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BUILDING AUTOMATION SIMULATION AND RESEARCH TOOLSET FOR BUILDING MECHATRONICS

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***Abstract*—** Building Mechatronics Research Centre in the University of Debrecen, as intelligent building provides research infrastructure for building mechatronics simulations. The energy consumption habits of education and living activity are investigated. Our major research topics are energy efficiency, optimization, the development of energy measurement technologies and intelligent building automation.

This article presents the history of the Research Centre and the building automation technology with the embedded device from National Instruments: sbRio reconfigurable FPGA platform, capable of massive parallel working and adjustable to the building services challenges. The real-time development environment to develop, test and evaluate different building automation scenarios including building structure, HVAC systems, control algorithms and inhabitants generated demands could be utilized by SMEs, providing building services as the enhancement of the competitiveness of the building services. The simulation environment could be more precise and capable of planning a renewable energy system more proper to meet costumer's ideas and requirements.

***Keywords*—** energy efficiency, energy in buildings, renewable energy sources, sustainable energy management

I. INTRODUCTION

NOWADAYS, growing demand is observed in the application of renewable energy or the optimised use of the conventional forms of energy. Building mechatronics can optimize the current systems; provide a higher level of security and surveillance of the building on-demand of the consumers.

In the University of Debrecen, Faculty of Engineering, Electrical Engineering and Mechatronics Department a unique form of education came to existence. Building Mechatronics is educated in Hungary only there. The Department has a Bachelor of Science Program and since 2013 a joint Master of Science Program in Advanced Mechatronics Systems in English with the Department of Mechatronics and Robotics, University of Oradea (Romania) and a Master of Science Program in Advanced Building Mechatronics in Hungarian.

The laboratories provide research infrastructure and knowledge base for the researchers and PhD students. The results of the research project are multiplied in the building energy domain by not studying the building materials, construction and construction methods. The buildings are examined with mechatronic devices based on artificial intelligence. The power consumption can be regulated and controlled based on efficacy. Building mechatronics' new and innovative knowledge will be generated with the development of the research platform in the fields of artificial intelligence.

The article introduces the Building Mechatronics Research Centre, presents the recent researches with the heat pump systems and with the devices of the **N**ational **I**nstruments (NI) Ltd. with the innovations of the Energotest Ltd.

The paper consists of the following: Section II is about the Building Mechatronics Research Centre and building mechatronics. Section III presents the features of energy consumption awareness. Section IV describes the NI Ltd's device, the NI sbRio 9606 and its graphical user interface, the NI LabVIEW program. Section V shortly introduces the Building Mechatronics Simulation System. Section VI includes the summary. Section VII provides giving thanks.

II. INTRODUCTION OF THE BUILDING MECHATRONICS RESEARCH CENTRE

Mechatronics is relatively a new branch of science and engineering, consists of the 21st century's most promising engineering disciplines. It is defined as the combination of mechanical engineering, electronic engineering, computer engineering, software engineering, control engineering, and systems design engineering in order to design and manufacture products [5].

Building Mechatronics is the integration of the followings:

1) Building automation and building surveillance
2) Building security and object security
3) Building informatics, communication nets and the maintenance of informatics solutions that can help building operation.

The Building Mechatronics Research Centre provides real-time investigation and measurement of the energy consumption behaviours of an education building and rooms for recreation. The purpose of the Research Centre is to create extraordinary and special measurement options to find effective methods for the anomalies of the consumers' behaviour and enumeration. Furthermore, find new ways to avoid the losses.

In the intelligent building two heat pump systems are capable of the heating and cooling of the 1066m^2 total area. Both of them are free forms of energy and provide heating - cooling and the **D**omestic **H**ot **W**ater (DHW) needed by the recreation rooms for visiting researchers. Genkinger [1] scrutinized the economic and environmental impact of air-to-water heat pump combinations to other heating systems especially for DHW preparation.

B. Heat Pump System with Air Duct

The parameters of the compressor of the heat pump can be measured as well as the incorporated 1000-litre-large heat sink. The monitoring is also possible via the information technological network of the building with remote contact.

The electric capacity of the heat pump is 1200W. The controlled melt of the system as well as the observation of the safety catch (high pressure, low pressure, liquid circulation, extreme values of temperature, direction of rotation, phase failure, carter temperature) are assured (shown on Figure 1.)

The system can be operated in island mode of operation and with independent electric control, through the **H**uman **M**achine **I**nterface (HMI) which can be locally measured. The operation parameters and measured values can be reached and changed through Ethernet network. Within rational limits, the apparatus enables the change of the parameters of the compressor, gas circle, evaporation and condenser circle. Therefore, the operation of the gas pump system can also be influenced. The control delimits the possibility of measuring by means of extreme values of functional conditions so the apparatus is screened from accidental false setting of operational parameters. The system can be connected to outside stores in the case of one-circle and multi-circular mode of operation and the produced heat energy can also be recovered. The device can be operated in the location of installation in different configurations (serial or parallel connection of stores, resp. their tandem or cascade mode of operation, incorporation into the HMI and/or heating circle of the building). The apparatus is also provided with a supplementary heating and anti-freezing function and its operational parameters can also be easily measured in the case of extreme meteorological circumstances. The **D**epartment **o**f **E**nergy (DOE) in the United States of America published a paper in Clearinghouse about air-source heat pumps [2]. It describes the improvement of performance, the operation and maintenance.

The heat pump can be easily reset, installed to another location and after the connection can be immediately switched on, put to use and has incorporated supplementary heating, regulator and circulating pump as accessories.

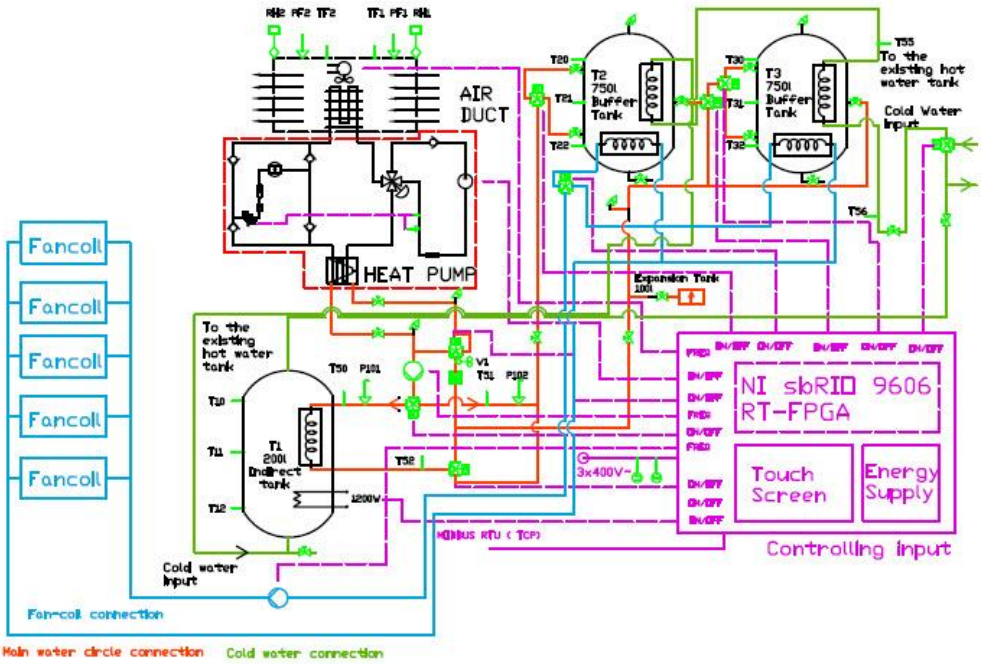

Fig. 1. Heat Pump System with Air Duct
Source: Compiled by authors

Vacuum Tube Solar Collector (1000W)

The vacuum-tube solar collector is mounted onto a stand and can be easily moved as well as easily and quickly connected to water-system. The outflow of the heat transmitting medium is assured by means of self-closing quick-connectors. The connection can be realized with flexible tubes in any position. The shape also assures the safe storage out of use (shown on Figure 2.).

The characteristics of the system are as follows:

- Vacuum-tube solar collector PERSC 1800/12V+;
- Direct-flow and heat-pipe embodiment;
- Shaped measuring points (temperature, mass current,) both on input and output side;
- Measurement of fall-in light capacity;
- Measurement of the temperature of the absorption surface;
- Shaped with a mobile stand and flexible tubes;
- Semi-automatic de-aeration after connection;
- Efficient electric capacity is 850W/m^2;
- Efficient surface is 1,26m^2.

It can be measured in mass current, input and output temperature, surface temperature and fall-in light capacity. The produced hot water is led to the buffer sink and then to the DHW system of the building.

C. Flat Solar Collectors

The characteristics of flat solar collectors are as follows:

- 1 pc 1.9-2.2kW/2.4-3.0m2
- 1pc thin-table flat solar collector 1.8kW

The heat pump system with solar collectors is controlled by an NI sbRio 9606 FPGA card (shown on Figure 2.).

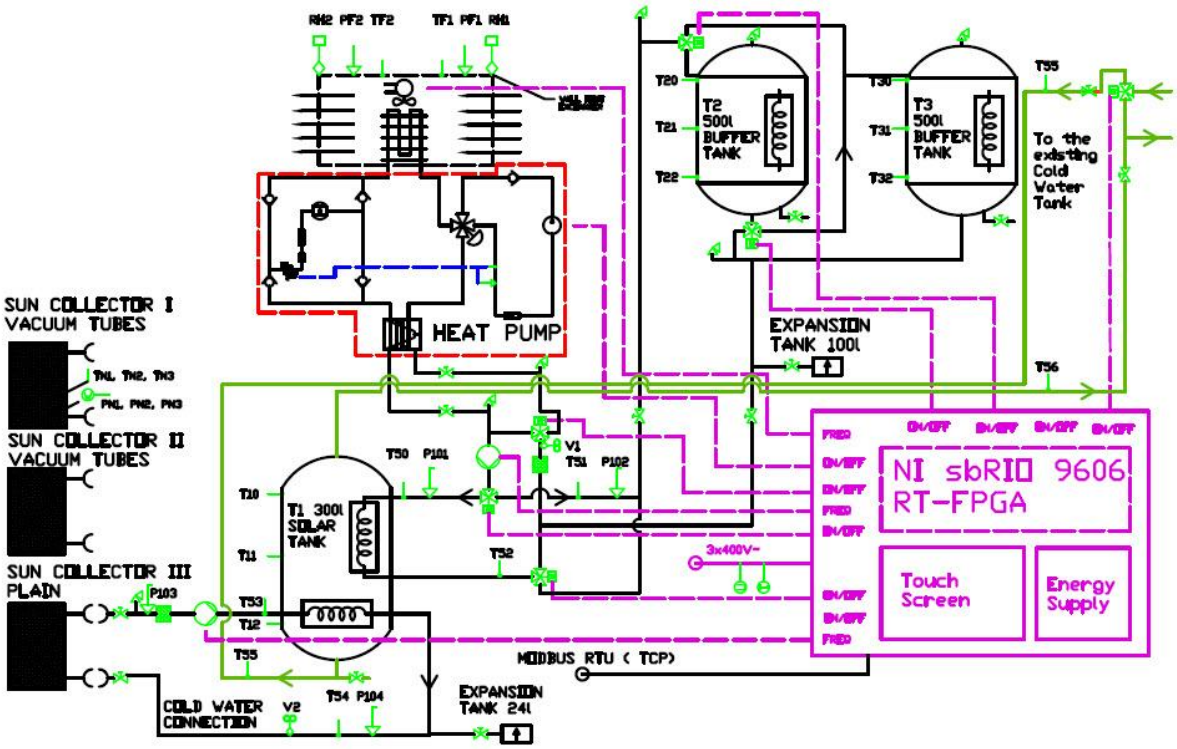

Fig. 2. Heat Pump System with Solar Collectors

Source: Compiled by authors

D. Wind turbine (600W)

The wind turbine is used to generate electricity from the kinetic power of wind. Three darrieus blades produce 600W electric capacity. The wind turbine serves as a standby power supply for electricity faults. Advanced computer cooling system enhances performance. The starting velocity of wind is 1m/s, the nominal velocity is 12m/s and the maximum is 65m/s. The direct-drive permanent-magnet synchronous generator is a three-phased AC engine. The output voltage of the controller is 12V and the intensity is ≤60A. The automatic brake system provides safe operation as well as manual shutdown. The working temperature ranges -30…+50°C.

III. Features of Energy Consumption Awareness

We would like to obtain higher energy consumption awareness through the examination of the consumers' behaviours. The reduction of the energy use can be reached by the means of energy control and an intelligent building management. The aim is to capture data which can be used for improved energy analytics and performance, facilities management and reduced operating costs [3].

We work on the next three levels:

- **Certification:** we utilize exterior references for design or use nominal data to create „medium" energy efficiency survey

with the appropriate prescript of the inland authorities or the European Union.

- **Operation:** we achieve higher energy consumption awareness through the examination of the consumers' behaviours. The reduction of energy use can be reached by the means of energy control and an intelligent building management.
- **Investment:** we can increase the energy efficiency with reconstruction, in other words we examine the return of the investment involve the full life cycle cost and examination of the consumers' behaviours.

New measurement procedures should be evolved to define, measure and compare the consumptions habits and make a complete definition of consumers' behaviours. In our research we create the reference of the building on the basis of [6] and [7]. The building energy certificate in Hungary (7/2006 TNM [8] as calculation method) is concerned for only residential, educational institutions and business centre. But what is the situation with the other industrial, local government and service buildings? How can we make a correct referential value, what is used to compare?

We observe the consumers' behaviour in real time environment to make values. The ordinary and renewable energy systems in the building are measured and models are created about them and the measured values.

In building mechatronics, measurement and data collection is of high importance. The reliability and repeatability of measurements is significant because of the complex energy and substratum streams as well as the non-repeatable ambient variables. Building mechatronics services requires high reliability and precision devices such as sensors, data collectors, data processors and stores.

IV. NI sbRio 9606 Card

The National Instruments' software and hardware means are keystones of technically sustainable development and infrastructure. The units driven by renewable energy are controlled by an NI compact controller. We chose the NI sbRio technology which is an FPGA-based technology. There can be built reconfigurable, parallel working real-time embedded controllers (shown on Figure 3.).

Fig. 3. NI sbRio 9606 Card[4]

NI sbRio 9606 Card integrated into heat pump system:

- 400MHz processor, 512MB non-volatile storage, 256MB DRAM for deterministic control and analysis
- Reconfigurable Xilinx Spartan-6 LX45 FPGA for custom timing, inline processing, and control
- 96 3.3V DIO lines
- Integrated 10/100BASE-T Ethernet, RS232 serial, CAN, and USB ports; 9 to 30VDC supply input
- -40 to 85°C local ambient operating temperature range

The NI sbRIO-9606 embedded control and acquisition device integrates a real-time processor, a user-reconfigurable FPGA, and I/O on a single printed circuit board (PCB). It features a 400MHz industrial processor, a Xilinx Spartan-6 LX45 FPGA, and a RIO Mezzanine Card connector, which is a high-speed, high-bandwidth connector providing direct access to the processor and 96 3.3V digital I/O FPGA lines.

This device features a built-in 10/100Mbit/s Ethernet port that can be used to conduct programmatic communication over the network and host built-in web (HTTP) and file (FTP) servers. The sbRIO-9606 also features integrated CAN, RS232 serial, and USB ports for controlling peripheral devices.

The professionals of Energotest built a carrier for the "mother card" (shown on Figure 4.):

- 32 digital inputs,
- 16 Push-pull outputs, 16 relay outputs
- 16 PWM (analogue) outputs and
- 32 (16 differential) analogue inputs

Because of the drastic decrease of the information technology solutions and the increase of individual solutions, the FPGA provides a flexible and reconfigurable system. It can extend the life of electronical devices.

Fig. 4. NI sbRio 9606 Card on the carrier panel
Source: Compiled by authors

The NI LabVIEW provides to create real time simulation systems in parallel processing. With the appropriate extensions the LabVIEW (short for **Lab**oratory **V**irtual **I**nstrumentation **E**ngineering **W**orkbench) is a system design platform and development environment for a graphical programming language from National Instruments.

The programming language used in LabVIEW, also referred to as G, is a dataflow programming language. Execution is determined by the structure of a graphical block

diagram (the LV-source code) on which the programmer connects different function-nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available. Since this might be the case for multiple nodes simultaneously, G is inherently capable of parallel execution. Multi-processing and multi-threading hardware is automatically exploited by the built-in scheduler, which multiplexes multiple OS threads over the nodes ready for executions.

The graphical programming user interface and philosophy provides further didactic chances. LabVIEW has plenty of implementations in industry as it can be used to test many important aspects of mechanical signals and systems; stress, strain, heat dissipation, moments and fluid dynamics are just a few examples. Information can be logged and rigorous automated DAQ (Data acquisition) schemes can be implemented entirely from within the LabVIEW environment.

Our department colleagues also develop Object oriented programs (Building-Mechatronic) in LabVIEW environment. The fully modular character of LabVIEW code allows code reuse without modifications: as long as the data types of input and output are consistent, two sub VIs are interchangeable and it can increase the productivity.

We chose NI LabView and sbRIO because of their reliability and easy-to-fitting-in. Furthermore, the software development is not difficult and the price/performance rate is prominent. Another reason was to find easy devices which have easy software complexity for our students to learn quickly. The Mechatronics Department use the National Instruments devices in various fields in the education: e.g. the ELVIS technology, in the education of digital circuits or the NI DAQ and other measurement, data collection for mechatronic projects.

V. Building Mechatronics Simulation System

In Building Engineering there is a constant need for measuring the following physical quantities, indoor and outdoor: temperature, moisture, pressure, CO_2 level. In the Building Mechatronics Research Centre a building mechatronic simulation system is developed and with the help of it we test Building automation methods and Information softwares:

- Communication protocol (field and broadband)
- Regulation performance and quality
- Stability examination: emergency, sectional failure treat, reduction of the extent of damage

Building Mechatronics simulation system has two sbRio FPGA card controllers: Master and Slave. (physical appearance is shown on Figure 5.)

The Master is for measurement control and makes building engineer simulation. The Slave is responsible for the regulation, the broadband communication and the treatment failure. This way a wide-range Building Mechatronic simulation is created.

The Master sbRio (Test controller) is the communication master. It produces building simulation by sensors, actuators, building engineer modelling and uploads the test exercise to the data base.

The Slave sbRio (DUT: Device Under Test) provides the communication tests, the test of the regulation functions and exercises as well as the test of the maintenance and alarm functions.

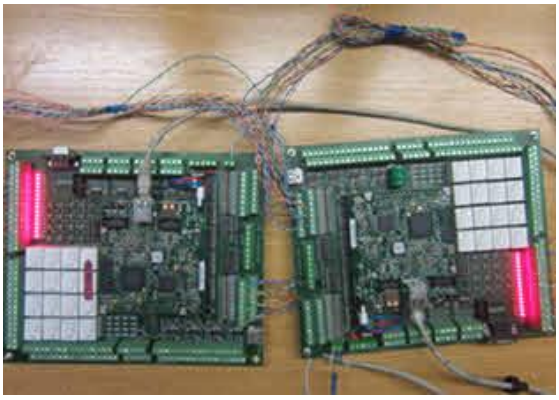

Fig. 5. The Master and Slave sbRio cards
Source: Compiled by authors

The LabVIEW software can communicate directly with SQL-compatible data base through Modbus connection (shown on Figure 6.). In other words it can realise direct data collecting and analysis.

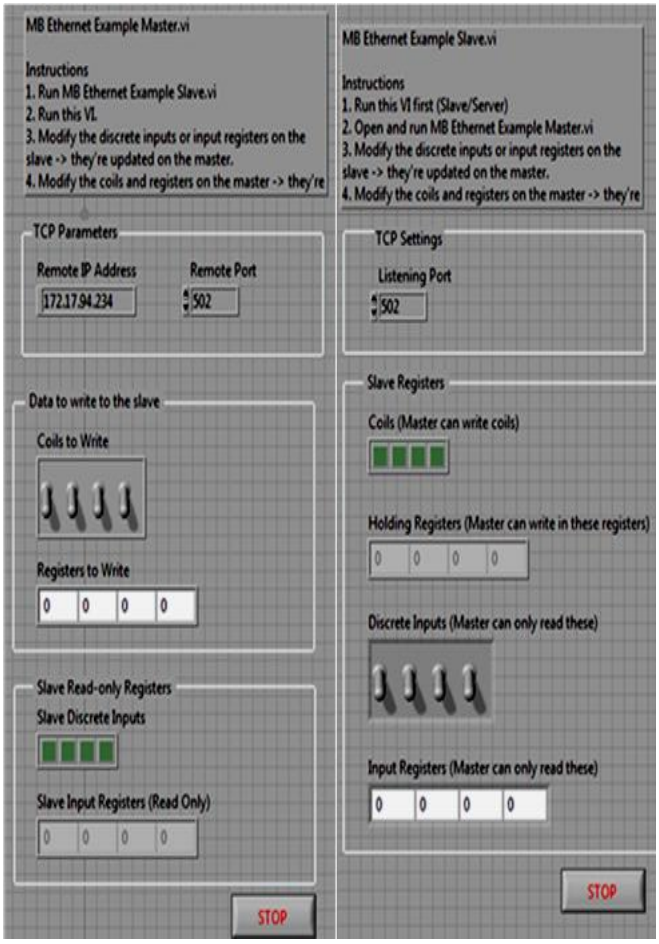

Fig. 6. Modbus TCP test

Source: Compiled by authors with NI LabView

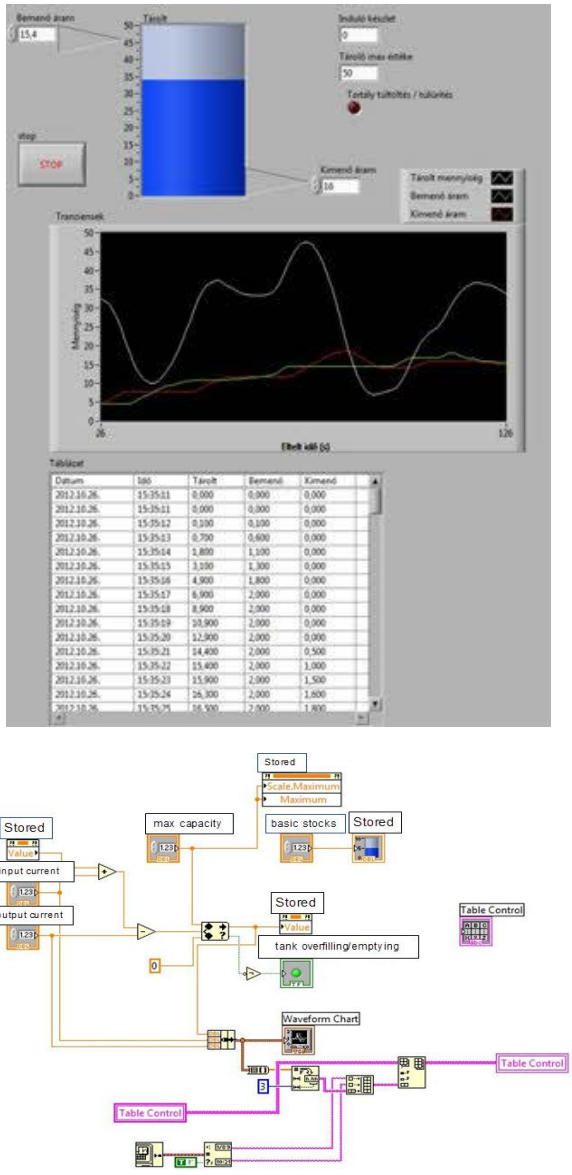

Fig. 7. Implemented Building Services
Source: Compiled by authors with NI LabView

The advantages of choosing NI FPGA based technology: sbRio is a real-time, parallel processing embedded device. The LabVIEW software provides the development of the programs on PC with TCP/IP. The Slave sbRio software is embedded into building engineering/ building management system without modification.

VI. Conclusion

The effective co-operation of industry and academy is required for the modern and qualified tuition. In the laboratories industrial technologies and results are needed to be taught and open technologies for researches: scientific works, thesis on the level of MSc and PhD.

The heat pump system controlled by the NI sbRio 9606 card was installed in the Intelligent Building. It is flexibly reconfigurable according to the building services demands. We built up a Master-Slave Simulation System from two FPGA controlled sbRio card which is able to simulate the building, the building services, supervision and communication. One sbRio 9606 is built in the Heat pump system with solar collectors. The tested programs can be transplanted without any change into the heat pump systems' control. The sbRio simulation system is up-to-date and can be used any times. There are some basic building services implemented in the system which proves the reliable working of the Simulation System.

VII. Acknowledgement

Our Department is committed for the devices and technologies of the National Instruments Ltd. We are pleased to be able to state our researches and tuition on a stabile technologic basement.

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