DISTRIBUTED WIRELESS MECHATRONIC SYSTEM OPERATED FROM MATLAB-SIMULINK ENVIRONMENT

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Abstract

The paper deals with a realization of control of distributed mechatronic system operated from MATLAB-Simulink environment. The mechatronic system serves as a laboratory model of simple manipulation system. The communication within the system is provided by wireless ZigBee protocol through a coordination unit. This unit is connected via serial interface to the control computer, where appropriate Simulink model runs. The paper addresses briefly individual physical components of the system (units, passive and active or executive elements etc.), specific blocks of used Simulink model and demonstrates the system behavior on several examples.

1 Mechatronic Systems and Wireless Communication

Up-to-date industrial machines, due to a requirement of just-in-time production and its diversification, have to meet a definite level of flexibility, movability and modularity. The machines have to be simply modifiable for product variations. In general, if the modern machines are analyzed, they are formed not only from mechanical parts, but they combine a lot of electro-mechanic and pure electric components. Used term for such machines or their groups is term “mechatronic systems”.

To operate and furthermore to develop a concept of modern production described above, it is important to provide and to improve a suitable communication among control or supervisory units and low-level working End Devices performing real manufacture or manipulation operations. Proven standard communication is communication realized by conventional wire connection. This solution may be sufficient within one individual machine, but it may be a limiting factor in the group of flexibly reconfiguring machines. Logical, promising and developing way is a solution via wireless digital communication. The wireless communication technology is limited only by radius of transceivers (i.e. transmitter and receiver – all in one) and it is fully disconnected from control unit. It is advantageous in several aspects. One of them is e.g. ability to supply the individual End Devices separately from different power-supply units independently of control and supervisory units.

This paper deals with a realization of control of one model of distributed mechatronic system representing specific manipulation system with several independent movable (main) units and stationery (auxiliary) units see Fig. 1.

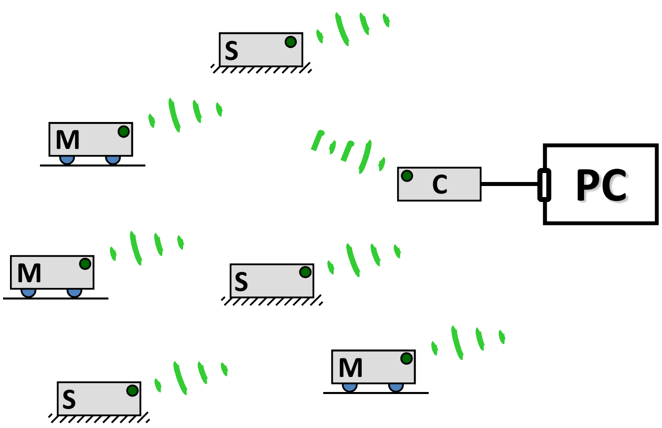

Figure 1: Distributed mechatronic system with several movable (M) and stationery (S) units and one unit for wireless communication coordination (C) connected to the control computer (PC)

The system is operated from MATLAB-Simulink environment. Specific wireless communication based on ZigBee protocol is investigated here. The communication is fully bidirectional from control computer to End Devices and vice versa. The explanation of the realization is provided in user point of view. The MATLAB-Simulink environment enable user to control the system both in manual mode and in simple automatic mode.

Organization of the paper is the following. Firstly, in section 2, the motivation for selection of ZigBee wireless standard is explained. Then, in section 3, the real mechatronic system or its main individual components are described. The following section, section 4, deals with a Simulink model and in it used blocks including connected standard peripheries; i.e. input and output blocks (interface), transformation and executive blocks and block of user visualization; mouse, joystick as standard input peripheral device etc. Last but one section, section 5, demonstrates time histories of several selected experiments recorded for different operational modes. Time histories include applied control actions, auxiliary sensor signals and position of movable units. Last section concludes whole paper with prospects for application of implemented wireless ZigBee communication in practice.

2 Wireless communication and ZigBee wireless protocol

Wireless communication consists in the data connection of two or more End Devices without any mechanical carrier. It can be realized as optical, radio or acoustic communication according to used carrier medium: light waves, radio waves or sound waves. The selection of suitable form is highly-dependent on target application. In case of distributed mechatronic systems, where each unit constituting the system should be more or less independent and energy self-sufficient, the communication has to be based on some low-power communication technology. Thus, it should not load the power supply of appropriate unit and be self-restarting in case of failure situations. As one suitable way, which follows mentioned criteria, is radio communication based on ZigBee protocol stack. It is selected for solution of the communication issue in this paper. ZigBee is given by ZigBee Alliance and it represents promising developing direction among other radio wireless communication technologies as Bluetooth, WiFi etc.

2.1 Features of the ZigBee protocol

ZigBee is a low-cost, low-power, wireless mesh networking proprietary standard of communication protocol. The low cost allows this technology to be widely employed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range. It is able to remain quiescent for long periods without communications and to allow devices to sleep without the requirement for close synchronization [2].

The ZigBee protocol is intended for use in embedded applications having low data rates and requiring low power consumption. A ZigBee's focus is to define a general-purpose, inexpensive, self-organizing mesh net-work that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, home automation, etc. The resulting network may use very small amounts of power. ZigBee has very low duty cycle, static and dynamic star, mesh or cluster tree networks with up to 65k nodes in one network, with low latency available.

2.2 ZigBee network

Individual devices – units of the wireless system are connected in ZigBee network. The devices are called nodes. The one network node can play a role of ZigBee Coordinator, Router or End Device. The role of the Coordinator is to set up a network, transmit network beacons (synchronizing signals), manage the nodes and store their information and route messages between paired nodes. It typically operates in the receiving mode. The role of Router and End Device network nodes consists in searching for available networks, transferring data from their applications as necessary, furthermore determining whether data is pending, and requesting data from the network Coordinator. These individual nodes do not work continually, but they can sleep for extended periods.

ZigBee network model is shown in Fig. 2. Whole figure represents cluster-tree network including one router as Coordinator, a group of separate routers representing mesh network and two indicated areas with several End Devices representing star networks [1]. The open network topology enable user to use variable interface without fix number of input and output channels.

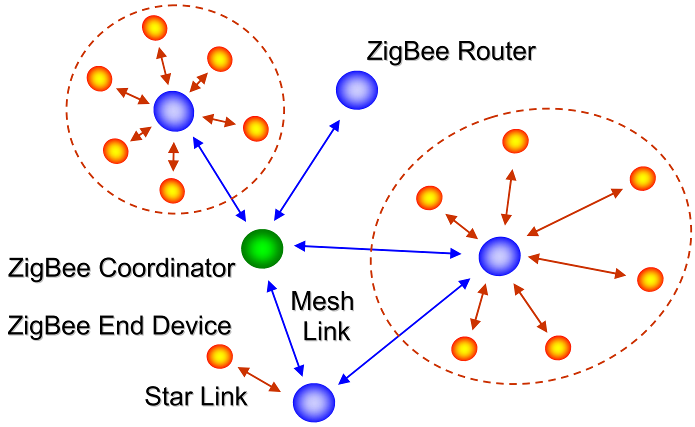

Figure 2: ZigBee network model (network topology)

3 Description of mechatronic system and its components

This section describes main components with respect to the realization of the ZigBee communication. The implementation is described partly in the relation to the used hardware components and the resultant function of the distributed system and partly in software point of view.

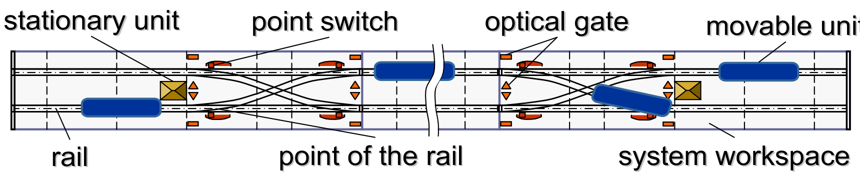

Figure 3: Mechatronic manipulation system

The mechatronic system (Fig. 3) consists of several distributed movable units and stationery units. Movable units provide discontinued manipulative operations and stationary units serve as monitoring and utility interface [11]. Each unit, movable and stationery, are independent of other units (autonomous of others) in all respects, i.e. self-controlling unit, energy self-sufficient etc. The units are equipped by communication transceiver. Movable units are driven by direct current (DC) motors and contain electro-optical positional sensors. The motors and sensors (let us say peripheries) are connected with transceivers to the ZigBee communication network.

The function of the system can be briefly described as follows. Movable units receive control commands from control PC. According the commands, the units move on rails and realize manipulation operations. Each movable unit transmits its topical position from built-in optical mouse sensor and auxiliary signals from infrared logical sensors. The railroad of individual movable unit is controlled by stationery units. They operate with point switches and ensure data acquisition from optical infrared gates. The gates serve the system to calibrate measured position to match with real position.

3.1 Hardware components

In the network topology point of view (see Fig. 2), the wireless communication in the considered mechatronic system is realized as one star network with a one main node working as a ZigBee Router and holding also the ZigBee Coordinator's function. This main node is a gateway for control computer, which provides real control of the system units. Individual movable and stationery units represent ZigBee End Devices.

The ZigBee Coordinator is connected to the control computer via USB interface. From the computer point of view, the ZigBee communication serves the computer as a very flexibly reconfigurable Input - Output interface with variable number of various inputs and outputs.

Main elements of the hardware are elements, which are able to provide the communication according to IEEE 802.15.4 standard and its extension defined by ZigBee Alliance. In presented solution, TI Development Kit CC2520DK is used [6]. On its basis, the suitable board for movable and stationery units was developed and realized. The main limit was an available build-in dimensions ($20\times20\times70mm$ or $35\times35\times85mm$) of the units for the board. The Fig. 4 shows hardware realization of trial all in one board and optimized combined board [12], [13].

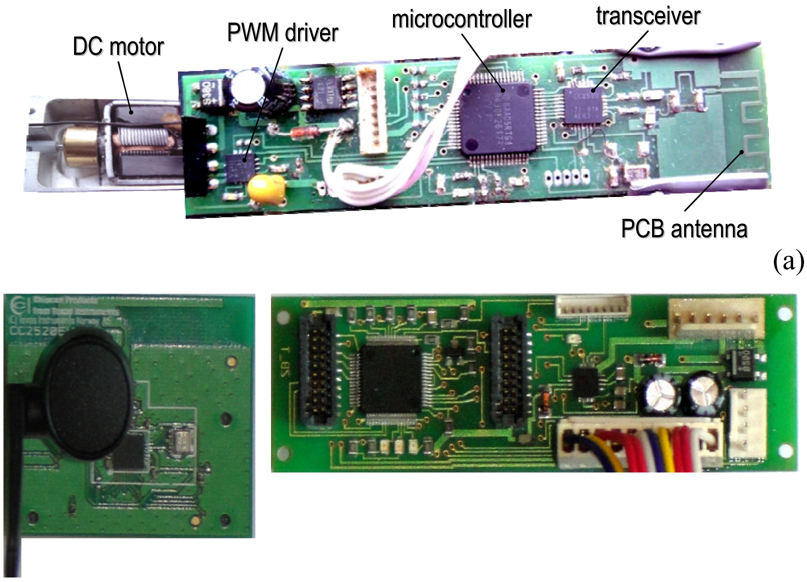

Figure 4: The boards with communication transceiver together with power-drive control of DC motor (a) – all in one solution including PCB antenna; (b) and (c) combined solution with separate boards: (b) – board of transceiver and external antenna, (c) – board of microcontroller and drive control

The circuits of the boards in Fig. 4 contain microcontroller MSP430F2618 [3], transceiver CC2520 compatible with standard IEEE 802.15.4 [4] and Pulse Width Modulation (PWM) power driver DRV8800 [5] of DC motor. In trial board, there is a Printed Circuit Board antenna (PCB antenna, monopole) for the transceiver. This circuit followed from the development kit CC2520DK is moderately adapted partly due to dimension requirements and partly due to attached peripheries: DC motor, optical position sensor, infrared optical gate, point switch etc. Separate antenna board (Fig. 4 b) represents standard commercial board of external antenna with usual SPA connector.

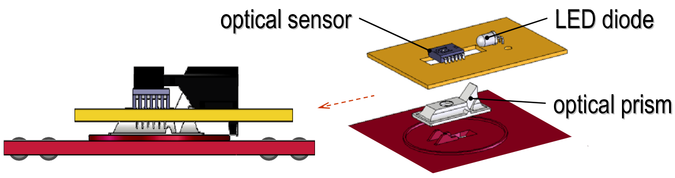

Figure 5: Optical sensor unit for position monitoring

Fig. 5 shows a vertical assembling disposition of optical mouse sensor PAN3401 [7] (LED, light emitting diode illumination) or PAW3601 [8] (infrared laser diode illumination) including other necessary optical elements. In the Fig. 6, there is an optical infrared gate circuit scheme (infrared emitting diode TSAL6100 [9] and receiver TSOP31236 [10]).

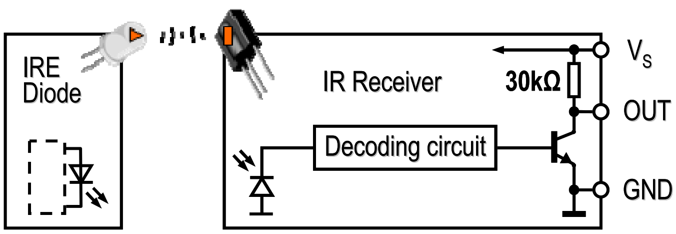

Figure 6: Circuit scheme of optical gate

4 Hardware in the Simulink model

The MATLAB-Simulink environment enable user to control the system both in manual mode by means of external input device – PC periphery (e.g. mouse or joystick) with Simulink model and in simple automatic mode via only Simulink model. Real experiments were realized with Simulink models shown in Fig. 7 and Fig. 8. The mechatronic system is connected via Standard Devices Serial Port – Stream Output (PWM data) and Input (Sensor data) Simulink blocks.

Let us proceed in systematical description of the main model blocks in the loop of Simulink model on the top of the Fig. 7 from Stream Input block. After the Stream Input, there are several transformation blocks serving to the position calibration and logical blocks processing the signals form the optical gates. All signals lead to Discrete-Time Integrator block having two extra external ports: reset and initial condition. This block integrates the position of the movable units and it can be restarted (reinitialized) just by mentioned two additional input ports. This position is processed in a user defined block ‘E MATLAB Fcn’ (left side bottom corner of the Simulink model), where, on its basis, the appropriate level or value of control action is selected. This value leads to ‘Stream Output’ block towards wireless interface of the mechatronic system (i.e. real hardware) and the loop is closed this way.

In the middle of the Fig. 7, there is a sample of the ZigBee communication caught by broadcast gripper. It shows transmitted data in frames and packets.

At the bottom of the Fig. 7, there are time records of position and control action for the one selected movable unit and the window of simple on-line visualization. Detailed views are shown in figures in section on Results.

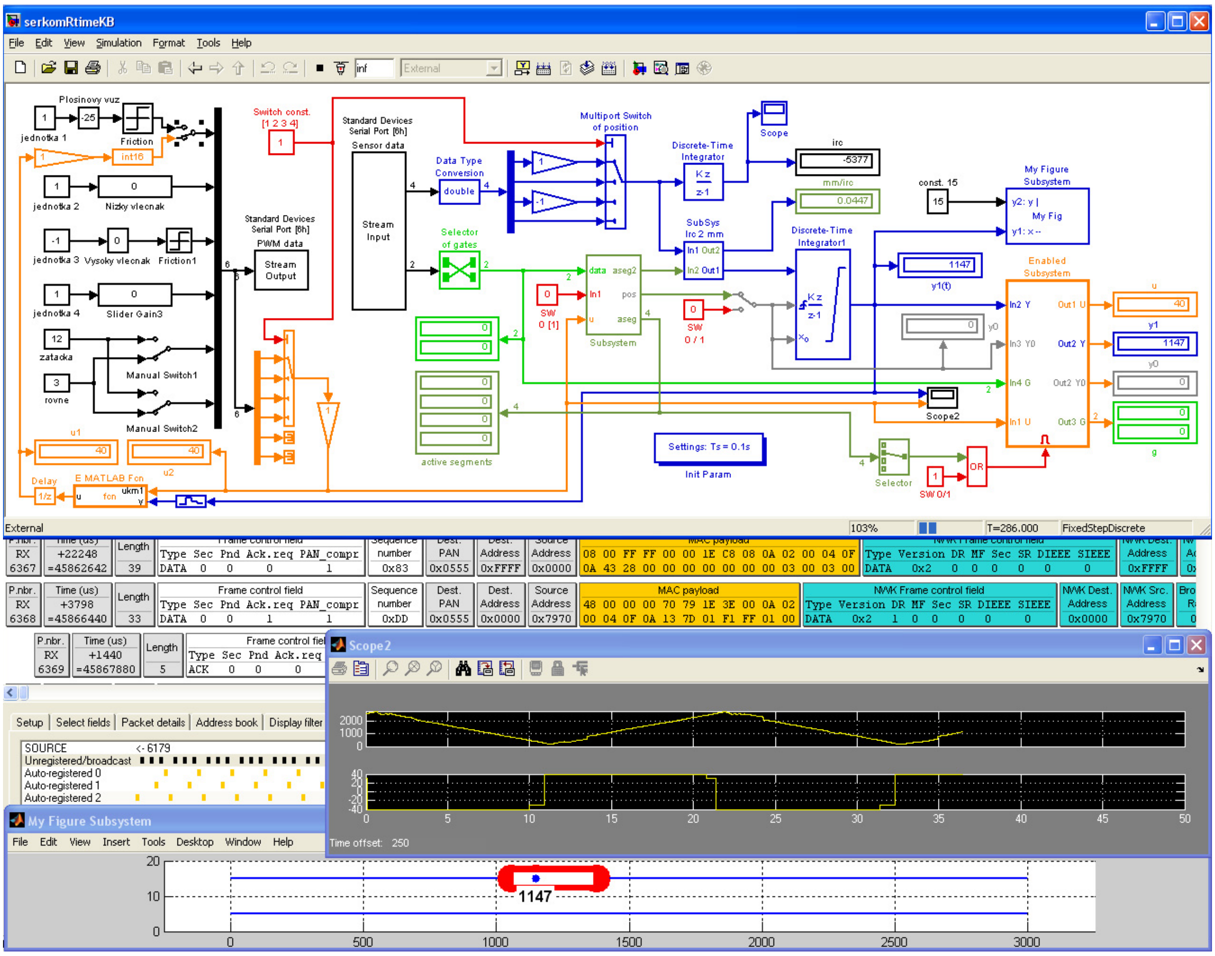

Figure 7: Screenshot of the real-time running Simulink model on control computer: Simulink model (in front and on the top); history of ZigBee frames and packets (in the background in the middle); on-line position and control action scope and simple visualization figure (at the bottom)

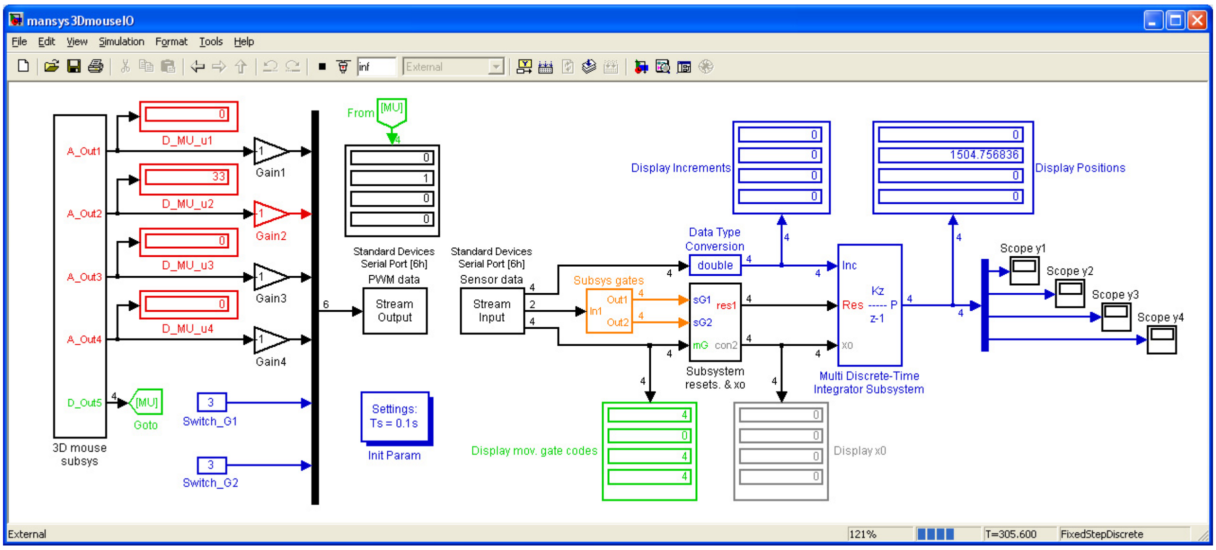

Figure 8: Screenshot of the real-time running Simulink model for simple manual control

Simplified Simulink model for manual control mode is shown in Fig. 8. It includes only the main necessary blocks as follows:

- manual inputs to the Simulink model (3D mouse subsys)
- outputs from Simulink model (Stream Output)
  (= input of the hardware; i.e. mechatronic system)
- inputs to the Simulink model (Stream Input)
  (= output of the hardware)
- positional integration block (Multi Discrete-Time Integrator Subsystem)
- visualization blocks (Displays and Scopes)

It is evident from this figure that the controlled mechatronic manipulation system consists from four movable units (D_MU_u*i* blocks – display of values of control actions; Display Increments – increments from laser positional sensors of each movable unit and Display Positions – integrated real positions of individual units), two groups of point switches (Switch_G*i*) and two group of optical gates (Subsys gates).

5 Results

In this section, firstly, there is a time record from manual control mode realized with Simulink model shown in Fig. 8. The user controls directly the value of control input to one selected movable unit. As input device, 3D mouse or joystick periphery devise [14] is used. It is visible that the record is finely changed at the passing the accurate position of individual optical gates (fixed positions: 520, 980, 2020, 2480 mm). The impulses from the gates improve discontinuously the obtained positions from increment integration by Discrete-Time Integrator. Due to used mouse sensors [7] or [8], which generate only pulses at the motion, this calibration is necessary, in other cases, the positions of movable units diverge from a reasonable range (the position range of movable units is $\langle 0 \div 3000\ mm \rangle$).

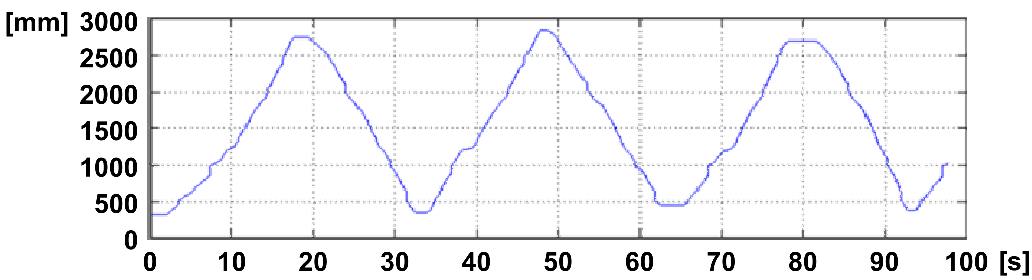

Figure 9: Time record of the position with manual control via 3D mouse

The detail of the records in simple automatic mode (Simulink model in Fig. 7) is shown in Fig. 10. In that figure, the reset of the integrator is indicated by red horizontal short lines, which correspond to appropriate signals from fixed optical gates. The pass the gates means that the movable unit interrupts the optical circuit (Fig. 6) as indicated at the bottom in Fig. 10. Individual levels (i.e. 1, 2, 4, 8) corresponds to the code of the activated gates.

The multi-level feedback control changes control action magnitudes according to topical position (positional feedback), therefore, before turning point, smaller action magnitude is generated.

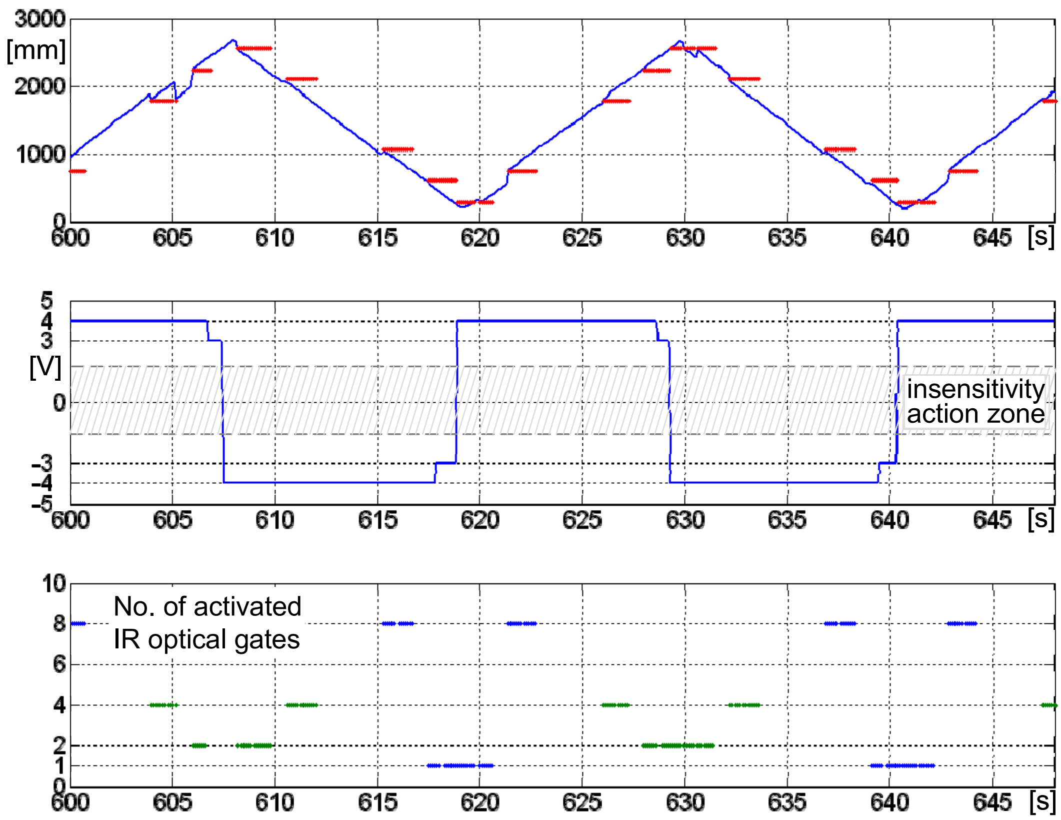

Figure 10: Control process of one movable unit: time histories of position (on the top), control actions (in the middle), activations of optical gates (at the bottom)

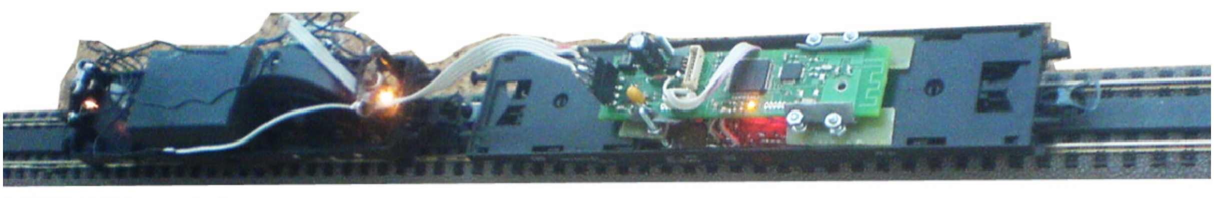

Figure 11: Movable unit as one of the End Devices of distributed mechatronic system

6 Conclusion

This paper deals with the wireless communication based on ZigBee networking proprietary protocol standard. The aim of the investigation and experiments was design and evaluation of possibilities of wireless communication to be implemented as full-value communication channel serving high-level model-based control strategies [15]. Those strategies are tested and prepared for mechatronic systems with number of distributed End Devices (see Fig. 11), where number of the conventional cables (wires) limits the system motion and modularity.

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