Proceedings of the 2015 International Conference on
Advanced Mechatronic Systems, Beijing, China, August, 22-24, 2015

Versatile Intelligent Portable Robot Platform for Flexible Robotic Cells with AGV

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***Abstract*— The paper studies the flexible robotic cells in cooperation with automated guided vehicle (AGV), in the presence of obstacles, at constant or variable speed and variable load, aiming to optimizing the interaction between AGV and flexible robotic cell components. Overall system performance is analyzed by using modeling tools for discrete event systems like Generalized Stochastic Petri Net (GSPN). The interaction between AGV and flexible robotic cell components is implemented through communication messages using serial data received from an optical XY encoder, communication protocol receive function is modeled with GSPN. Improving of the stability performances and real time motion control are analyzed and the virtual projection method is adopted using the Versatile Intelligent Portable Robot Platform VIPRO. The obtained results, validated on the experimental RTOS robotic platform and DMQX language extension for robotic applications, lead to higher performance in relation to interaction optimization, decrease the flexible cell's cycle time, increase mobility and stability of the AGV and also the development of new technological capabilities of the control systems.**

Keywords*— intelligent control, virtual projection method, real time robot control, automated guided vehicle AGV, Generalized Stochastic Petri Net, flexible robotic cell

I. Introduction

The paper presents a new approach in flexible cell type robotic systems using distributed control. Manufacturing systems have gradually evolve from manual production to automated lines and serial flexible cells, toward nowadays flexible manufacturing systems (FMS) [1-3]. The industrial robot represent the main component of flexible manufacturing systems due to its execution capability of discontinued automated processes having a high complexity level. The industrial robot can be re-programmed and is easy adaptable to manufacturing process, involving lower costs in terms of workmanship, energy and materials.

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Modern assisted design is achieved with design tools using dedicated software like Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) or Computer Aided Engineering (CAE) in parallel with the use of simulation programs (e.g. structural and operational analysis, manufacturing processes optimization). Resource planning has an important role, starting with how clients requests are managed, followed by automated scheduling of materials list according to items requested from manufacturing process flow and then launching the items in production based on their priority level and time interval availability criteria when the items are part of a manufacturing subansamble.

For the FMS characteristics improvement, the distributed intelligence plays a significant role. The use of distributed control technologies offers the optimal solution through communication based controllers which ensure both local and remote control functions inside a SCADA system [4-6].

In the paper is presented a new control strategy based on communication methods (message exchanges) between the system components by programming language extension which contains functions designed for real time operating systems (RTOS).

The control methods presented in this paper combine the communication protocols applied in artificial intelligence (multi agent systems, MAS) with industrial communication protocols (e.g. Modbus, OPC server).

The paper, also presents a robotic platform with innovative hardware-software controllers using real time operating system and extension language with data acquisition for later robotic system discrete states evolution and performance analysis.

By using Petri Nets, the operations flows were modeled for different configurations of flexible robotic cells using DMQX robotic controllers [7, 8]. The collaboration was achieved between system components – as MAS system approach, and

978-1-4673-7995-3/15/$31.00

between robot components – as autonomous agents having the purpose of different tasks implementation at local level.

Through message based communication, an improved collaboration between flexible cell components was achieved for complex robotic tasks implementation. From the programming point of view, the scope was to obtain algorithms optimization and source code simplicity by keeping the flexibility characteristic and developing adjacent functions inside the language extension.

As result, a distributed system for flexible robotic cell with virtual projection method was implemented, integrated in Versatile Intelligent Portable Robot Platform – VIPRO, and using a communication with modified Mbus protocol with DQMX language extension for RTOS robotic controllers.

II. Modeling CPN and GSPN for Communication Protocols in FRC

Colored Petri Nets (CPN) represent a graphical language used for concurrent systems models construction and their properties analysis [9]. CPN is a Discrete Events Systems (DES) modeling language which combines Petri Net capabilities with those of the high level programming languages, compared with simple Petri Nets which ensure the foundation of graphical notation and the basic primitives for modeling the concurrence and synchronization. The CPN Modeling Language (CPN-ML) is based on Standard ML functional programming language [10], which gives the basic elements for data types defining, for data manipulation description and for creating compact and parametric models. CPN modeling language is a general use language, for example it is not directed to a specific category but to a large system classes having in common the process concurrence property. Anyway, CPN can also be applied for systems modeling where processes concurrence and communication represent important characteristics (e.g. manufacturing systems and multi-agent systems).

The CPN modeling of the mMbus ASCII communication in a network with data loss is shown in Figure 1.

The states noted S_t, S_i and S_r, are connected to the transitions T_t, T_i and T_r through unidirectional arcs. The states are represented with oval forms, marked with one or more tokens. The token associated value at a given time is identified by color. By using the CPN representation convention, the name of states and transitions is placed inside of the graphical forms. The states are grouped depending on communication sequence type:

S_t = {*Transmisie*, *CaracterTransmis*, *Următorul_caracter*, *ContorCar*, *RecAcc* } (1)
S_i = {*A, B, C, D, EroareCar, FaraAcc, TP, TC* }
S_r = { *Receptie, RecCar, UrmRec*}

The colors set for the states noted *Transmission, A* and *B* is defined as <INT x DATA>, and represents the possible combinations set in matrix (INT, DATA), used for data packet modeling. For the *Reception* state is defined <DATA> type, used to data packet load modeling and represents the set of character arrays of <STRING> type. For the states *CharacterTransmitted, FollowingCharacter, ContorCar, ErrorCar, C* and *D* was defined a <INT> type colors set.

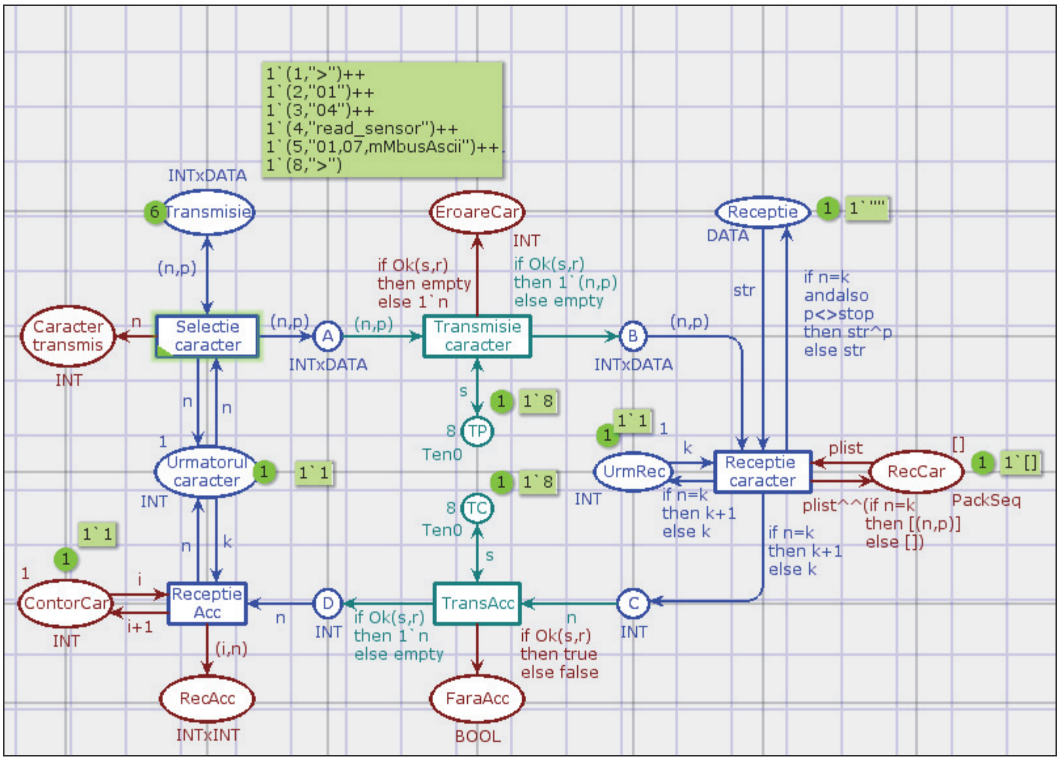


Fig. 1 CPN modelling for mMbus-ASCII communication in a network with data loss

The data packet used for sequence communication evaluation contains de description of a command having „>” start identifier, the address “*01*”, Mbus register number “*04*”, function identifier “*read sensor*” from DMQX extension language having the arguments “*01,07,MbusASCII*” and at the end “>”terminator character. Thus, the initialisation of *Transmission* state is defined with 6 tokens of characters arrays type which are concatenated by the “++”operator, in the following form :

1` (1,”>”)++
1` (2,”01”)++
1` (3,”04”)++ (2)
1` (4,”read_sensor”)++
1` (5,”01,07,mMbusAscii”)++
1` (8,”>”)

By using this description and composition way for the communication messages, the CPN model implements the DMQX language extension function, with the suppression of limitations imposed by a classical infrastructure from a distributed system which uses a less robust protocol but having a large scale usage - Mbus, and adding improved characteristics (e.g. the retransmission of sequences from the data packet in case that unpredictable errors were encountered during the communication process).

III. Optimization of Intelligent Control Methods Using the Vipro Platform

The intelligent control method allows optimization of interaction between AGV and flexible robotic cell components.

In this context the VIPRO platform brings back the virtual robots into real world, based on virtual projection method.

This method enables the development in a virtual environment of mobile robots mechatronic systems that comminicate with real robotic systems through high speed interfaces. The result will consist in the development of a versatile, intelligent, protable robotic platform, VIPRO, which will ensure the improvement of motion stability perfromaces in, both, virtual and real enmvironment, for flexible robotic cell.

The VIPRO platform architecture (Figure 2), in correlation with the virtual projection method, has as main component the intelligent control interface module. It uses advanced control strategies adapted to robot environment, such as: extended control (extenics), neutrosophic control human adaptive mechatronics, etc., implemented by IT&C techniques, fast-processing and real time communication ones. This module contains mainly the interface for intelligent neutrosophic control by integrating the Robot Neutrosophic Control (RNC) method, Extended Control Interface through Extenics (ICEx) and Haptic Robot Control Interface (HRC).

Robots Neutrosophoc Control Interface (ICNs) integrates the robot control neutrosophic method, Robot Neutrosophic Control (RNC), known as Vladareanu-Smarandache method [13].

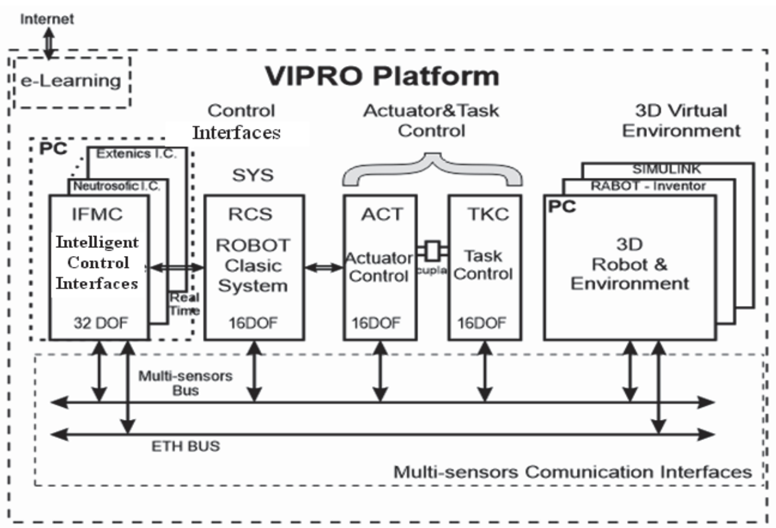


Fig.2 The architecture of the VIPRO control system

ICNs uses the neutrosophic logic to fuse information from robot sensors in order to obtain a high accuracy result of sensor data. This result is further used in decision making process of the robot. The force – position hybird control of flexible cell robots equipped with the compliant joints also have to consider the system’s passive compliance. The generalized space (coordinates) where robot works can be defined in a six degree of freedom constant space, representing force constraints in normal direction to the working surface and force constratints in tangential direction.

When there is the fusion of information received from different sensors, a certain rate of conflict is possible to occur. In this case, the robot will use the fuzzy and netrosophic logics [11-13]. So, real time dynamic neutrosophic fusion is considered and an autonomous robot can make a descision at any moment. In order to combine information, there can be applied information fusion theories (Dezert-Smarandache theory, Dempster-Shafer theory, trust transfer model of Smets) together with different fusion rules, such as: conflicts proportional distribution, hybrid rule, etc.

More, there can also be applied fuzzy logic / sets and neutrosophic logic / sets so that to obtain a combination model for the information received from robot sensors, using neutrosophic logic operators (N-norm si N-co-norm) representing generalisation of fuzzy operators (T-norm si T-co-norm).

Neutrosophic method of robots control, Robot Neutrosophic Control (RNC), known as Vladareanu-Smarandache method [13], due to the application of neutrosophioc logic and Dezert Smarandache Theory in robots control (DSmT), does stand for a new method combining fussy theory and information fusion.

By implementing the RNC method inot VIPRO platform, it has been developed a new control interface for improvement of flexible robotic cell and AGV interaction performances.

The interface of robots extended control integrates the extenics methods of robots real time control, by applying the extenics theory for solving contradictory problems [14-18]. Extenics is a science dealing with solving contradictory problems. The systems extended control enables the optimization of control process applying extenics theory, metrics and extended function to extenics space defined by the extenics logic. Real time operating consists in implementing the robots extended control inteface (ICEx) into the basic scheme.

The scientific fundamentals are based on extenics theory for defining position extended distance, $\rho(X,X_o)$, force extended distance, $\rho(F_a,X_{Fo})$, dependence function $K(X, X_o, X_{CR})$ of the current position signal, X, relative to the positive standard interval of reference position, X_o and positive transtion interval of position, $\mathbf{X_{CR}}$, respectively, the dependence function, $K(F_a, X_{Fo}, X_{FCR})$, of force signal, F_a, relative to the positive standard interval of reference force, X_{Fo} and positive transition interval of force, $\mathbf{X_{FCR}}$, This is how, there is obtained an extended transformation through a relationship including a dependence function extended to measurement universe, U by position extended distance, $\rho(X,X_o)$ and force extended distance, $\rho(F_a,X_{Fo})$ thus, leading to the optimization of interaction between AGV and flexible robotic cell components.

IV. Design of the VIPRO Open Architecture System

Lately, the mobile robots have got special attention from, both, research scientists, and manufacturing industry specialists, so that there resulted important hardware and software development

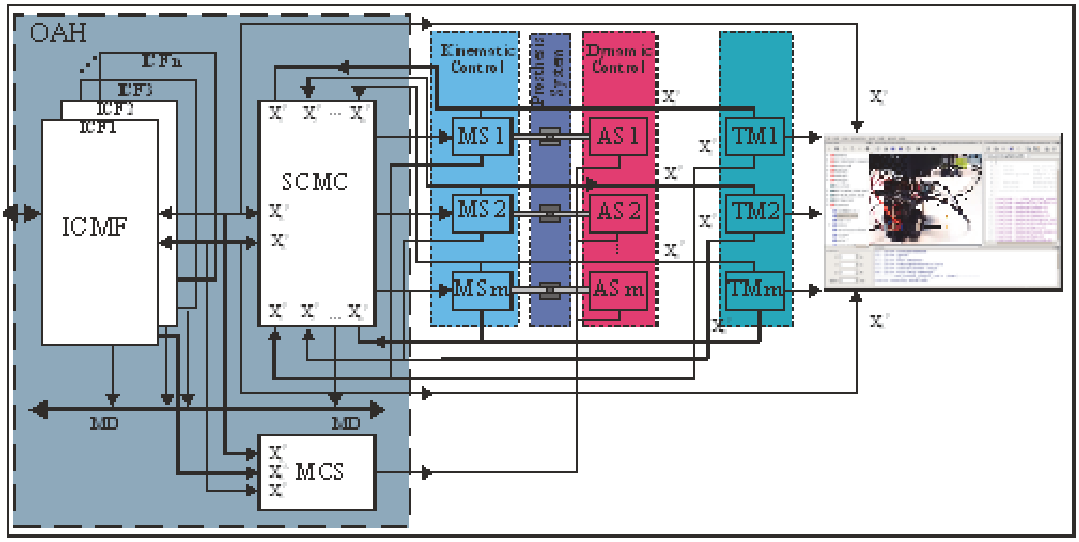


Fig.3. Virtual projection method by Vladareanu-Munteanu applied to VIPRO Platform

Real time control robots with remotely controlled network and human operator abilities have a highly important role in the concept and performance improvement of flexible robotic cells. Huge research resulted in the development of different robots types with sensing, transport and manipulation abilities for different application [20, 21].

Research activities performed for developing 3D virtual environment platforms lead to the gain of important expertise on robots motion in virtual enrironments, based on high abilities of navigation, cooperation, obstacles avoidance, simulation of high reliability virtual environments but, there is no interaction of virtual environment : virtual robot – real robot.

The VIPRO platform mentioned in this paper and evidenced in Figure 2, is based on the virtual projection method, known as Vladareanu-Munteanu method – see Figure 3 [21, 22]. The notations stand for the following: SCMC is the classic control system, which drives the servo-actuators MS1, MS_m,-with „m" being the number of the robots degrees of freedom, and receives signals of TM_1-TMm measure. The methods refers to an open architecture real time control device for robots. It is aimed at improving control performances and fit for application in control systems of nano/micro/macro manipulators and robots.

The problem solved by the virtual projection method is that of enabling to desgin, test and experiment different control methods on a real time control system, on-line, even if there is no real mechanical structure [23-25]. There is its virtual projection and, thus, it is possible to efficiently improve performnaces of robots control systems, that already exist.

A corresponding number of load actuators are rigidly coupled to the servo-actuator modules receiving control signals from a MCS load controller module which ensures the load of the MS servo-actuator modules. Also, a number of m AS load actuator modules rigidly coupled to the „m" MS servo-actuator modules receive control signals from a MCS load controller module with the role to ensure the load of the m MS servo-actuator modules.

An MCS load controller module receives the XRP and XRF, position and force reference and a XRS reference signal to generate loads to MS servo-actuator modules, from the ICMF multi-function control interface with the role to ensure the real time control and the load of the „m" MS load actuator modules.

In Figure 4, there are presented the simulation results for the simplified GSPN model of receiving in RF mMbus communication protocol, with average number of tokens for the places and the other states coresponding to other variables (e.g. *cmd_index, buf[]*) used for modelling.

Receive_USARTdata, *Verify_USART_Errors, getc_USART,*

Verify_(cmd_index,ch), *cmd_receive, respond_to_cmd*

Firings: 100 Replications: 5

Results

Petri net simulation results

Place	Average number of tokens	95% confidence interval (+/-)
Receive_USARTdata	0.19802	0.01901
Verify_USART_Errors	0.18812	0.01901
getc_USART	0.18812	0.01227
Verify_(cmd_index, ch)	0.18812	0.01227
cmd_index = 2	0.05941	0.02126
cmd_index = 1	0.0297	0.02263
buf [cmd_index] = ch	0.0495	0.01901
cmd_receive	0.0495	0.01901
respond_to_cmd	0.0495	0.01901

Fig. 4 Simulation results for the simplified mMbus GSPN model

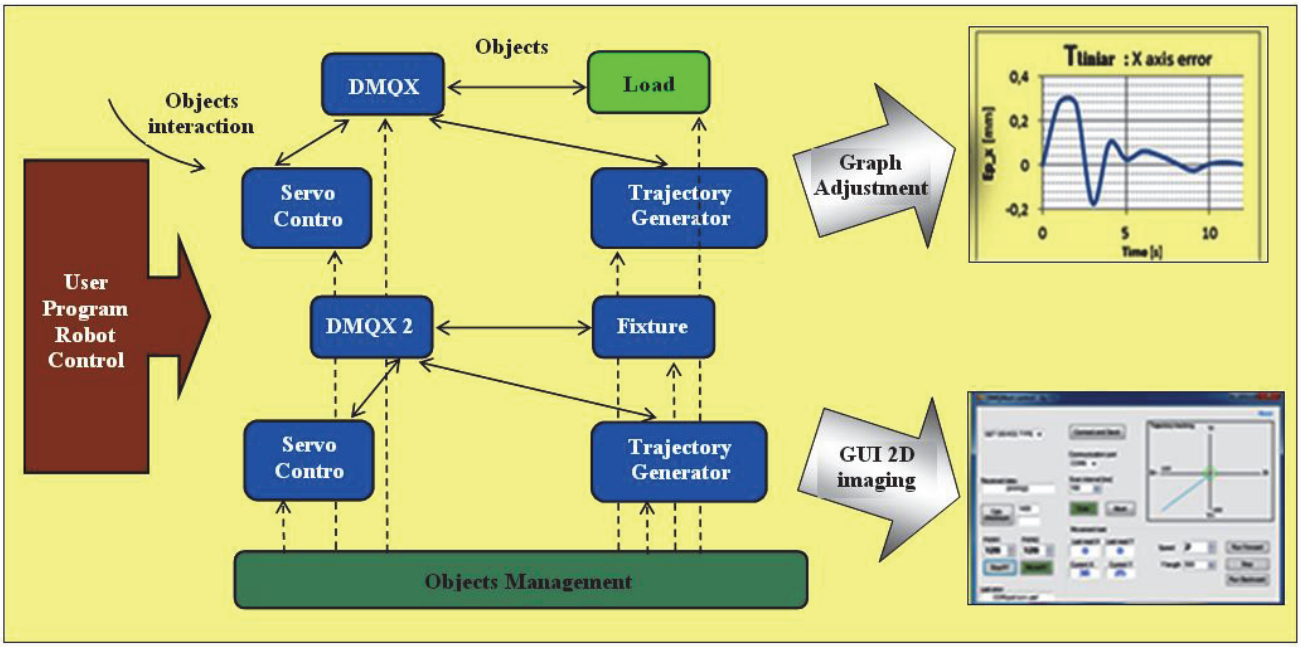


Fig. 5 Robotic platform with DMQX controllers – the software architecture

The software architecture implemented for the robotic platform testing (Figure 5) highlights the connection between software objects for a demo scenario using DMQX robotic controllers,. There are the next requirements: trajectory generation, objects manipulation and positioning feedback loop control for the RC servo motors of the robotic manipulators.

The simulation results using *GSPN* for the simplified model of receiving with *RF mMbus* protocol is presented in Figure 6.

State space and invariant analysis which indicated that the net is covered by positive T-invariants and bounded, with the following P-invariants equation:

$$\begin{gathered} M(buf[cmd\_index] = ch) + \\ M(cmd\_index = 1) + M(cmd\_index = 2) + \\ M(cmd\_receive) + M(getc\_USART) + \\ M(Receive\_USARTdata) + \\ M(respond\_to\_cmd) + M(Verify\_(cmd\_index, ch)) \\ + M(Verify\_USART\_Errors) = 1 \end{gathered} \tag{3}$$

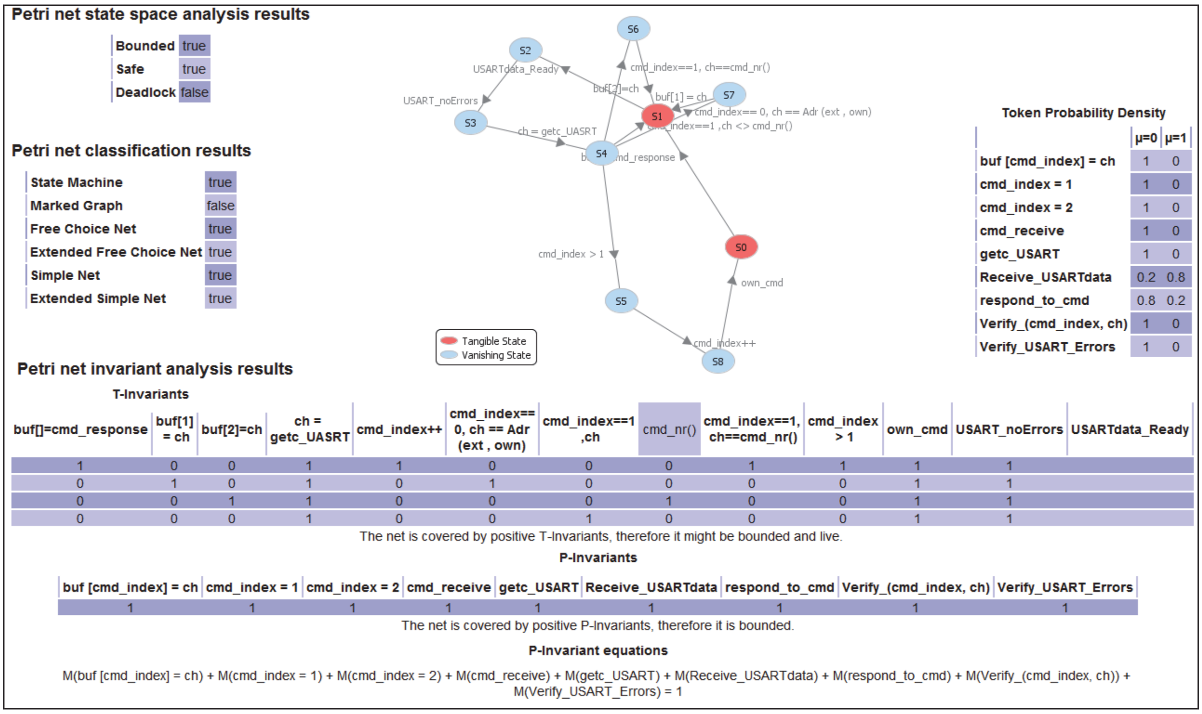


Fig. 6 PIPE simulation results for GSPN simplified model of the receiving

V. Results and Conclusions

The user program for robotic application using DMQX controllers is developed using Microsoft Visual Integrated Development Environment (IDE), with functions implemented through language extension that can be called from customizable Graphical User Interface (GUI). The DMQX controllers are connected into a wireless communication network, using mBus protocol for the message transparency during receiving or transmission sequences.

The scope is to develop a dynamic versatile intelligent portable robot platform by using 3D virtual representation, on a PC with high graphic processing power and advanced programming languages, of robots through mechanical structure modeling. It is build an open architecture system made of a robot classic control system (with embedded software) and intelligent control interfaces (fuzzy, information fusion, multi-agent, hybrid force position dynamic control, robot neutrosophic control, dynamics and adaptive, robust and iterative learning control, etc.) implemented through IT&C techniques on fast time and high data processing PC server, in order to improve the stability performances and real time motion control.

For the wireless communication (using 2.4GHz free band), the mMbus-RF protocol provides the standard functionality of Mbus-RTU or ASCII protocol, but additionally implements a mechanism for receiving the messages of each active node from the network, by configuring additional data registers. The supervisor node received information is processed and then displayed in a graphical form or is logged on data storage device for later data analysis and to evaluate the performance of the robotic system.

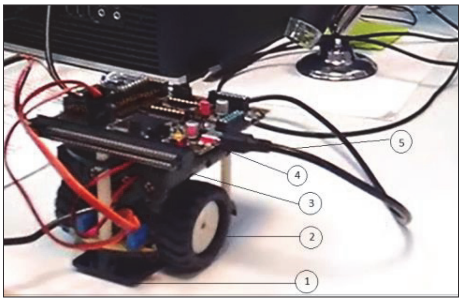
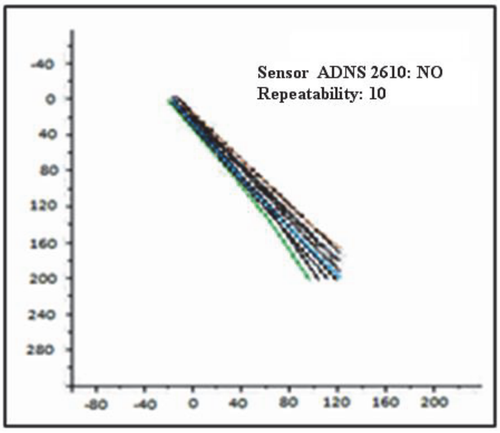
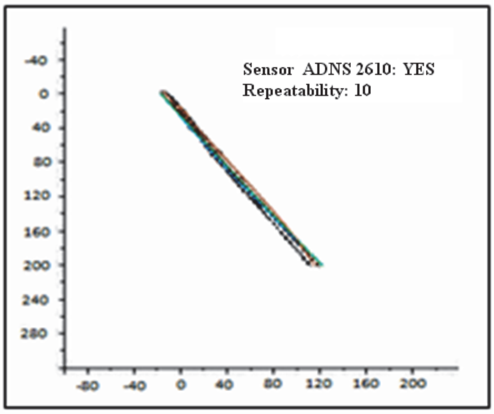


Fig.7. The AGV prototype using XY optical encoder and DMQX controller

For programming the operations that are involved by the robotic application, the flexible cell is considered as a discrete event system – DES. Based on previously simulated models with instruments for Petri Nets (CPN or GSPN), the states and the transitions of the system are defined, At tthe end, through source code recompilation, the robotic application can be verified or simulated by running the custom user program.



a)



b)

Fig.8 Positioning precision variation : a) without trajectory adjustment b) with trajectory adjustment using feedback from optical sensor

Starting from the principle of using communication based digital sensors, for increasing the coordination precision of the robotic arm movements, a feedback control loop was implemented for RC servo motors acting, considering the information provided by an accelerometer for the cinematic inertia. In Figure 7 is presented the AGV prototype using XY optical encoder and DMQX controller.

The components are identified as follows :

(1) independent direction wheels controlled by RC servo motors
(2) accumulators for autonomous supply
(3) DMQX robotic controller
(4) communication port for programming and testing the robotic controller

In Figure 8a, is presented the variation along XY axes for the positioning information provided by the image sensor of XY optical encoder, during the repetition of AGV trajectory which was predefined by the user program configured with graphical user interface. The repetition number defined by the program is rt=10. In Figure 8b are presented the results obtained for the same trajectory and the same rt repetitions, but with implemented corrective control for the M1 and M2 RC servo motors that drive the AGV wheels.

The obtained studies and research lead to the conclusion that the innovative VIPRO platform is conceptually competitive with other similar virtual application platforms such as CDA, CAM, CAE, Solid Works or MatLab, Simulink, COMSOL, Lab View, etc., but will also allow the design, testing and experimentation of intelligent control methods in real time, integrating the classical robot system in modeling and simulation of the robot, thereby providing the opportunity for the VIPRO platform to enter the IT market as a new component among existing.

ACKNOWLEDGMENT

This work was accomplished through the Partnerships Program in priority fields - PN II, developed with the support of MEN-UEFISCDI, PN-II-PT-PCCA-2013-4, ID2009, VIPRO project no. 009/2014, Romanian Academy and FP7-PEOPLE-2012-IRSES RABOT project no. 318902.

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