IMPLEMENTATION OF A J2ME FUZZY CONTROLLER EMBEDDED IN A SUN SPOT MOBILE DEVICE.

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Abstract. *Fuzzy intelligent systems are present in a variety of equipment, ranging from household appliances to small devices like digital cameras and cell phones, being used primarily for dealing with the uncertainties in the modeling of real systems, which are typically nonlinear. However, commercial implementations of fuzzy systems are not general purpose and do not have portability to different hardware platforms. Thinking about it, this paper proposes the implementation of a system capable of generating a Takagi-Sugeno fuzzy controller written in Java To Platform Micro Edition (J2ME), whose modular design makes it portable to any mobile device that supports J2ME. Thus, the proposed development platform is capable of generating all classes of a controller and the code responsible for fuzzy logic is completely independent of hardware and interface. All parameters of the fuzzy controller are configurable from the membership functions and rule base, even the universe of discourse of the linguistic terms of output variables. The process of testing and validating the system will use the Sun SPOT ® mobile device with J2ME code embedded controllers, which were previously generated and tuned on the proposed system. As a case study, the fuzzy controller embedded in the Sun SPOT ® will be used to control a Quanser® level system, and the graphics resultant of the tests will be presented.*

***Keywords**: Fuzzy, J2ME, Embedded Systems, Sun SPOT®, Level Control.*

1. INTRODUCTION

The increase of microprocessor speed has enabled the industry to embed more complex control systems in smaller devices. Various mobile devices are emerging on the market, not only equipped with faster processing units but also with varied sensors. One of these devices is the Small Programmable Object Technology (SPOT) developed by Sun Microsystems, better known as Sun SPOT ® (SUN, 2009). It is a programmable platform in Java Platform Micro Edition(J2ME) with various coupled sensors (accelerometer, luminosity and temperature), analog and digital inputs/outputs and Zigbee communication protocol. This device was created to promote research on embedded systems developed in Java.

Many modern devices have embedded systems. Larger ones like automobiles have control systems that automatically recognize the driver and adjust the positioning of seats and mirrors, or appliances as refrigerators are equipped with controllers to identify when any item is missing. Even smaller devices like digital cameras and cell phones have embedded systems. They all have embedded systems, according to the definition cited by Feitosa (1992): computer systems that perform dedicated functions and are encapsulated in the device or system which it controls.

The demand for smarter devices has improved the research in the area of embedded intelligent systems, especially with application of fuzzy logic, as show in the works of: Sanchez-Solan et al. 2007; Yang, 2004; Baturone, 2008. Fuzzy systems can portray the behavior of a human operator and translating it into a computer system, making possible strategies and decision in complex problems (Shaw and Simões, 1999).

Many works deal with the implementation of embedded fuzzy systems to control different kinds of plants, some of them in robotics as proposed by Sánchez-Solan *et al*. (2007). The fuzzy controller was developed for a general purpose processor and embedded in FPGA to solve navigation problems of an autonomous vehicle. The work of Baturone *et al*. (2008) proposes a fuzzy control system embedded in a digital signal processor (DSP), developed with interface Xfuzzy 3, to solve the parking problem of a robot named ROMEO 4R. The test environment proved the functionality of the implementation.

Based on the growing number of mobile devices (cell phones, Smartphone's, PDAs) that have Java support, some equipped with multiple resources (accelerometer, GPS, camera, Wi-Fi), and the opportunity to use them to control numerous nonlinear applications, this work proposes the implementation of a system capable of generating a fuzzy Takagi-Sugeno type (Takagi, 1985) to Sun SPOT mobile device and due to its modularity can be embedded in other hardware platforms that support to J2ME and SDK 1.5, being necessary changes in the hardware class due to the different types of hardware available, and too considering that all other classes have been implemented with standard Java code and the portability of J2ME was mentioned in several other articles (Knyziak and Winiecki, 2003; Omar et. Al, 2004). The proposed tool allows fuzzy parameters to be tuned in order to control any system. The choice to implement the interpolation model of Takagi-Sugeno (Takagi, 1985), instead of the classic Mamdani model (Mamdani, 1975), two of the most popular fuzzy inference systems, was because the first one does not have the defuzzification stage which requires more processing and, consequently, higher battery consumption of mobile devices.

The system proposed in this paper consists of a desktop system developed in Java, which can create and tune all parameters of a fuzzy controller and export it in XML to a system written in J2ME embedded on a mobile device. The chosen device to be loaded with fuzzy settings preconfigured in the desktop system is the programmable platform Sun SPOT®.

The embedded system is completely modular and independent of hardware platform. It can be portable to any other mobile device which supports J2ME and be used to control various types of systems.

As a test scenario to validate the functionality of the embedded controller loaded in the mobile device Sun SPOT®, it is developed a level control system for coupled tanks manufactured by Quanser®. This plant was chosen due to its nonlinearities, which makes it a good scenario to test embedded fuzzy controller, principally because fuzzy controllers are robust, easily adaptable, are able to incorporate features that conventional systems are not, and found great utility in non linear systems, being able to withstand disturbances and even plants certain noise levels (Sandri, 1999).

2. SUN SPOT®

Project Sun SPOT ® was initiated by Sun Microsystems in 2003 as a research area on wireless transducer technologies. Since then, Sun is investigating a new way to make a device smart, small and secure. After project completion and launch of the device, several researchers have used the Sun SPOT ® as a controller for different types of systems, as shown by Acharya *et al.* (2008). It was proposed an automatic collision detection system for vehicles which communicates to a emergency medical service centre when collision occurs between vehicles. Another work has implemented a system for remote monitoring of patient health parameters such as temperature, blood pressure, heart condition besides monitoring of environmental variables such as room temperature, light, noise and door status, parameters that could impact on the data collected from each patient (Aijaz, 2010).

Sun SPOT® (Small Programmable Object Technology) is a platform whose size is smaller than a hand palm (Fig.1), powered by Java software and capable of equipped airships, missiles, control robotic hands, and monitor a system of industrial tests (Sun, 2007).

Figure 1: Image of Sun SPOT® Device.

Based on a ARM920T 32-bit CPU of 180 MHz with 16KB of data cache, 16KB instruction cache, 512 KB of RAM, 4 MB Flash Memory and a radio of 11 channels from 2.4 GHz using Zigbee protocol for communication, the Sun SPOT ® was created to allow developers to build applications written in Java using familiar IDEs such as NetBeans IDE to write their codes (Sun, 2007).

After the process of software development, it is necessary to load it on the Sun SPOT ® device, something that can be done by the NetBeans interface, making the device totally independent of the computer being powered by a battery of 750mAh and consuming about 70 to 120mA running with a processor and operating radio, 24mA in idle mode and 32µA in sleep mode (Sun, 2007). The Sun SPOT ® was developed in a modular way, making its main components (battery, processor board and sensor board) totally independent of each other as shown in Figure 2.

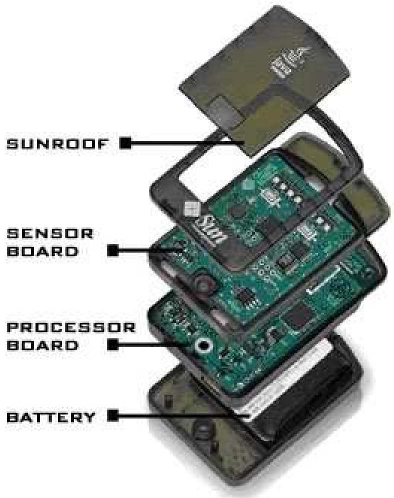

Figure 2: Sun SPOT® Modules (Sun, 2007).

The main board contains: the main processor, memory, power management circuit, transducer 802.15.4, antenna, battery connector, daughter board connector. The sensor board has: connector for the motherboard, processor ATMEGA88, accelerometer three axes, temperature sensor, light sensor, flash memory, eight tri-color LEDs, and a connector with input and output pins where its distribution is seen in Fig.3. The pin electrical characteristics are shown in Table 1.

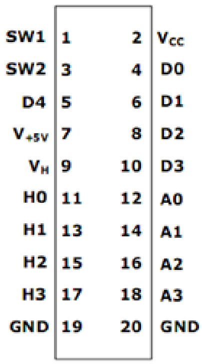

Figure 3: In Out Pin Distribution.

A complete description of all the electrical parameters of the I/O pins and the values of voltage and maximum current can be found in the manual and the Sun SPOT ® and observed when the electrical connections are made with the Sun SPOT ®.

Table 1: Electrical characteristic

Pin	Description	Voltage /Current
Vcc	output	3V DC 100mA Maximum
V+5	output	5V DC 100mA
VH	input	4.5V until 18V DC
A0-3	Analogical Input	10bits, 0V until 3V DC
D0-4	Input Output of General Purpose	Rx e Tx Communication with UART

The software developed in J2ME runs on the Squawk Virtual Machine (SVM), a small Java virtual machine for Platform Micro Edition (J2ME) present in the Sun SPOT ® and most current mobile devices that allows applications to run directly on the CPU without depend on any operating system (Sun, 2007).

The Sun SPOT ® accept board several types of codes, supporting most of the functionality of Java with small limitations from J2ME and Squawk JVM, which is not as complete as the traditional Java and Java Virtual Machine (JVM) that’s run in a desktop computer. This difference is mainly to avoid compromising the performance of mobile devices, which generally do not have a large capacity of processing and memory.

Use of tools and Squawk Java eliminates many of the difficulties of traditional embedded development. With the Squawk developers can build applications using the simplicity of Java, as well as provide a binary package customized to the capabilities of micro-embedded target platform and the required application services, all with a very significant learning curve (Simon *et al.*, 2006).

As the micro-embedded devices have different attributes of traditional computer hardware, Squawk differs from traditional Java virtual machines in some respects. One of the most important differences is the capacity of run without an operating system running directly over the hardware, and how the Squawk can be used to compile and optimize the core components of the Java VM and other components and byte codes ahead of time (AOT). Moreover, Squawk compiles Just-In-Time (JIT) byte code.

Due to the ability to run directly on the hardware, to perform JIT byte code compilation from the squawk and the ARM920T processor capacity of 180 MHz it is possible to execute a fuzzy control system embedded in the device to control a big quantity of real systems, depending on the system response time and the number of membership functions and rules that may require a largest hardware capacity.

3. FUZZY CONTROLLER

In 1965, Professor L. A. Zadeh, UC Berkeley, USA, suggested an alternative theory to the conventional theory of sets, giving rise to the theory of fuzzy sets (Zadeh, 1965). Some years later he proposed the theory where the passage of relevance to irrelevance is made of a slow and gradual and not abrupt as in the conventional theory of sets (Zadeh, 1978).

In 1994 Welstead (1994) defined a fuzzy control system as the combination of fuzzy sets defined by linguistic variables of input and output, along with the set of fuzzy control rules, which in turn, link one or more sets fuzzy input to a fuzzy set output.

From the 1990's fuzzy systems have been implemented in chips in large scale and embedded in various types of devices, such as refrigerators, vacuum cleaners, washers, dryers, pots for cooking rice and air conditioners (Toshinori, 1994). Nowadays it is very common to find fuzzy controllers in video cameras, automobiles and aircraft aviation.

Fuzzy controllers are present in several areas and are frequently used without been perceived. For example when using an auto adjustment of focus of digital cameras, when drivers use the ABS brake of modern cars, or even in commercial passenger jet, there is fuzzy logic (Klaus, 2002). Many of these controllers have been developed by the academia, generally being designed and tested initially with software such as MATLAB® or being embedded and tested in hardware like FPGA board (Sánchez-Solan *et al.*, 2007).

One major reason for the popularity of fuzzy controllers is because they are robust and easily adaptable, are able to incorporate features which conventional systems are not, finding very use in control of nonlinear systems and being capable of supporting plants with disturbances and even certain noise levels (Sandri, 1999).

4. PROPOSED SOLUTION

The proposed solution is design a environment capable of generating a fuzzy controller type Takagi-Sugeno (Takagi, 1985) for general purpose that can be embedded on any mobile device with J2ME support to control any system

The system proposed consists of two systems, both developed using the Net Beans IDE version 6.9.1, a desktop system that was developed in Java and runs on any PC (with Java Platform installed) , which is responsible for creating and tuning the parameters of fuzzy controller, and plot the graphs which indicating the parameters of the system being controlled (Level Tank, Error, Error Derivative) and the other system developed in J2ME, and written in a modular way, leaving a layer of fuzzy logic completely independent of the access layer the physical interfaces (I/O), making with that controller can be embedded in any mobile device, such access class to the hardware of Sun SPOT can be used with any other controller (PI, PD, PID) in the upper layer.

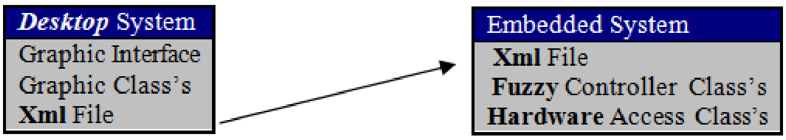

Figure 4: Proposed software classes

Figures 5, 6, 7, 8 show the main screens of the proposed system, as well as a brief description about the functionality of them.

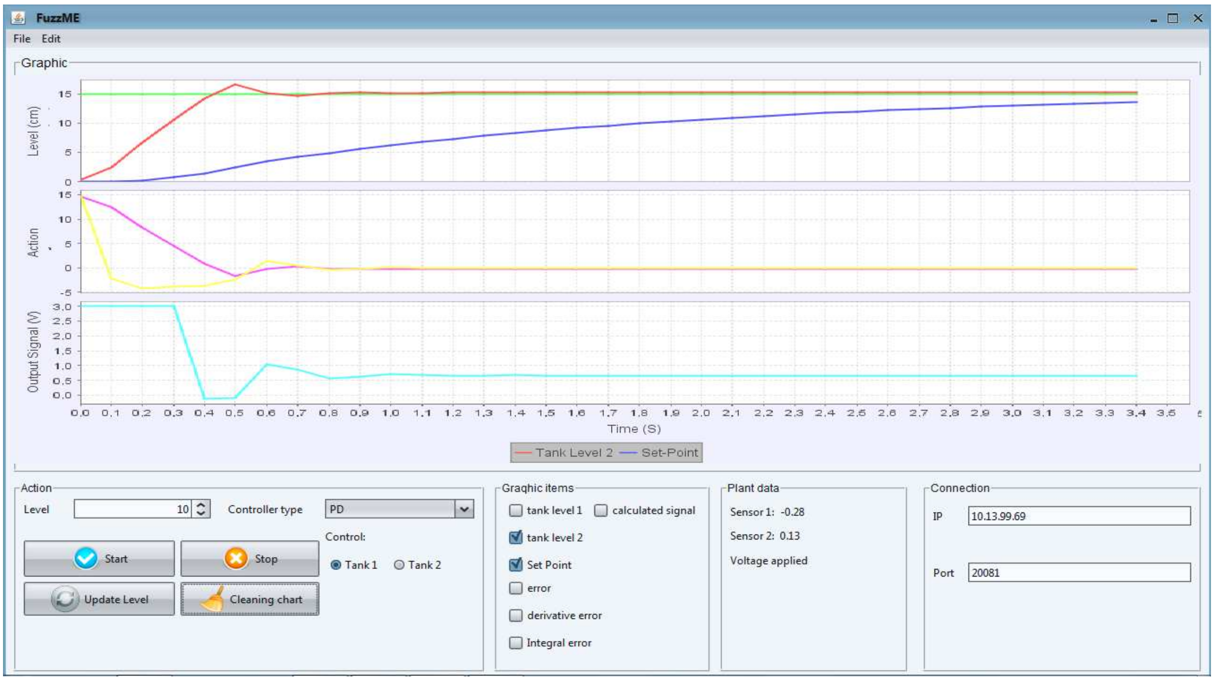

Figure 5: Main Screen

The main screen of the system is responsible for showing the real-time graphical simulation of the tank system, the first graph showing the reference level, and levels of tank 1(top) and 2(lower). The second chart shows the values of error and error derivative. Third graph shows the value of controller output to be applied to the plant. The main screen permits to select the desired level, the type of fuzzy controller (proportional-derivative action or integrative), and the tank to be controlled (tank 1 or tank 2).

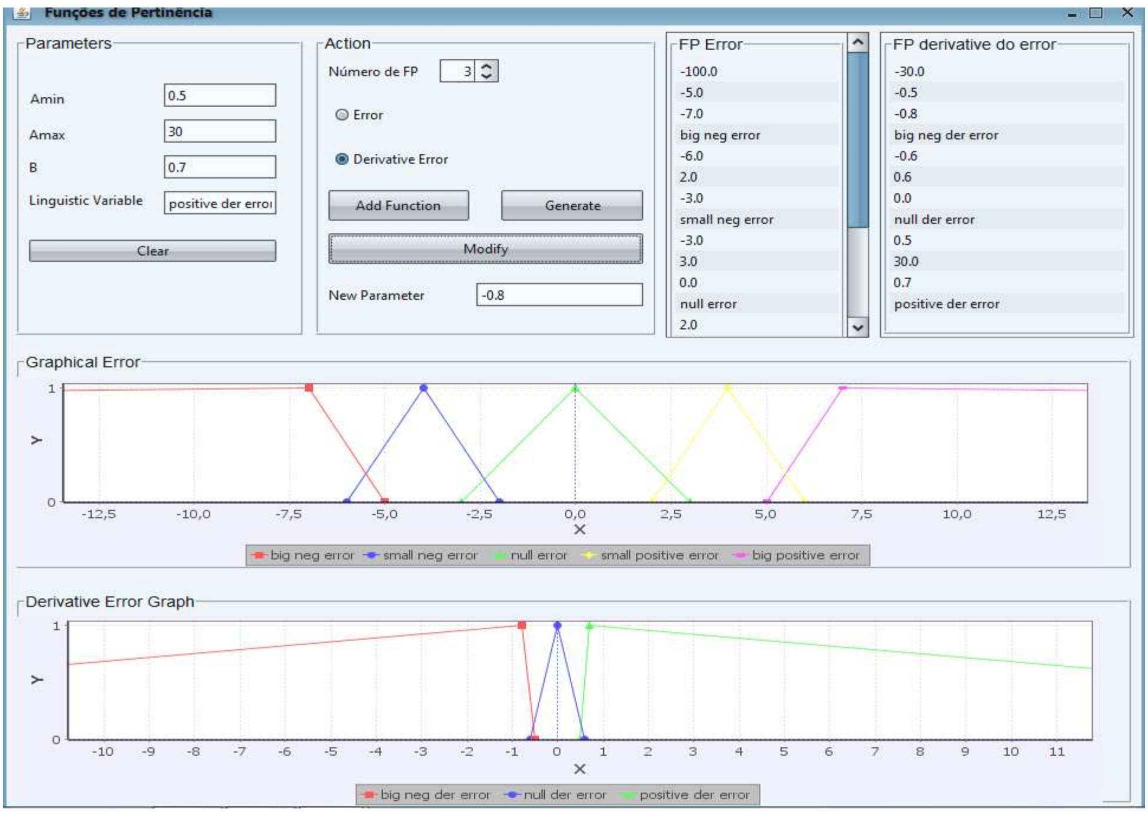

Figura 6: Membership Functions Screen.

In screen of membership functions we can define the number and parameters of membership functions for input variables: Derivative Error and Error.

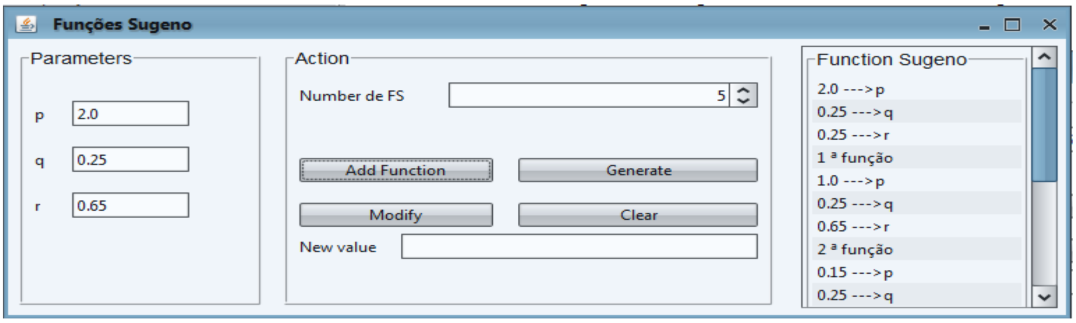

Figure 7: Set up Parameters of Takagi-Sugeno Output Terms.

The setup screen for configure the parameters of Takagi-Sugeno output terms is responsible for registering the number and configuration of the parameters of the terms of Sugeno Output.

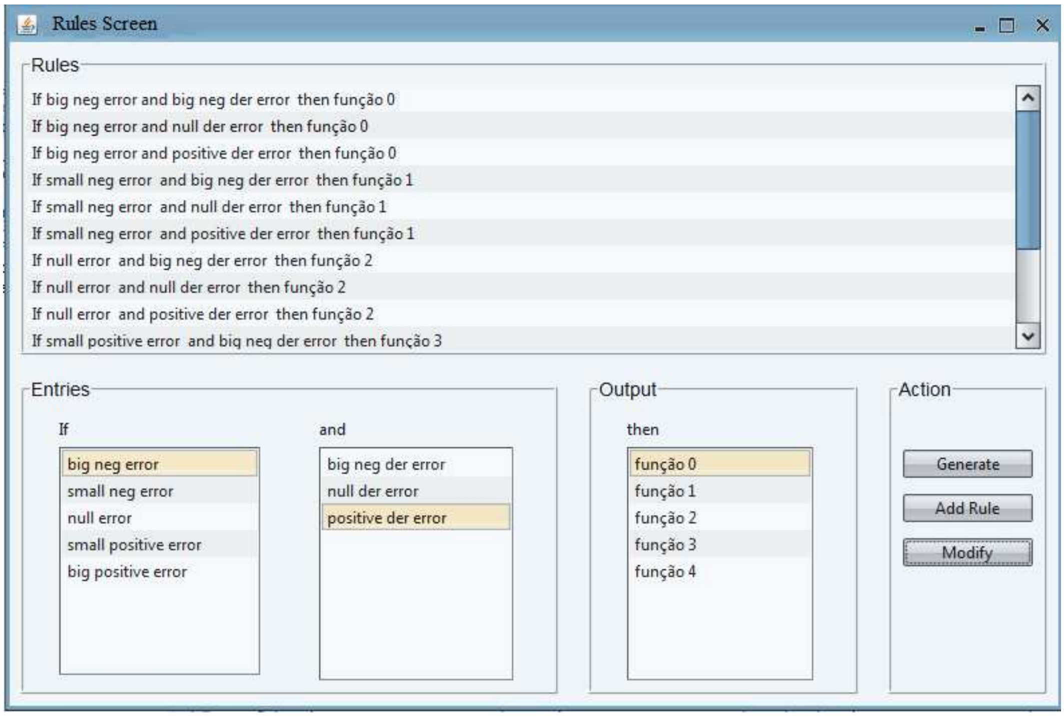

Figure 8: Rules Screen.

On the screen of rules can be configured the fuzzy controller base rules that includes the relationship between the input membership functions and output functions Sugeno.

5. TEST ENVIRONMENT

The test environment to validate the proposed system consist of a Sun SPOT ®, a Power Amplifier Module UPM 2405-240 (Quanser, nd) and a plant-level Quanser (Quanser, 2008) with two coupled tanks, sensors level in two tanks and a two-way hydraulic pump connected to the upper tank, as is seen in Fig.9.

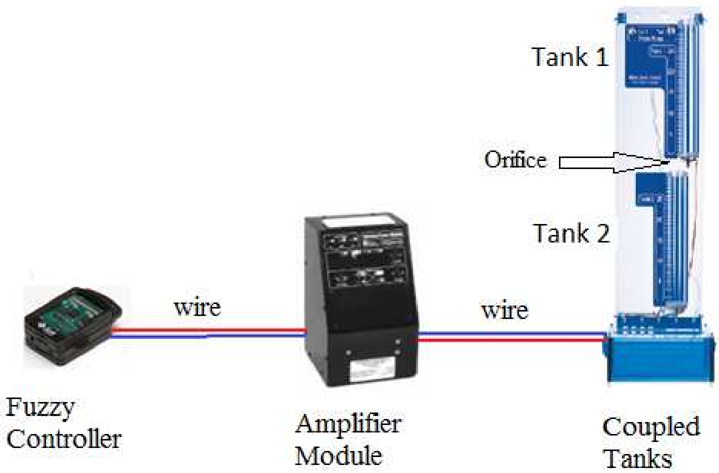

Figure 9: Test Enviroment

The need to use the power amplifier module is mainly due to the low current provided by the Sun SPOT ® (maximum current output = 120 mA) that is not sufficient to feed the tank system pump. The electrical and hydraulic specifications of the tank system are shown in Table 2 (Quanser, 2008).

Table 2: The Electrical and Hydraulic Specifications Of Tank System

Specification	Value	Unity
Pump Constant Flow	4.6	$cm^3/s/v$
Pump Max Flow	100	cm^3/s
Pump Voltage	±15	v
Pressure Sensor	±12	v
Pressure Range	0 ~ 6.89	KPa
Sensitivity	5	cm/v

The power module UPM 2405-240 is capable of providing a continuous voltage of ± 24 volts and a maximum current of 5 Amps. Its specifications are shown in Table 3.

Table 3: UPM Power Module 2405-240, Electrical Parameters

Parameter	Value	Unity
Amplifier Voltage Gain	1,3 ou 5	V/V
Maximum Direct Voltage Amplified	±24	V
Maximum Direct Current Amplified	5	A
Direct Voltage of Output	±12	V
Maximum Direct Current of Output	1	A
Alternate Voltage Supply	100/120/230/240	V

After setting the parameters of the controller in the desktop system and the embedded controller in the Sun SPOT, it is necessary to do the electrical connections among the Sun SPOT, the amplifier module and the tank system. The nominal currents and voltages of each device must be observed before the system is ready to collect the results.

6. RESULTS

The graphs presented in this paper were collected at the interface of the desktop system using a zigbee connection with the mobile device that was running the fuzzy controller (Fig. 10). The embedded controller is connected to the amplifier module which, in turn, is connected to the tank system (Fig.9). The second Sun Spot® is plugged to the notebook because it does not have a Zigbee network interface for communication with the fuzzy controller.

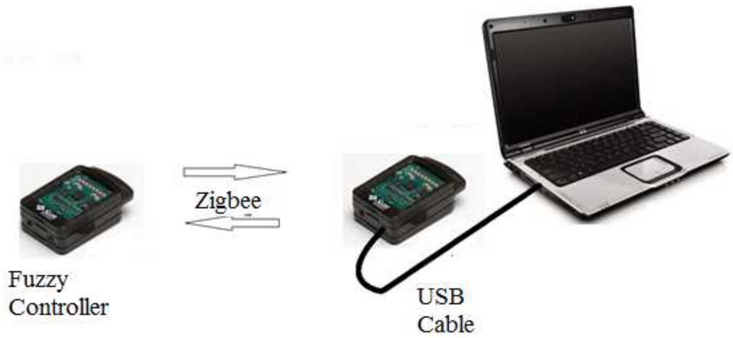

Figure 10**:** Communication between Desktop System and Embedded Fuzzy Controller

For test the controller will be presented graphs of the control level of tank 2. It is supplied with water from the orifice at the bottom of the top tank which is fed by a pump. The inputs to the fuzzy controller are derivative error and error between the reference and the measured level. The actual tank level is measured by a level sensor installed in the lower tank. The controller output is the voltage applied to the pump connected to the top tank.

The chart in Fig. 11 shows the behavior of the fuzzy controller to the level of 15 cm, with a settling time of 80 seconds, consistent with the dynamics of the system and an over shoot approximately 15 percent, suitable for a second order system with only two inputs (error and error derived from the tank 2).

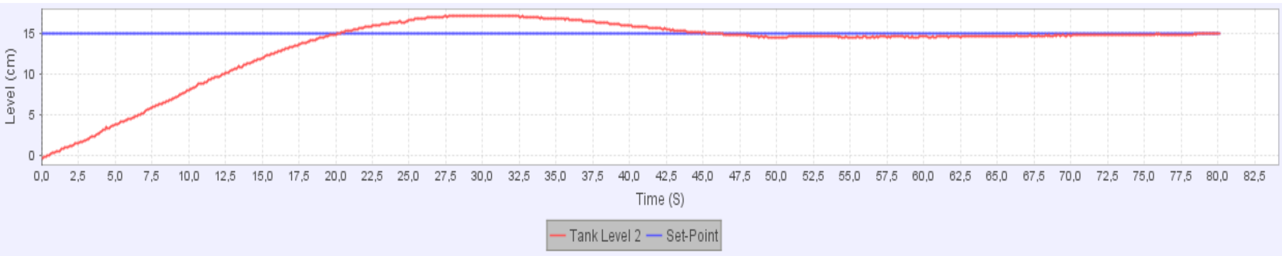

Figure 11. Graph Set Point 15 cm

The chart presented in Fig.12 shows that the tuned controller was able to maintain control of the system even when subjected to some variations in the level of the tanks, but had a small stead state error to the level of 10 cm. The suggested solution to mitigate this error would be the implementation of an integrator in the code of the embedded system.

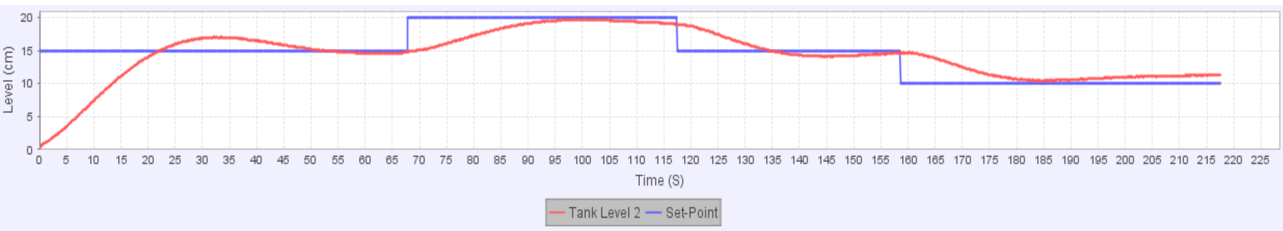

Figure 12. Graph with Level Variations

6. CONCLUSION

The proposed system was effective in generating fuzzy controllers to be used in a Sun SPOT, and tune it from knowledge of a human operator for control any system. The controller generated and tuned in the proposed system for the control a system level Quanser ® demonstrated a satisfactory performance of the controller for operation at 15 cm achieving a good performance even when subjected to variations in the level. It has demonstrated the proper operation of the system as a whole and more specifically of embedded controller interconnected with the level plant in question.

As a suggestion for future work, is the possibility of testing the system on other mobile devices with J2ME support, considering that this was not possible due to lack of time to build an electronic board and their drivers to realize communication between other device mobile and tank level system.

The system proposed in this work will be available as an open-source software which can be used by other researchers who need a fuzzy controller for mobile devices.

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