JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Multi-channel Process Instrumentation and Control Trainer

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Abstract

Software simulation tools, Augmented Reality (AR), video games and a wide spectrum of learning aids have been developed to enhance the teaching of practical engineering courses. These tools, despite their wide adoption as learning methods, cannot re-create real-life situations that make it easier to translate knowledge into an actual skill set. To address these learning gaps, the use of models is judged as one of the most effective learning tools in education. They provide actual, real-life components on a small scale so that learners can easily relate to physical objects. Although little attention was given to model-based learning, it has a huge potential in educational systems. In this paper, a model-based teaching aid for pump station operation is presented to enhance knowledge of process control and instrumentation design in the downstream. C# was used to develop an intuitive instrumentation and control user interface with piping and instrumentation diagram (P&ID) flow symbols. MySQL was used for the database. The application monitors and tracks user events for performance evaluation. The hardware was developed using an ATmega2560 microprocessor and it has eight (8) channels consisting of a solid-state interface driver for interface with the instrumentation and control model pump station.

Keywords: Hardware in the Loop, Process control, teaching aid, instrumentation, Arduino

1. Introduction

Many theoretical models, simulators and concepts have been used as aids in teaching students process instrumentation and control. The use of teaching aids offers an alternative form of learning that actively engages students in acquiring knowledge and skills set [1, 2, 3]. Practical teaching aids provides students with the opportunity to have hands-on experience and observe real phenomenon occurring [4]. MATLAB and Simulink have been used as key tools for teaching modelling and development of control systems in process operations [5, 6]. Labview by National Instruments is also being used as a teaching aid for process instrumentation and control. These tools have a powerful, very interactive graphical user interface that allows students to model and constructs functional systems by drag and drop method. The use of theoretical models and graphical user interfaces are based on abstract models that do not resemble the actual real-life system. The use of simulators and GUIs do not provide hands-on activities and the necessary skills for Oil and Gas process operations.

Various teaching aids were developed to bridge the gap between academic work and the actual industrial situations, especially in Oil and Gas process operations. Alternative teaching methods address the limitation of the traditional learning methods and engage more students in building skills acquisition and knowledge. Teaching aid greatly influences students learning process and their ability to assimilate abstract concepts [1].

1.1 Types of teaching and learning aids

The proliferation of computer technology into everyday objects has greatly evolved the process of learning and how new tools in education can be created and improved. Some of the tools used in process instrumentation and control training are discussed below

1.1.1 Avatar and Video games

Various studies have been conducted on the connection between video games and education. Research shows that well-designed video games, natural learning machines, greatly improve the learning experience and increase learning outcomes [7]. A good video game inculcates a sense of determination, persistence and endurance in players. 3D online (virtual world) games have explored game-based learning to improve high order skills, problem-solving, analytic ability and strategic thinking of students [8]. Games are visual tools that can be used to enhance students' attention to detail and activities. The work in [2] models the relationship between virtual aid and the learning outcome in a linear equation where virtual content is regarded as independent variables while enhancing the learning process is the dependent variable. Using equations to model how visual contents affect learning outcomes, graphical relations can be plotted which takes a form of a linear graph. In recent times, gamification, an act of adding a gaming element to non-game contexts to foster learning is being applied in education [7]. Research shows that by gamifying some courses in both middle and higher learning, students can gain significant knowledge about a subject or courses being taught [8]. For example, NASA explored gamification to design GamiCAD, a tutorial that teaches how to perform line trimming operations in AutoCAD [7].

1.1.2 Mathematical modelling and simulation

The developments in high-speed computing and advanced graphical user interface programming have made possible the implementation of simulators. Over the years, the quality and performance of simulators improved with processing speed. Simulators based on mathematical models are routinely used in the design of industrial process instrumentation and control for educational purposes [9]. This includes online virtual simulators and offline simulation application packages, which has been used in diverse fields to enhance learning. Dynamic simulators are widely applied in engineering designs and operations, which help students to master engineering courses [10]. Educational system integration that comprises mathematical models, simulations, and real laboratory works is the most efficient way of mastering engineering courses [9]. Commercially available software for chemical engineering education such as D-Spice, Hysis, ASPEN PLUS and K-Spice are popular in some universities' curricula but simple dynamic simulation software such as MATLAB/SIMULINK are widely used [10]. MATLAB provides an idealized simulator for constructing process control systems and deducing some dynamic behaviour of the system at varying conditions [11]. This provides students with a cost-effective way of learning process control and design.

1.1.2 Hardware in the loop method

The introduction of hardware as part of a system development and software simulation loop or hardware in the loop (HiL) has revolutionized laboratory experiments. It allows the actual controller software to be programmed in real-time using a computer-aided control design [12]. HiL provides experience-based learning, in which students can demonstrate and evaluate different practical scenarios. It is an environment where students and trainees can translate theory into actual practice. HiL has been successfully used in modelling traffic engineering and reducing performance discrepancies between simulations and the actual field implementation [13]. Embedded computing is one of the areas where HiL is widely used. Some parts of the embedded system can be simulated in real-time, which help to reduce time to market and development efforts [14]. Fig. 1 shows a typical development cycle of Integrated Real-time Control and Simulation Environment (IRCSE).

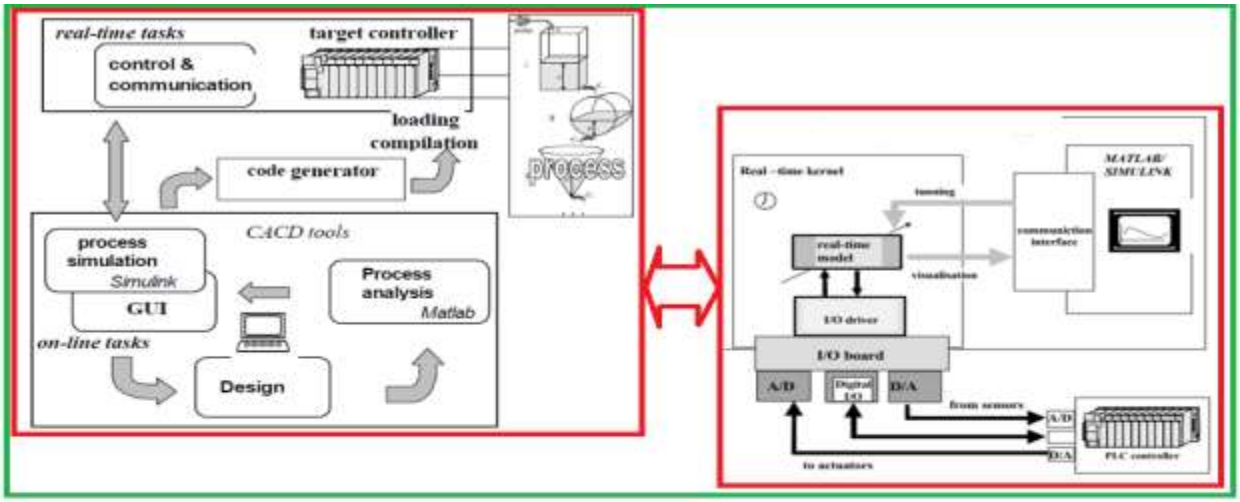


Fig.1: Hardware-in-the-loop Development cycle [12]

In HiL as shown in fig.1, the process starts with developing a simulation model of the target application and then translating it into an actual controller specific program that can be uploaded into the hardware. This is a typical scenario when developing an industrial application using programmable logic circuit (PLC). The ladder logic of a system is developed and simulated in a simulation environment. The environment translates the ladder diagram into actual, real-time executable code targeting PLC hardware.

HiL provides an efficient tool for the analysis, evaluation and validation of networked electrical power systems. HiL is finding applications in automobile industries to supports the development of specialized Electronic Control Units (ECUs) under realistic conditions [15].

2. Materials and Methods

In this section, the design of process instrumentation and control platform as a teaching aid is presented. Fig.2 shows the block diagram of the process operations, control and instrumentation teaching aid. The system has three sections namely the process interface application (Graphical User Interface), embedded controller and high-speed input/output (I/O) driver and a model of pump station (plant).

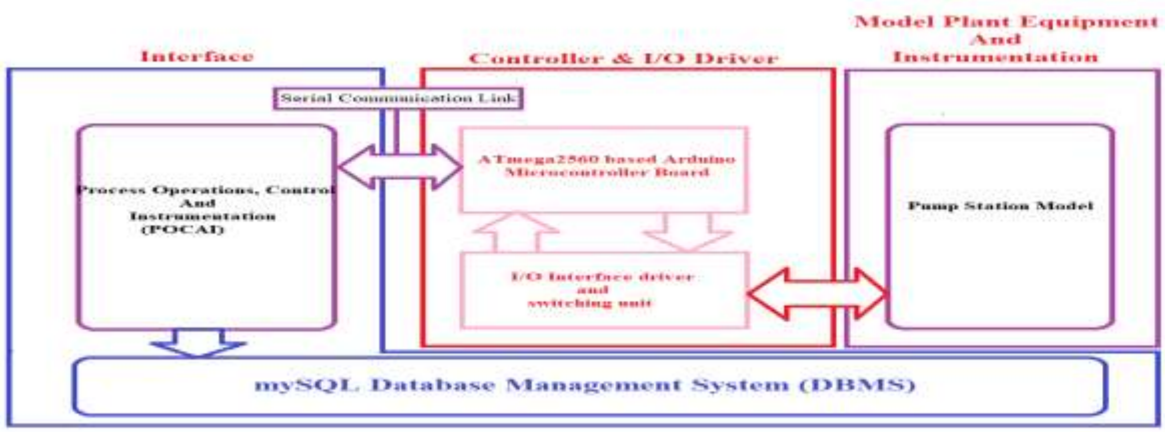


Fig.2: Block diagram of the proposed process control and instrumentation teaching aid.

2.1 Graphical user Interface

The graphical user interface was developed using C# and linked to MySQL database management system. In the interface, the process flow diagram of the plant to be controlled was implemented using industry recognizable symbols for piping and instrumentation diagram (P&ID). The student or user interacts with the system through the interface. Fig.3 shows the use case diagram of the user-system interaction during training.

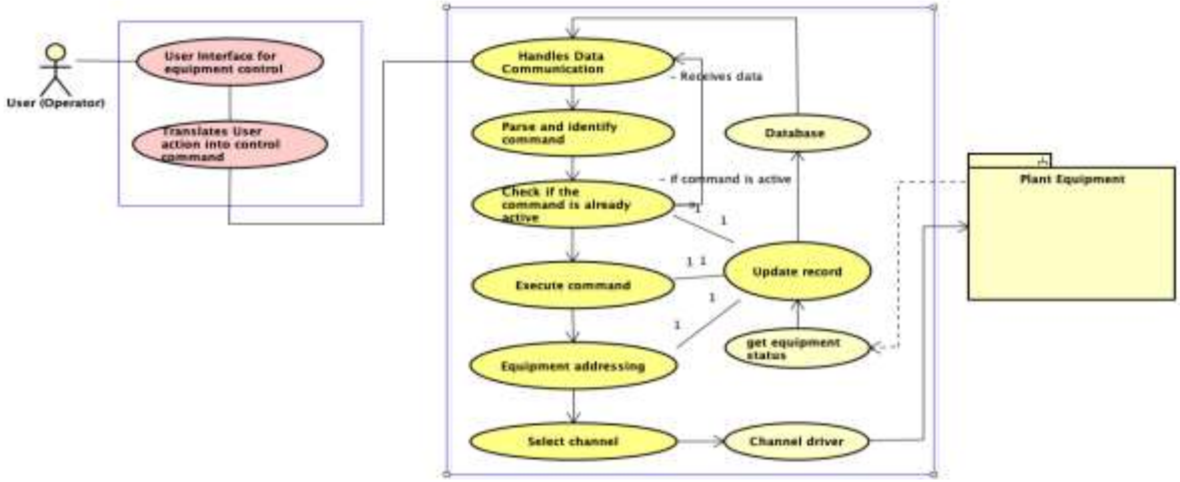


Fig.3. Use-case diagram of user activities on the teaching aid.

Each user is assigned a unique login ID that can be used to track activities associated with that user on the database management system. The interface authenticates each user by taking user input from the user_ID field and search through the database. Once user inputs are verified and validated to be correct, the main interface is loaded and visible. The main process operations, control and instrumentation interface was implemented as shown in fig.4. An alarm panel for each of the pieces of equipment on the P&ID is displayed. The Red buttons indicate equipment status on the OFF state while the Green buttons indicate the ON state. Each action (on or off) is completed after the user has confirmed the action initiated. All events are registered in the database and classified according to the type of operations with associated user_ID.

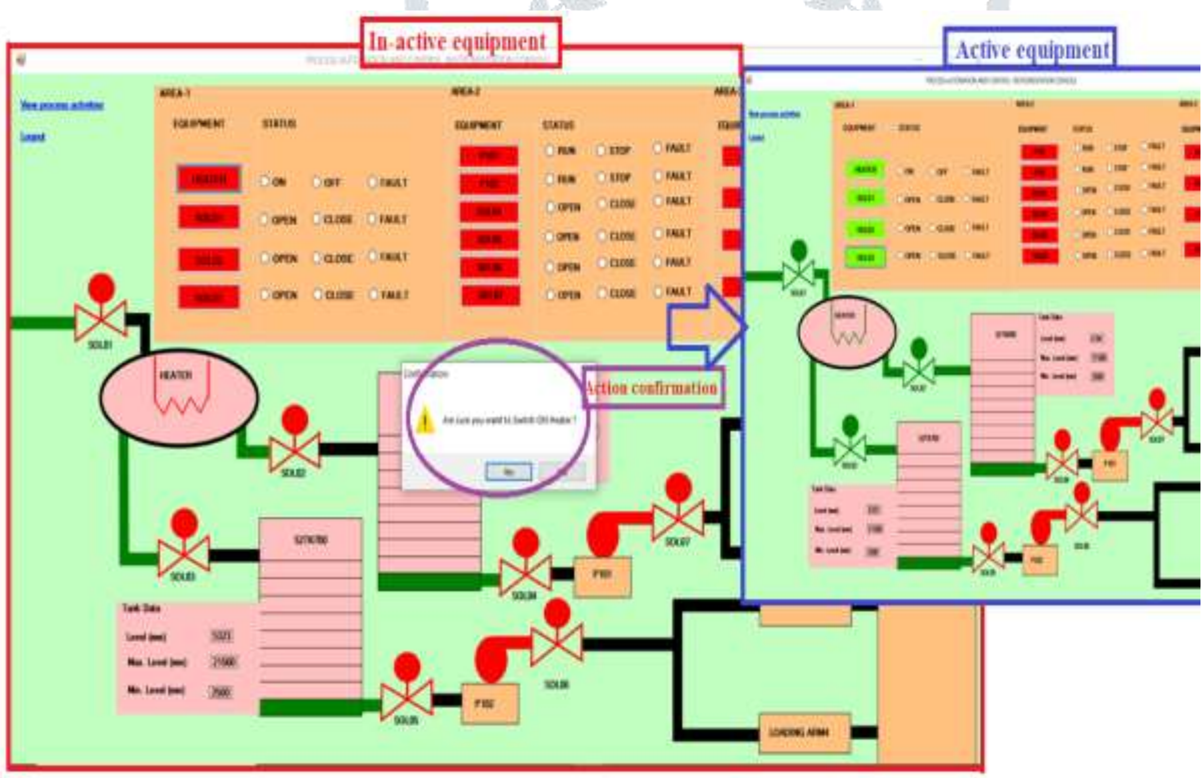


Fig.4. Process operations, control and instrumentation interface showing equipment status

2.2 Controller and I/O driver unit

The communication and processes between the software process operations, control and instrumentation interface and the model of the pump station (Plant) is modulated by the controller and I/O driver unit. The I/O unit controls the plant by receiving user commands from the interface using serial communications to activate either solenoid or pump. Different types of interfaces for different applications can be implemented to communicate with the controller and I/O driver unit. Arduino Mega based on ATmega2560 microcontroller is used to implement serial communication protocols and different commands required to drive external load or the plant. The I/O driver unit can drive eight (8) solenoids or motors or a combination of both depending on the plant equipment.

The plant logic was implemented in the interface to make the controller and I/O driver unit more independent of any control interface implementation. Plant configuration can be changed by modifying the program in the ATmega2560 microcontroller board for the I/O interface driver. The communication diagram between the software application and the controller and I/O driver unit is as shown in fig. 5. The use of a sequence diagram is to capture the interaction between objects in the context of collaboration. It visually shows object instances that participate in the role and the order of interaction but does not show structural relationships between objects. The system communication diagram in fig.5 shows how data flows from the actor through the user interface to the embedded server. Interactions between the main units of the controller and the I/O driver unit are represented by a directional generalized line which is similar to methods on a class. Control of information is initiated by the user, in which a channel or channels are activated to perform a given task. In this work, a model of the actual process plant is built using solenoids as valves. Using control command, valves can be open and closed, and other equipment actuated

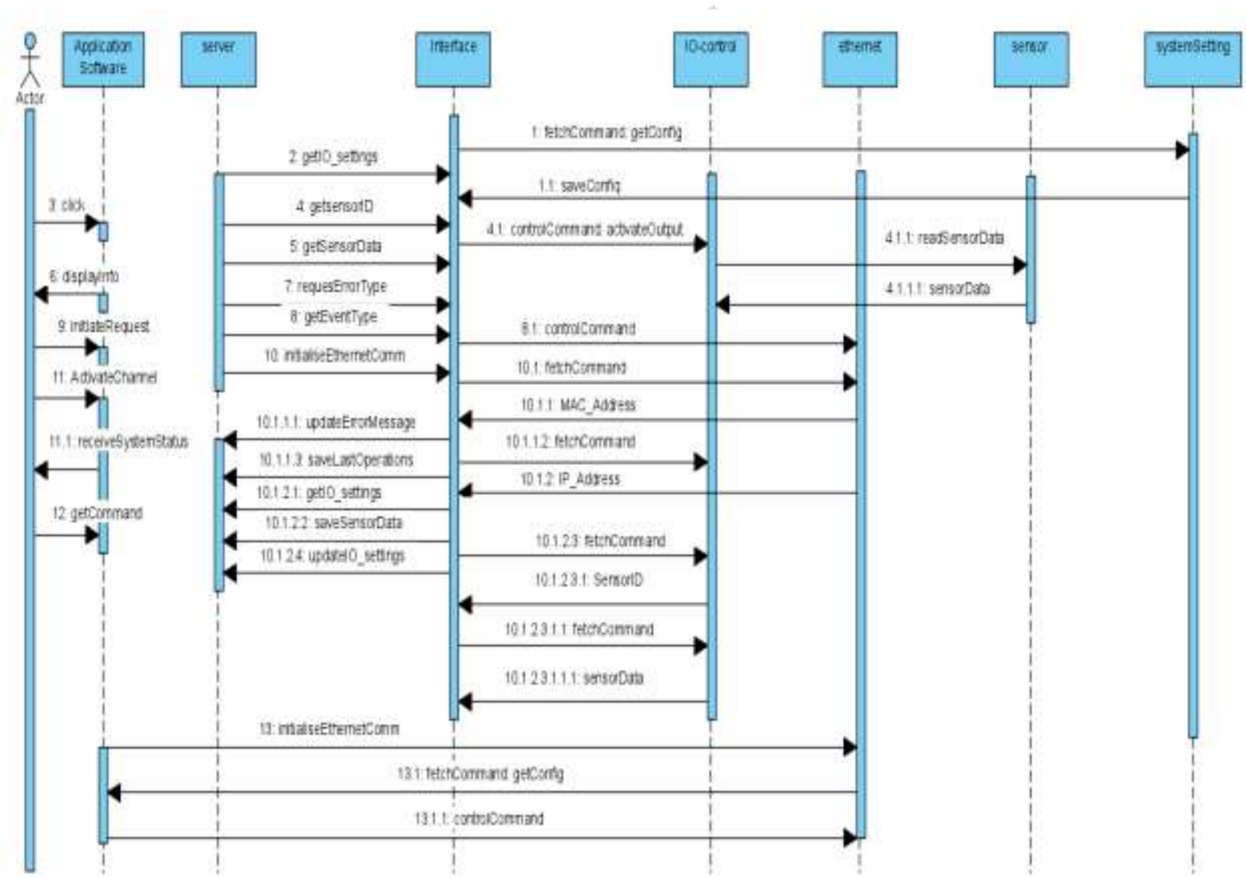


Fig.5. Communication interface for the controller and I/O driver unit.

2.3 Database management system

The system database was implemented using MySQL database management system. User-initiated events and activities from the process operations, control and instrumentation interface are logged into the MySQL database. As shown in fig.6, seven (7) tables were created to handles login records, Staff records, operations and activities, loading operations, tank operations and mal-operations. The records in the Staff_ID table were manually entered into the database by the backend administrator. There is no access to this table from the user interface or the process control user interface to prevent unauthorized access to the control software application. The number of correct operations is aggregated in the **OperationalActivities** table while the number of incorrect procedures of operations is stored in the Maloperation table. Using data from these two tables, user performance can be evaluated and ranked.

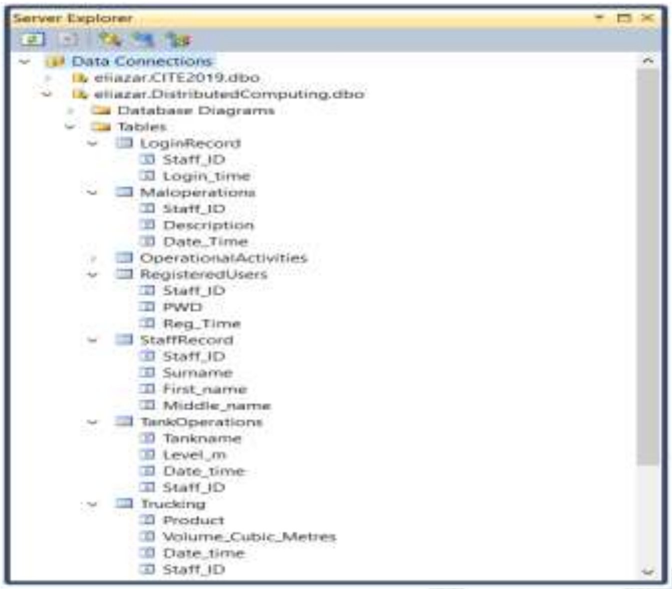


Fig.6. Database tables and their attributes

3.0 Results and discussion

All the three major components of the system as discussed above were integrated to form the proposed learning/teaching aid as shown in fig.7

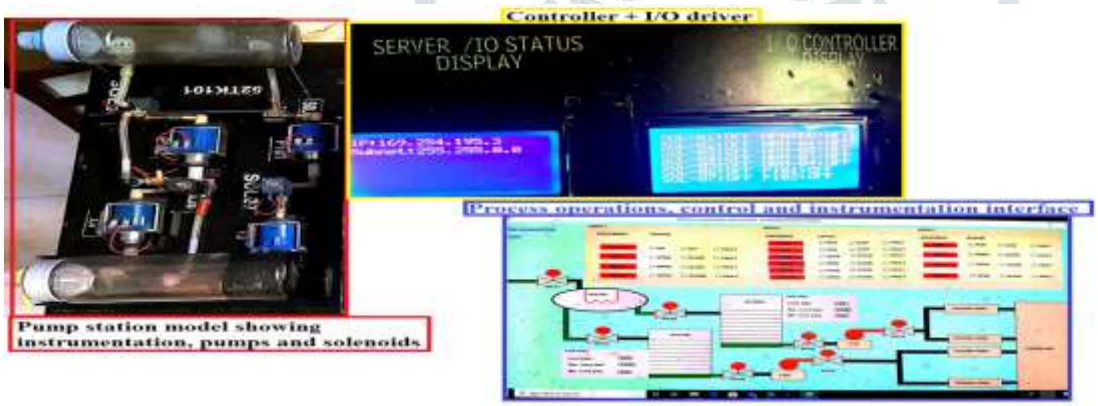


Fig.7. Integration of model, software and HiL (Controller).

To evaluate the performance of users on process operations, control and instrumentation, we created login IDs in the database for each user. We used results in **the OperationalActivities** table and **Maloperations** table. The tables contain information about successful and unsuccessful attempts during process operations.

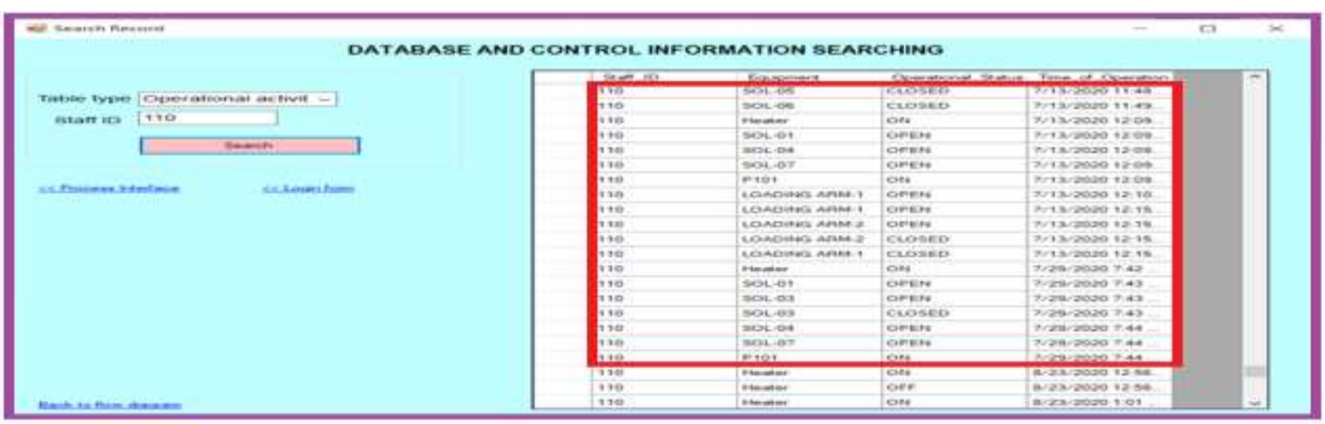
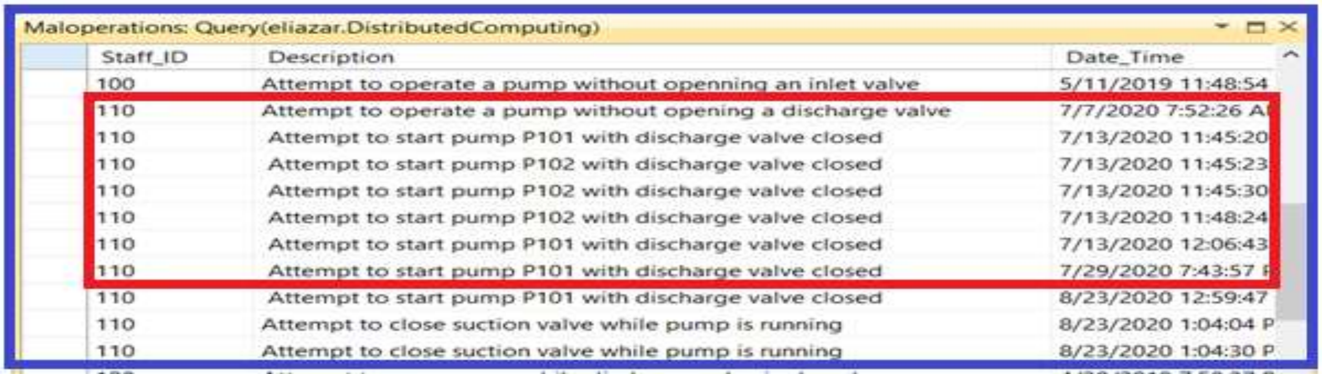


Fig.8. Successful process operations for user_ ID=110



Maloperations: Query(eliazar.DistributedComputing)

Staff_ID	Description	Date_Time
100	Attempt to operate a pump without openning an inlet valve	5/11/2019 11:48:54
110	Attempt to operate a pump without opening a discharge valve	7/7/2020 7:52:26 A
110	Attempt to start pump P101 with discharge valve closed	7/13/2020 11:45:20
110	Attempt to start pump P102 with discharge valve closed	7/13/2020 11:45:23
110	Attempt to start pump P102 with discharge valve closed	7/13/2020 11:45:30
110	Attempt to start pump P102 with discharge valve closed	7/13/2020 11:48:24
110	Attempt to start pump P101 with discharge valve closed	7/13/2020 12:06:43
110	Attempt to start pump P101 with discharge valve closed	7/29/2020 7:43:57
110	Attempt to start pump P101 with discharge valve closed	8/23/2020 12:59:47
110	Attempt to close suction valve while pump is running	8/23/2020 1:04:04 P
110	Attempt to close suction valve while pump is running	8/23/2020 1:04:30 P

Fig.9. Time-stamped incorrect operational activities for user_ ID=110 and user_ID100

Table 1. Simple tasks to evaluate trainee performances

Task no.	Task
1	Start and stop P101
2	Start and stop P102
3	Transfer from the heating unit to 52TK800
4	Transfer from the heating unit to 52TK700
5	Transfer from 57TK800 to Loading Bay (Order of operating equipment is important)
6	Switch Off P101 to end task 5
7	Transfer from 52TK700 to Loading Bay (Order of operating equipment is important)
8	Switch Off P102 to end task 7
9	Transfer from 52TK800 and 52TK700 to loading Bay simultaneously
10	End task 9.

Fig.8 and fig.9 show table views and partial contents of **the OperationalActivities** table and **Maloperations** table. Using these results, each user can be evaluated in terms of performance and knowledge of the process. 10 different tasks were performed by the users to evaluate their understanding of process operations. To complete these tasks, several valves and pumps were operated which test their understanding of basic plant rules regarding valve operations in the pump station.

Table 3. Success operations

x	f	fx	$(x - \bar{x}_{su})^2$		$f\,(x - \bar{x}_{su})^2$	**Percentage**
1	0	0	36		0	00.00%
2	0	0	25		0	00.00%
3	1	3	16		16	07.14%
4	0	0	9		0	00.00%
5	2	10	4		8	14.29%
6	2	12	1		2	14.29%
7	3	21	0		0	21.43%
8	3	24	1		3	21.43%
9	2	18	4		8	14.29%
10	1	10	9		9	07.14%
	14	**98**	**105**		**46**	

The frequency represents the number of trainees that obtained a particular score shown in table 2 and table 3. The percentage of the number of trainees for each scored point (or task) was computed, 21.43% of trainees scored 8 points out of the 10 points. One trainee got all the 10 points. The mean value of the successful operations out of the 10 points is given by equation (1).

$$\bar{x}_{su} = \frac{\sum fx}{\sum f} = \frac{98}{14} = 7 \quad (1)$$

The variable or spread in the dataset of successful attempts on the 10 tasks can be measured using the standard deviation.

$$s = \frac{\sqrt{f\,(x - \bar{x}_{su})^2}}{\sqrt{\sum f - 1}} \quad (2)$$

$$s = \sqrt{\frac{46}{14 - 1}} = \sqrt{3.538} = 1.88 \quad (3)$$

Fig.10 shows the pictorial representation of the number of trainees that scored a particular point in percentage. 46.86% of the trainees completed between 7 and 8 number tasks out of the 10 tasks designed to evaluate basic process understanding while 7.14% of the trains completed 3 tasks out of 10. Only 1 (7.14%) trainee completed all the 10 tasks.

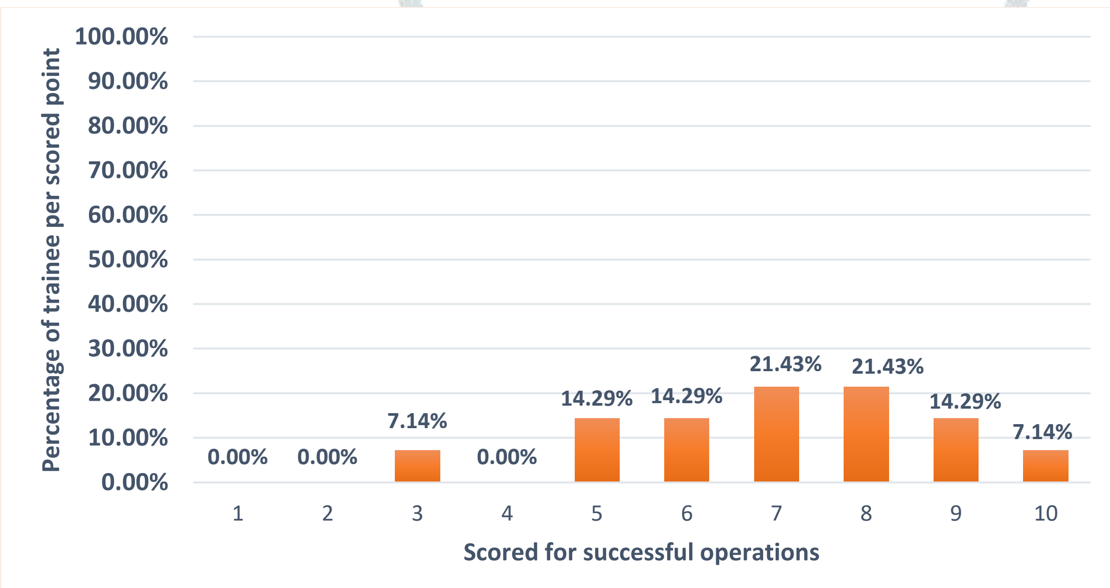


Fig.10: Percentage of the trainee for each successful task

In fig.11, only 7.69% of the trainees failed 7 tasks out of the total of 10 tasks. 46.16% of the trainees failed between 2 and 3 tasks. 15% failed only 1 task out of the 10 tasks and another 15% of the trainees failed 4 tasks out of the 10 tasks. This statistical analysis demonstrates how performance evaluation can be done on user's activities on the process operation, control and instrumentation interface. Depending on the criteria used and method of evaluation, the different scoring schemes can be implemented to monitor learning progress.

Table 4. Unsuccessful operations

x	f	fx	$(x - \bar{x}_{un})^2$	$f(x - \bar{x}_{un})^2$	Percentage
1	2	2	4.973	9.946	15.00%
2	3	6	1.513	4.539	23.08%
3	3	9	0.053	0.159	23.08%
4	2	8	0.593	1.186	15.00%

5	2	10	3.133	6.266	15.00%
6	0	0	7.673	0	0
7	1	7	14.213	14.213	7.69%
8	0	0	22.753	0	0
9	0	0	33.293	0	0
10	0	0	45.833	0	0
	13	**42**	**100.737**	**36.309**	

$$\bar{x}_{un} = \frac{\sum fx}{\sum f} = \frac{42}{13} = 3.23 \quad (4)$$

$$s = \sqrt{\frac{36.309}{13-1}} = \sqrt{3.02575} = 1.74 \quad (5)$$

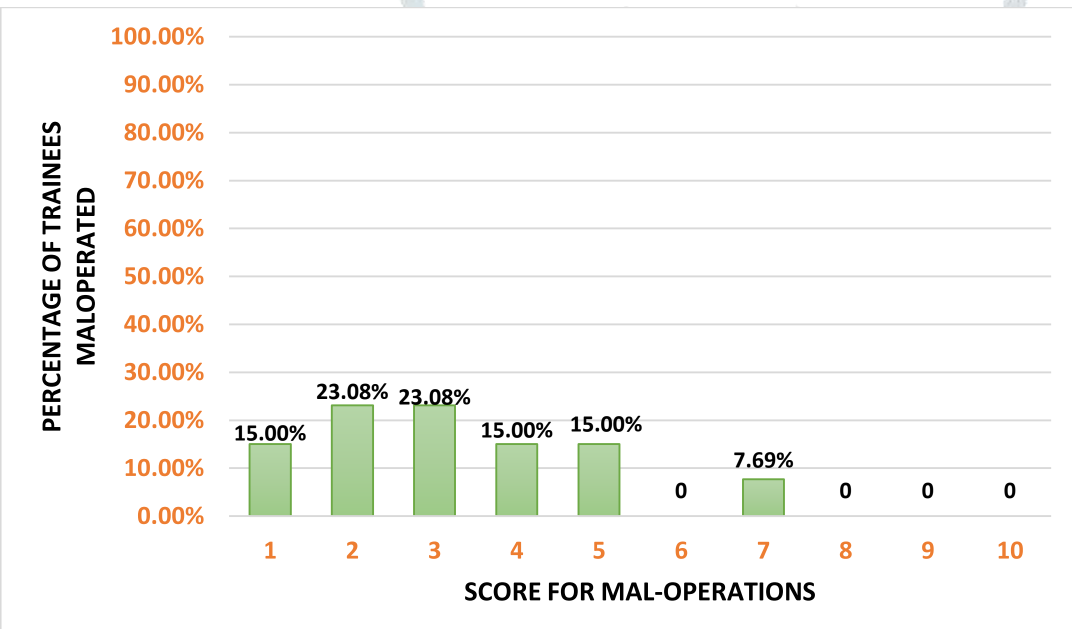


Fig.11. Percentage of trainees that mal-operated and their scores

4.0 Conclusions

In this paper, the combination of a real, small scale model and hardware in the loop (HiL) was proposed as a learning/teaching aid for Oil and Gas process operations, control and instrumentation. The system was validated using tasks developed to demonstrate the performance of the appraising system. The teaching aid provided a real-life scenario of pump stations and their process operations. Using the performance evaluation of the teaching aid, progress on students and trainees operational skills can be monitored and tracked.

References

[1] M.L. Dewi, A.R. Hakim, A. Setiawan, S. Adhisuwignjo and E. Rohadi, Mathematics Teaching Aids to improve the students' abstraction on Geometry in Civil Engineering of State Polytechnic Malany, IoP Conference series: Materials, Science and Engineering. (2018) 434. https://ir.upsi.edu.my/detailsg.php?det=5012

[2] G. Shabiralyani, K.S. Hasan, N. Hamad, and N. Iqbal, Impact of Visual Aids in Enhancing the Learning Process Case Research: District Dera Ghazi Khan, Journal of Education and Practice. 6(19) (2015) 226-233. https://www.semanticscholar.org/paper/Impact-of-Visual-Aids-in-Enhancing-the-Learning-Shabiralyani-Hasan/32294f38a1d5b424de3540f91037039cc7873ade

[3] G. Rodriquez, A. Soria and M.C. Isistan-Conicet, Virtual Scrum: A Teaching Aid to introduce undergraduate Software Engineering Students to Scrum, Computer Applications in Engineering Education.(2013). https://onlinelibrary.wiley.com/doi/abs/10.1002/cae.21588

[4] D. Ambarwanti,, I.M. Astra, A.A. Yaqin, and I. Sugihartono, Theremin as teaching aid to improve student understanding of waves, Journal of Physics: Conference series. 4th Annual Applied Science and Engineering Conference (2019). http://sipeg.unj.ac.id/repository/upload/artikel/Journal_of_Physics_Vol.1402,_Issue_4_Design_of_SIW_.pdf

[5] P. Karel, and Z. Tomaz, Multimedia teaching Aid for students of Basics of Control Theory in MATLAB and SIMULINK, Proceeding Engineering. 100 (2005)150-158. https://www.researchgate.net/publication/272946530_Multimedia_teaching_aid_for_students_of_basics_of_control_theory_in_MATLAB_and_SIMULINK

[6] P.H. Silva, L.G Nardo., S.A.M. Martins, E.G. Nepomuceno and M. Pese, Graphical Interface as teaching aid for nonlinear dynamical systems, European Journal of Physics. 39 (2018) 1-18. https://www.semanticscholar.org/paper/Graphical-interface-as-a-teaching-aid-for-nonlinear-Silva-Nardo/96a46f00fa1670dad160ed01f3be1687b7e0f684

[7] G. Barata, S. Gama, J. Jorge and D. Goncalves, Engaging Engineering Students with gamification, 5th International Conference on Games and Virtual Worlds for Serious Application (VS-GAME), (2013) 1-8.

[8] E.Ye, C. Liu, and J.A. Polack-Wahl, Enhancing Software Engineering using Teaching Aid in 3-D Online Virtual Worlds, 37th ASEE/IEEE Frontiers in Education Conference, Milwaukee. (2007). http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.92.1090&rep=rep1&type=pdf

[9] A. Babich, and K.T. Mavrommatis, Teaching complex technological processes using Simulations, The International Journal of Engineering Education. 25(2) (2009)209-220.

[10] T.M. Komulainen, R. Enemark-Rasmussen, G. Sin, J.P Fletcher and D. Camaron, Experiences on Dynamic Simulation Sofware in Chemical Engineering Education, Education for Chemical Engineers. 7(4) (2012) e153-e162.

[11] X. Li, and Z. Huang, An Inverted classroom approach to educate MATLAB in Chemical process control, Education for Chemical Engineers. 19 (2017) 1-12.

[12] W. Grega, Hardware-in-the-loop Simulation and its application in Control Education, 29th Annual Frontier in Education Conference. 2 (12) (1999)6-7.

[13] D. Bullock, B. Johnson, R.B. Wells, M. Kyte and Z. Li, Hardware in the loop Simulation, Transportation Research PartC: Emerging Technologies. 12(1) (2004) 73-89.

[14] J.A. Ledin, Hardware in the Loop Simulation, Embedded Systems Programming. 12 (1999) 42-62.

[15] D.S. Buse., M. Schettler, N. Kothe, P. Reinold, C. Sommer and Dressler, Bridging worlds: Integrating hardware-in-the-loop testing with large-scale VANET simulation, 14th Annual Conference on Wireless On-demand Network Systems and Services (WONS), IEEE. (2018) 33-36.