Cloud based low cost educational robot

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***Abstract*—This paper presents a novel Internet and Telephony cloud based system for low cost educational robotics. A webserver provides a web based on-line application that allows students to write block based or textual programs for a robot. When the program is executed, this server calls a standard mobile phone using the public switched telephony network and uses the telephony audio channel to send actuator commands and read sensors through audio tones. The proposed architecture allows the construction of low cost educational robots that can be programmed and controlled from the web via any mobile phone that can receive calls and has standard earphone connectors.**

I. Introduction

Educational robotics has been gaining great interest over the last years in all levels of education. One of the reasons for such interest is the motivation and interest that robotics awakens on students. In fact, several authors have already shown that the use of robots on education offers stimulating and motivating environments [1], [2], [3], [4], [5], [6], [7], [8].

However, one of the major problems for a broader adoption of educational robotics is its high costs [3], [9], [10], [11]. This problem is even worse in developing countries that don't have much financial resources and still need to import educational robotics kits. One recent effort to solve this problem is the African Robotics Network (AFRON) 10-dollar robot design challenge held on 2012, and the ongoing Ultra Affordable Educational Robot Project.

N-Bot, one of the winners of the 2012 AFRON 10-dollar robot design challenge relies on a mobile phone as a control unit. One interesting feature of this robot is that instead of using digital channels such as RS-232, Bluetooth, USB or wifi, it uses a standard audio channel to receive control information from the phone that acts as the robot controller [12].

Although the initial version of N-Bot used the audio channel even to close control loops [12], its first prototype was based on an smartphone as controller, which is not accessible to a broader population due to its costs. On the other side, developing countries have a wide penetration of mobile phones. In Brazil, for example, there are more than 1.3 mobile phones per inhabitant.

Given this scenario, this article proposes a low cost educational robot architecture based on a mobile phone. Its only requirement is a phone capable of making telephone calls and having an audio connector for headphones. In order to work, the system relies on a cloud system: both the programming and execution of the robot softwares occurs on the cloud, and servers are responsible to send actuator commands and receive sensors status via the audio channel of the telephone call.

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Briefly, the system works as follows: first a student accesses a web page hosted on a server on the cloud. This web page allows the student to program her robot using a textual language similar to LOGO or program the robot graphically by connecting blocks. When the programming is finished, the user clicks on the execute button, which will cause a server to dial to the mobile phone of the student. The student then answers the phone, puts the phone on the robot and the audio channel is used to exchange control commands from the server to the robot and also to read sensors on the robot and send their information to the server, which will use it on the program.

Even if a student does not have a mobile phone, she could try to obtain an old or used model. Mobile phone operator companies could also provide used phones for educational robotics applications on public schools, helping to reuse electronics devices that would be normally discarded.

This article is structured as follows: first, we present some related works regarding mobile phones usage as robots' remote controls via audio channels. Next we present details of the proposed architecture followed by results of its implementation. Finally, the Conclusion presents our final remarks and future trends.

II. Related work

This section reviews works related to the proposed system regarding its audio based communication system and web-based programming environments for robots.

A. Audio control channel

One approach commonly used to remotely control devices using audio tones is based on the Dual Tone Multi Frequency (DTMF) system. DTMF signals provide a robust way to transmit information via audio channels, even noisy ones. It is most known by its use on telephone keyboards, as the press of each digit on a phone's keypad produces a unique DTMF signal. These are frequently used in Interactive Voice Response systems (IVRs), such as banking applications that allows customers to check their balance by typing a password on the phone after calling the bank. Although DTMF was created more than 60 years ago, the system is still pervasive in telephony systems and used in practically all new phone projects [13].

DTMF usage to remotely control robots has been already explored in several works, such as the systems described by Patil [14] and Sai et al [15]. Manikandan et al [16] present a robot that uses two mobile phones: one installed on the robot, and another that functions as a remote control. In both projects, the robot control is based on the telephone keys pressed on the remote phone. A DTMF decoder circuit receives the audio signals from the headphones output of the phone and provides 4-bit control codes to a microcontroller that will effectively generate the desired movements.

In the same way, Tuljappa et al [17] propose a system that uses DTMF to remotely control home appliances and robots via telephone calls. Another work [18] directly map certain phone keys to basic movements of a remote robot controlled over a phone call: digit 2 for front, 8 for back, 6 for right and 4 for left. Naskar [19] also presents a system that uses DTMF tones sent remotely to control a military robot, including even keys to trigger real guns. In this work, instead of phones, radio devices are used to transmit the DTMF signals.

We emphasize here the novelty of our work: while related works use the audio channel and DTMF signals to build remote control systems, our system uses the same principle to transmit actuator commands that were previously programmed by the user or student. Moreover, the system also offers feedback with sensor reading information. In that way, our proposal consists of a fully programmable system, instead of simply remote control over the phone.

B. *Web based robot programming*

In order to program robots, even educational ones, users must install, configure and learn to use specific robot programming environments. Such tasks may hamper the usage of robotics in education, as even teachers are frequently not experienced with new software installation and configuration. Moreover, public computers in schools or libraries might have restricted usage policies with no software installation permissions [20].

One of the solutions for such problem that has been proposed by several authors is to provide web based programming environments for robots [21], [22], [20], [23], [8]. These authors explain that such systems allow any computer with a web browser to be used to program a robot, without the need to install any additional software. Although these works do solve the mentioned problem, avoiding the need of program installations and configuration, they are only applicable to sophisticated robots that are equipped with some sort of Internet connectivity system in order to be remotely programmed.

In the next section, we present the proposed system, which offers a web based programming environment and a system for the execution of the robot software on the cloud that will actually control the real robot. The circuit used on the robot is simple, without the need of Internet connectivity and reducing its costs.

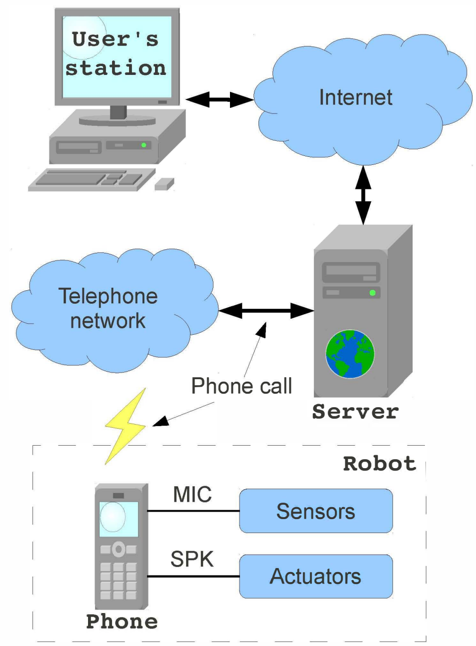

Fig. 1: High level overview of the proposed system

III. Proposed System

Figure 1 shows an overview of the proposed system. A student can design her program by accessing a web page. After programming the robot using blocks or a textual language, the server will associate the newly created program with the user's phone number. When the program is executed, the server calls (or receives a call) to/from the phone attached to the robot using the Public Switched Telephone Network (PSTN). As the call is established, DTMF tones are exchanged between the robot and the server during the whole program execution. The program execution itself actually happens entirely on the server, and the audio tones are used to transmit actuators commands.

A. *Robot's hardware*

The robot's hardware is backwards compatible with any robot that can receive remote commands using DTMF via a telephone call. In that way, all robots mentioned on section II are automatically compatible with the proposed system. For completeness, we provide here an overview of a low cost hardware for such robot.

Figure 2 shows a block diagram of the robot's circuit. A microcontroller is programmed to both decode DTMF tones and to generate DTMF tones, thus being able to receive commands and send sensor data. Using an AtMega, for example, the microcontroller used on Arduino boards, would allow a robot to have up to eight servo-motors that can be smoothly and independently controlled. The remaining digital and analog ports of the microcontroller can be used to read sensors and generate corresponding DTMF signals that are sent to the server encoding sensor states.

In order to build such system, an algorithm running on the microcontroller must identify DTMF digits to decode them

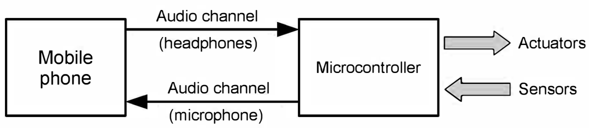

Fig. 2: Block diagram of the circuit of the proposed system

and execute actions. As DTMF tones are always characterized by a pair of frequencies, the natural solution for such requirement would consist on using the Fast Fourier Transform (FFT), however, for performance reasons we use the Goertzel algorithm [24], which looks for fixed frequencies on a given signal. Thus, the program execution on the server generates DTMF digits that will be sent over the phone line, decoded by the microcontroller and result in an actuator action.

B. Web Server

The web server is responsible for receiving user connections from their web browsers. It is divided on the server side and client side. The server side is responsible for storing the web application. When the user writes a new program, it is sent to the server, which stores the program as a file for further usage.

The client side consists of JavaScript and HTML content delivered from the server to the browser of the user. It includes the Blockly language, an open source project that allows programs to be graphically developed by connecting blocks. Blockly includes a code generator that generates the source code for several languages based on the block based program. We have added a new language to Blockly, which is generated after the block program is designed. We also added new blocks for robot actions such as reading a sensor, front and back.

Students can develop the block based program and then generate the source code. If needed, users can directly type textual source code. In both cases, the program can be edited and executed again. Once de program is saved, it is shared with the telephony server to be executed.

One important input of the web page is the user's phone number, which will be used to call the user's phone or identify the call from this specific phone in order to execute the program associated with it.

C. Telephony Server

The telephony server relies on Asterisk (*), an open source framework that allows the implementation of communications applications, Voice over IP (VoIP) gateways, conference servers and custom phone applications. An Asterisk based telephony server can be connected to standard analog or digital phone lines, mobile phone lines or cluster of lines, such as T1s. These connections require specific hardware, however Asterisk can also be connected to virtual telephone lines, which are offered as VoIP services. Several providers offer VoIP lines with real phone numbers associated, that can be used for incoming and outgoing calls to the Asterisk server.

One powerful feature of Asterisk is the Asterisk Gateway Interface (AGI). This systems allows developers to write programs in several languages that will be automatically executed by Asterisk on certain telephony events. For example, Asterisk can start a call to a phone and execute a sequence of steps specified by an AGI program. Another common usage, is to associate incoming calls to AGIs. Thus, when a call is received, the program is executed and interacts with the phone call. One common usage of AGIs is to develop Interactive Voice Response Systems (IVRs), such as on-line systems that say "Dial 1 to check your account balance, 2 for support and 3 for new products".

Asterisk also offers a caller identification feature, which we use to identify the origin of phone calls and execute the program associated with a certain phone. For the execution, an AGI program first identifies the caller number and then starts parsing and interpreting the program created by the user. While the program is interpreted, execution status is sent back to the user's browser so that the student can see interactively each piece of code highlighted as the program is executed.

Regarding calling or receiving calls, both options are possible: the system can automatically dial to a user's cell phone when the program execution starts, or the system can wait for a phone call from the user's phone. When a call with the user's number is identified, the server automatically starts the associated user program.

D. Programming Language

We created a simple programming language for the proposed system. This programming language offers basic elements such as variables, repeat instructions and conditional instructions. The main robot control commands of such language are:

- FRONT X: Go front X centimeters
- BACK X: Go back X centimeters
- LEFT X: Turn left by X degrees
- RIGHT X: Turn right by X degrees
- PEN (UP or DOWN): Release or retract a pen
- SENSOR X: Read the value of a sensor

The user types or draws her program by accessing the web application from her Internet browser. When the execution starts, each command above mentioned generates a DTMF tone that is sent to the user's phone. Then, the circuit of the robot decodes the tones and executes the desired command. None of the commands generate an acknowledge message, however, in the case of SENSOR command, the robot's circuit answers by generating one or several DTMF tones with the sensor reading information to be used by the program running on the server.

The language is simple and works as a proof of concept, thus it can be extended, modified or translated.

IV. RESULTS

In order to test the proposed system, the robot, shown on Figure 3, already described and built by Aroca et al was used

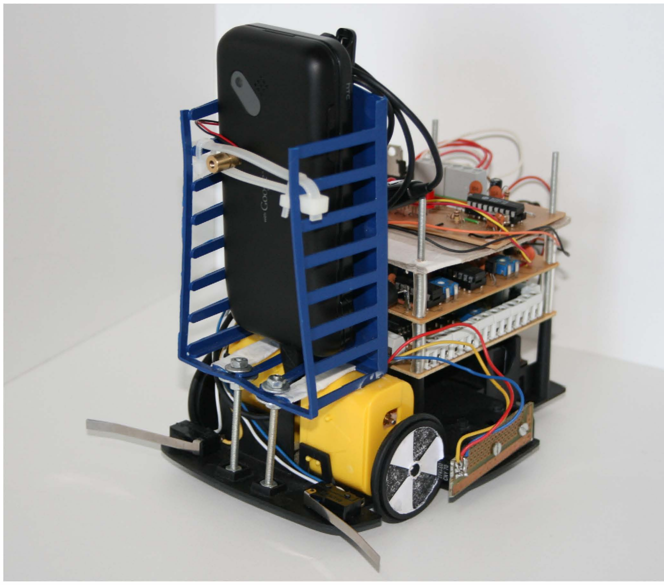

Fig. 3: A robot controlled by the audio channel using the proposed system

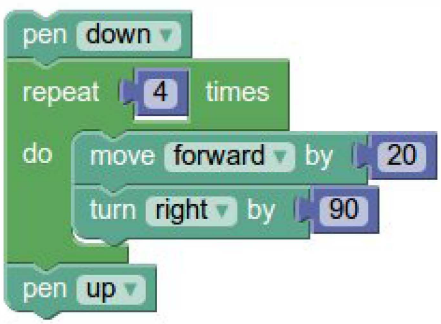

Fig. 4: Example of block based programming using Blockly for the robot to draw a square on the floor

[12]. This prototype robot has a P2 earphone plug connector that was connected to a standard mobile phone.

Figure 4 shows an example of block program which is translated to the code listing shown in Listing 1.

```
PEN DOWN;
REPEAT 4;
FRONT 20;
LEFT 90;
END REPEAT;
PEN UP;
```

Listing 1: Block program translated into text program for the robot to draw a square on the floor

Figure 5 shows another block program that instructs the robot to draw a circle by drawing 360 small lines continuously. The execution result is shown on figure 6. This robot chassis was built by students of the NatalNet laboratory and has a carton based chassis. Note also that an audio cable is connected to the earphone output of the phone, and that a simple phone

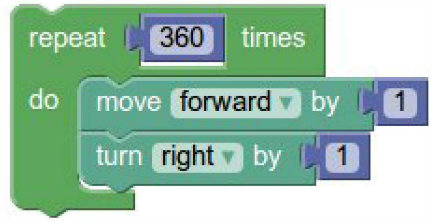

Fig. 5: Example of a block program to draw a circle

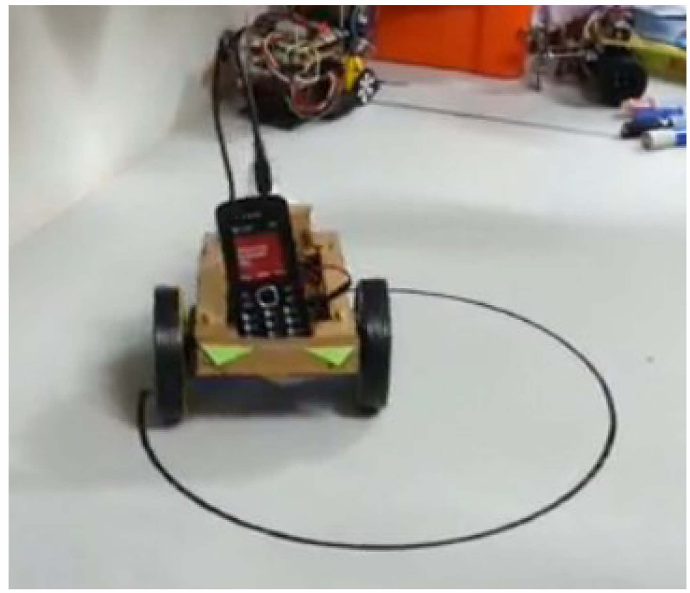

Fig. 6: A robot with carton made chassis drawing a circle

is used: all the processing happens on the server.

A. *System costs*

Table I shows the bill of materials for the proposed system if parts were purchased to build 100 units. Note that although cheap, the system includes motors and sensors.

Finally, one of the drawbacks of the proposed system are the calling costs involved during the execution of robotics programs, which could be high or even impractical. However, we remember that calls within the same operator are usually free and without limit. Moreover, a partnership could be made with telephone companies that would support the project for

Item	Value (US$)
Microcontroller	1.7
General components	2.0
Printed Circuit Board	1.2
Servo Motors (2)	6
Sensors (2)	2
Screws	0.30
TOTAL	US$ 11.2

TABLE I: System costs considering the acquisition of parts to build 100 units

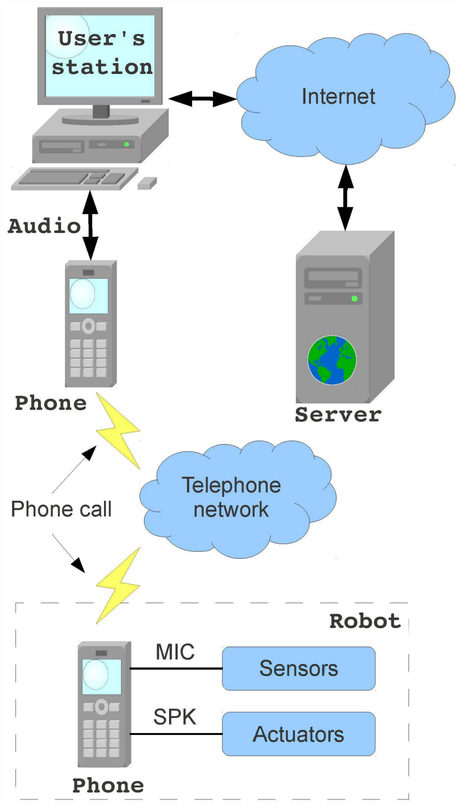

Fig. 7: High level overview of the proposed system using an alternative connection scheme with a pair of mobile phones.

public schools.

Another additional possibility to avoid telephony expenses is to use a pair of phones that make free calls among them (usually subscribers of same company). One of the phones should be placed on the robot, and the other should be connected to the user's computer audio jacks, which will generate the desired audio tones as the program is executed. In such setup, N-Bot Web based programming environment could be promptly used. The audio generation and decoding are all performed by the web page without any additional software installation requirement. A live demo and source code can be both found on the N-Bot project web page [25]. Such setup is depicted in Figure 7.

V. Conclusions

This article presents a simple, yet novel, flexible and affordable architecture for low cost educational robotics projects. The system relies on a cloud system, which consists on a webserver and a telephony server. The webserver offers a web application that can be used by students to draw graphical programs or write textual programs for robot control. The telephony server is responsible for calling or receiving calls to or from the robot and executing the program.

We remark that all programs are interpreted and executed on the server. Only actuator commands and sensor data are exchanged in real time via the telephone line. As the phone acts just as a wireless transmission line, any phone that can place calls could be used in the proposed system, even the simpler ones. A prototype was build as a proof of concept to validate the system, which has worked as expected.

Future works include the usage and adoption of such system in public schools and the partnership with telephony company operators to finance the calls. We highlight that telephony companies have considerable tax reduction and government incentives when they support educational projects. Moreover, offering free calls for such system would not be too much costly for such companies, as they already have all the infrastructure available.

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