 shows the robot in the classroom performing his duty as a teaching assistant whilst the lecturer moves around the room and conducts the lecture.

Figure 6 – Boris Acting as a Teaching Assistant

Research Design

Based on this initial work, the cloud robotics framework will be developed by a research assistant in several stages using a design-based research (DBR) methodology, following Bakker & van Eerde (2015). DBR entails three key phases: “preparation and planning”, “teaching experiment”, and “retrospective analysis”.

The first stage of this process has been conducted, with initial data gathering from stakeholders such as teachers having been obtained, and an initial prototype developed that will be used for several rounds of usability testing with teachers and students to refine the prototype.

Once this has been done, classroom testing will be conducted in several sample lessons, with students given access to the app and then asked to complete a survey, based on the Teaching Acceptance Model (TAM) (Bagozzi, Davis & Warshaw, 1992), on how they felt the tool assisted with their learning. Finally, two lessons will be selected in which the cohort will be split, with one group receiving robotic assistance and the other not, and a pre and post-test of student understanding of the content will be conducted to see if the robotics intervention improves learning outcomes.

Both qualitative and quantitative analysis of information will be undertaken in the project. The qualitative information for the project constitutes students' subjective responses to the pre and post-test assessment questions, while the quantitative information will stem from the survey. More particularly, the survey questions will concern existing theory on the digital competency of students, and include demographic questions as well as Likert scale quantitative questions to assess student feeling on the new tools, allowing for correlation between student demographics (such as international and domestic student details, age, gender etc.).

In addition, open-ended qualitative questions will also be included in the survey to allow students to provide additional details including their desirability of the new tools and their views upon employability of similar tools in other courses. Potentially, this qualitative information, further to discussions on evaluations with the research group, will facilitate answering how the derived research outcomes may be generalised across disciplines. Also, due to the complexity of this question, and depending upon the survey results, a focus group may also be conducted to collect further rich data on student experiences that relate to this research question. Ethics approval for the pre and post test, survey and the possible focus group will be obtained from the CQUniversity Human Ethics committee prior to administration.

Quantitative data will be analysed using R to identify significant levels of difference in student satisfaction and to analyse whether a significant difference in student outcomes was identified. It is further expected, that data mining approaches, as supported by R, will be utilised to gain broader insights upon the students' satisfactions and learning outcomes than possible through statistical analysis. Qualitative data will be analysed using NVivo and coded to identify significant themes present in comments by the students.

Conclusion

This paper has presented a prototype framework for the use of a Nao robot as a teaching assistant in a classroom, along with a research methodology to test the use of the robot. The outcomes of this work will give a greater insight into the use of robotics in the classroom in this way, specifically in relation to student acceptance of the technology as well as the effect of the technology on learning outcomes. It will also produce a framework, confirmed by the prototype software, for the use of robotic teaching assistants in the classroom.

Initial trials of the robotics architecture have produced promising results, and revisiting Table 1 from the introduction, which detailed the tasks that a teaching aide commonly completes, shows that the Nao robot was able to complete 3 of the top 4 tasks indicated in that table. This suggests that it is possible for a Nao robot to act as a teaching assistant in the classroom, and future work will look to confirm the effectiveness of this approach.

Future work could also look at expanding the framework provided, specifically to empower the cloud based server with artificial intelligence (AI), through affiliation or, within itself. This would enable the AI to formulate instructions to the robot itself, and the effectiveness of this strategy could be tested through a larger, more rigorous research project similar to the one conducted for this pilot study.

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