Raspberry Pi-based HIL Simulator

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ABSTRACT: Hardwar-in–the-loop (HIL) simulation or HWIL is a technique that is used in the development and also in testing of complexity of real time embedded systems. Excluding hands-on training from control education with physical plants is enticing in many ways but at the same time it is very risky. This paper explains why, and suggests a balance between challenging physical plant maintenance for students to monitor and rely on pure numerical simulations in the curriculum. The golden mean may be to use real-time simulators with physical inputs and outputs, i.e. simulators with hardware in the-loop (HIL). This offers three examples of HIL simulators, including a series of coupled vehicles, a quarter-car model and a series of a nuclear reactor. HIL simulation provides an effective platform by adding the complexity of the plant under control to the test platform. This paper also reviewed several paper and gained knowledge about HIL simulators.

KEYWORDS: Control Education, Hardware-In-The-Loop, HIL, Real-Time Simulation, Raspberry Pi.

INTRODUCTION

Some new technologies for simulating complex structures are implemented in software tools over the last decade. It has never been easier to build a simulation model of complex electrical, mechanical or hydraulic systems or complete technical units, with packages such as MATLAB / Simulink / SimScape or OpenModelica available. In addition to this development, several virtual laboratories have emerged, making the simulations accessible with a single mouse-click. However, these unimaginable possibilities are slowly changing the way Universities teach automation and feedback control. Physical models of regulated plants (e.g. innumerable combinations of coupling tanks with pumps and valves, mechanical setups with engines, springs and weights, models of heating or ventilation systems, etc.) vanish one by one from the laboratories, being replaced by mere software simulation models that are used to illustrate feedback control in practice.

At the point of view of educators, this is not shocking. The running of physical models not only presents problems with the safety of the students during laboratories, but also involves the maintenance of models and their repairs (pumps get stuck, wear out bearings, burning of motors, etc). From this viewpoint, simulation-based control education appears to be the perfect solution-guaranteed no complications, zero maintenance, repeatability, and sustainability.

The aim of this paper is by no means to condemn or oppose the use of simulation devices, quite the contrary. But simulation needs to be used no earlier than it is ready for the students. The students will first be subjected to hands-on interaction with the control loop of physical feedback. The knowledge needed to implement a simple comparator algorithm is minimal, while the benefits of witnessing it in real-time in practice are massive. What is a better motivator to research feedback control theory than a practical experiment which clearly shows that minimizing a relay controller's hysteresis band simply doesn't do the trick?

Without personal experience with control loops for physical input, students may leave the university prematurely because they do not really understand what they're learning. And worse yet, they quit the university with a bachelor's and master's degree given the ignorance of the field of research, just to find out that they are unable to contribute something about what they have learned so much in industrial practice.

Advantages of using HIL simulators:

HIL simulators in control education has the following advantages:

- After completing their studies, students work with actual devices (PLCs, PACs, compact controllers) that they use in industrial practice.

- It is obvious at first glance where the controller is located, where the controlled plant is located and what the interface between them is.
- Students must obviously learn about issues such as sensor adjustment and measuring noise.
- There are no issues with the maintenance and health of the mechanical sections of actual models. There is no water moving from the simulator to the laboratory floor, no costly components that could be damaged etc.
- The algorithms built are immediately applicable so that the students can observe the effects of their research right away. This creates trust in the theoretical framework used in the curriculum for students.
- Repeatable tests and equivalent ones. No more papers about control of coupled tanks which no one can check and compare simply because the physical setup given is special.
- The machine simulated can be monotonous, oscillating, integrative or even dysfunctional.
- One can simulate any plant or technology. Models can be planned and tailored for a particular study field. The days of plant modeling with similar RLC circuits are over.
- If required, model parameters can be customized. Thus, each student may monitor a specific plant, thus avoiding plagiarism.
- The model should be scaled in time for a very slow process so that students should work with it during the workshop, but still experience the pressure of waiting for a stable state, for example. This gives them a good understanding of why math and simulation modeling save time and money.

There is no point in challenging the role of the software simulation tools in the design and education of control systems. They simply need to be supported by additional instruments and equipment, connecting the realm of simulation to the real world. If the students have at least experience with a controlled plant's HIL simulator and a real PLC or controller, let them go for the simulation anyway. The difference is that they must work with complete comprehension of the topic and this has tremendous positive implications.

LITERATURE REVIEW

This paper describes a framework that is incredibly inexpensive, straightforward and remarkably efficient to implement real-time control algorithms. The interface contains an Arduino board and a Raspberry Pi that powers the REX Control System. The Arduino board is used by its inputs and outputs for interaction with the physical world. The REX Control System helps students to build and test Simulink's control algorithms, and then run them in real time with a few mouse clicks. The REX Control System, however, is by no means based on Simulink, it is completely functional even when there is no Simulink license[1]. This paper describes home appliance system based on raspberry pi powered by humanoid application. Within the initial stage associated with home automation was recalled an application was built in the stage based on the humanoid process. Mobile devices area unit gloriously delivering a system in an extremely handmade approach to automation. And will be ready to connect with a home automation network via the internet associate, but ineffective to bear instantly with devices within the network, as such devices are in all probability put in low power protocols much like ZigBee, Wi-Fi etc[2]. Raspberry Pi is a Linux device measured by credit card built on the architecture of ARM 11. A robot controller is a suitable position for it to play, due to its small size, low power consumption and powerful performance. Speech recognition for controlling the robot and voice input to users as a robot with artificial intelligence is essential parts of the entire system. A robot named Lisa is built in this essay, and a speech control and interactive framework is implemented based on Google Voice API which is a voice recognition platform provided as a cloud service, hi order to analyze complex voice commands, a semantic method is developed to extract key words from command sentences[3]. This home automation system provides remote control of various lights and appliances inside your home to the user. This system is designed to be cost-effective and expandable allowing control of a number of devices. Home automation and advantages should concentrate on the use of raspberry pi, and how this can be accomplished[4]. This paper addresses IoT and can be used to implement smart home automation using Raspberry Pi. This device consists of a smartphone along with a website that includes information about home appliances with ON and OFF conditions. Smart phone connects to Raspberry Pi via Wi-Fi, using Raspberry Pi's IP address. The user friendly wireless device increases productivity and lifestyle. The device effectively overcomes the limitations of Bluetooth and

ZIGBEE technology. Internet of Things (IoT) is one of the innovative technologies that can be used to link, monitor and manage smart objects that are linked to the Internet through an IP address. The goal of this project is to use Wi-Fi as communication protocol and raspberry pi as server system to control home appliances via smartphone. Here, the user can switch directly with the device via a cloud-based interface over the cloud, while home appliances such as lights, fan and door lock are operated remotely through a simple website. An additional aspect that improves the fireplace security element is its ability to sleeve the smoke in order to attach a warning message and send a picture to the smartphone in the event of any fireplace. The server will be interfaced with circuits of relay hardware which control the appliances running at home[5]. This paper introduces a scalable and inexpensive home control and monitoring device by the use of Raspberry Pi based network and the use of Arduino Microcontroller. Using Android-based mobile application or server computer, the interface between the Access Point and switches with IP connectivity to access devices and appliances and remotely monitor them will be made. This switch node connected to electrical devices that can be operated using sensor and remotely controlled via an access point, the Smart Switch network for the production of Smart Home consists of two major parts which are smart switch device and access point[6]. Then the Raspberry Pi is actually widely used in everyday life, one of which is used for the automatic use of media-based Raspberry Pi in smart home Wi-Fi. Smart home system is a device that can operate automatically, based on the Android feedback and the Raspberry Pi embedded software. WiFi as a means of communication for transmitting data or input from an android application which acts as a remote control device for home appliances. Generally speaking, control of home appliances is still manually operating making it less effective, the goal of the smart home system design tool is to build a device that can help people perform household activities to automatically control home appliances using smartphones via android application.[7]. The project uses an integrated microprocessor and microcontroller to offer a low cost and scalable home control and monitoring system with IP connectivity for remotely accessing and controlling devices and appliances using Smartphone technology. With respect to similar systems, the proposed system does not require a dedicated server PC and provides a novel communication protocol to track and manage the home environment with more than just the switching features. Devices such as light switches, power plug, temperature sensor, and current sensor can be incorporated with the home control system to demonstrate the functionality and efficacy of this device[8]. This work demonstrates a simple home automation device that allows the user to wirelessly monitor the home appliances. Among the devices which can be used in this system are lamps, air conditioners, electronic doors and fans. In this device the devices can be managed and monitored in two ways. The first approach is to use a web server while the second method is to use an Android application-based smartphone. This web interface has a system known as Restful Api, and uses http request to monitor Raspberry Pi gpio[9].

METHOD

Typically, when HIL simulators are included in the course, the students begin with simple experiments with the real time simulator, observing the response of the plant to various external signals. The plant's natural actions and dynamics are easily recognized. Plant linearity or nonlinearity may be observed by measuring static characteristics and reaction to differing amplitudes of harmonic excitations. The simulator will contain all actual plant and actuator imperfections such as saturation, rate limits, back-lash, dead zones etc. Artificial noise and other parasitic effects, including offset or drift, can corrupt the output signals to imitate true physical transducers.

Then follows the data-driven identification process. The purpose is to derive a gray-box model's unknown parameters with the structure described in the previous step. The students are led on the HIL simulator to select correct excitation signals and execute identification experiment and to collect input-output data. Methods of device recognition are employed for parametric model estimation. The mathematical model's output is then correlated with real-time simulator behavior. Any control design technique can be implemented once a checked mathematical model of the controlled plant is available. In this paper this element is intentionally reduced to a minimum. Figure 1 HIL stimulator of coupled tanks model.

Components used are:

- Raspberry Pi 3 B+ with 1 GB of RAM and 1.4 GHz quad-core CPU (The Raspberry Pi Foundation, 2018).
- 7” touchscreen display for the Raspberry Pi.
- Monarco HAT add-on board with analog and digital inputs and outputs.
- REXYGEN software tools to build the HIL simulator without hand-coding.

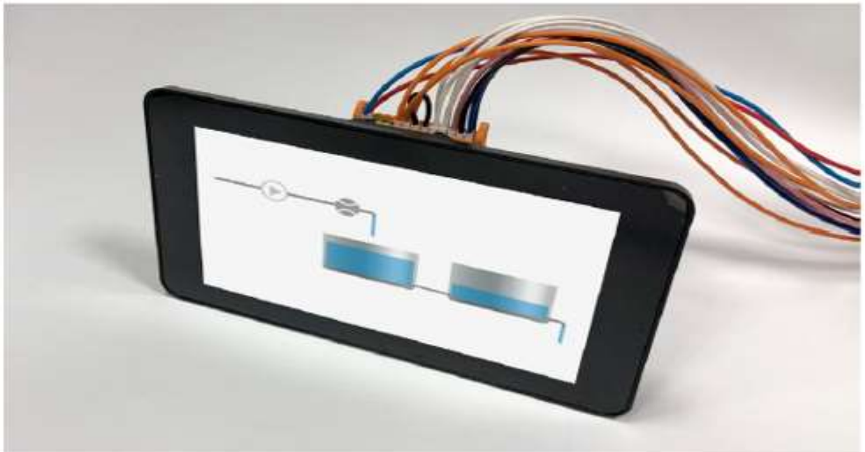

Fig.1: HIL Simulator of Coupled Tanks Model

The HIL simulator accepts inputs and provides outputs in standard industrial ranges (digital signals in 24V logic, analog signals in 0-10V range), which is why almost every PLC or compact controller on the market will control this. The Raspberry Pi's CPU provides adequate computing power, while the complexity of the simulated plant is largely restricted by the available I / Os on the Monarco HAT board, which provides 4x digital input, 4x digital output, 2x analog input and 2x analog output. The Refresh rate attainable is 500 Hz.

The model of coupled tanks shown in Figure 1 is possibly the most typical of controlling courses across all continents. There is one controllable pump which defines water inflow. The water flows at variable speed from tank 1 to tank 2 which is determined by the difference in water levels in different tanks. Tank 2, where the water enters the farm, has an uncontrollable outflow. The goal is to keep the water level at the set point in tank 2.

The pump is powered by a regular analog signal of 0-10V, which determines its power from 0-100%. Two analog signals show the water levels, again within the normal 0-10V range. At tank 1, there is one limit switch which stops the pump if the water level in tank 1 rises too high. There is one digital output signaling this. While being very easy to explain and understand, the configuration of the coupled tanks provides a wide variety of experiments to conduct. Students may observe the plant's monotonous and non-linear behavior and apply control strategies PI / PID or build state-space controllers. State observer may be built in advanced courses, where the level in tank 1 is reconstructed from measurements of the control signal and tank 2. Cascading power can also be implemented using PI / PID controllers. Figure 2 shows the HIL simulator emulates the plant and its sensor and actuators in real-time.

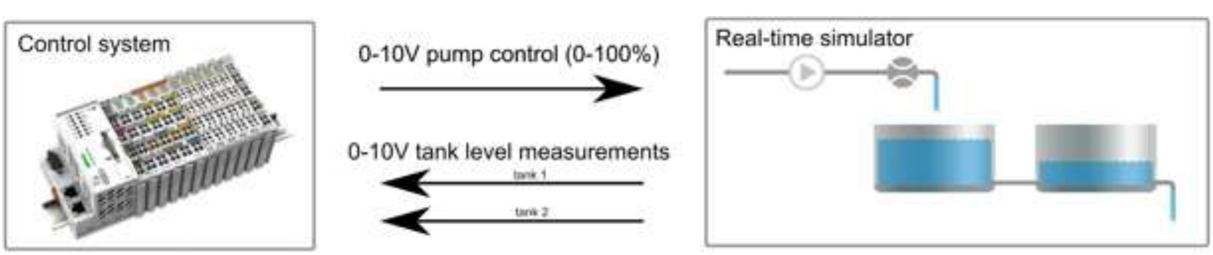

FIGURE 1. HIL simulator emulates the plant and its sensors and actuators in real-time

Fig.2: HIL Simulator Emulates the Plant and its Sensor and Actuators in Real-Time

CONCLUSION

This paper discusses the value of hands-on experience in managing schooling, resulting in students who are much better prepared for the industrial practice challenges. All students should be introduced as soon as possible to the challenge of running one physical field. In the other hand, in terms of upkeep, management and distribution of funds physical plants can be troublesome. The paper sets out a compromise: real-time simulators with physical inputs and outputs. Such simulators allow students to go through all stages of designing control systems while minimizing the downsides of true physical plants.

Compared to traditional control courses, which are mostly taught only by offline numerical simulations, the use of real-time simulators provides some fundamental benefits to the students:

- The use of separate hardware platforms for both the controller and the controlled plant subsystems creates a deeper understanding of basic feedback control concepts. When only operating in the simulation setting, the general feedback loop structure can seem too abstract to some students.
- Students will learn an important lesson that every mathematical model is merely a simplified truth abstraction.
- Students are subjected to day-to-day problems of the control engineering domain, including plant nonlinear, imprecise sensors and actuators, and controller hardware and software restricted resources for programming and tuning.
- The students get in contact with the related hardware platforms and software resources in the industry.
- The students witness the incremental progression from theoretical analysis to equations, numerical models and the final implementation in real-time environment of planned control rule, which are the basic skills of today's control engineer.

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