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The optimization of intelligent control interfaces using Versatile Intelligent Portable Robot Platform

Victor Vladareanu^a, Radu I. Munteanu^b, Ali Mumtaz^c, Florentin Smarandache^d
and Luige Vladareanu^a *

^aRomanian Academy, Institute of Solid Mechanics, Bucharest 1, ROMANIA

^bTechnical University of Cluj-Napoca, 15 C-tin Daicoviciu, Cluj Napoca, ROMANIA

^cDepartment of Mathematics, Quaid-i-Azam University, Islamabad, PAKISTAN

^dUniversity of New Mexico, 705 Gurley Ave. Gallup, NM 87301, USA

Abstract

The paper presents a VIPRO versatile, intelligent and mobile platform for robots, using an original virtual projection method which involves the representation of modern mobile robots in a 3D virtual environment using a strong robotic simulator, an open architecture system and adaptive networks over the classical control system of the robot, developing intelligent control interfaces. The advanced control technologies adapted to the robot environment such as neutrosophic control, robot Extenics control and robot haptic control are used. The obtained results lead to the conclusion that the VIPRO platform is to be integrated on the IT market as a new component alongside the existing ones, allowing a correct evaluation of robot behaviours in hazardous or challenging environments and high level real-time simulation in order to correctly model interactions among the robots and between the robots and the environment.

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1. Introduction

Robots with artificial intelligence and networked remote control by human operators are playing increasingly important roles in hazardous or challenging environments where human lives might be at risk. This imposes the

* Corresponding author: Luige Vladareanu, Tel. +40 744 756005, Fax. +40 21 315 7478
E-mail address: luigiv@arexim.ro.

urgent need for the development of autonomous mobile robots which can be controlled remotely and can provide support in case of natural disasters, fires or calamities, dangerous landmine detection activities and other explosive devices (Fig.1a). Following the terrible earthquake from Japan an international project named “RoboCup-Rescue project” which reunites important research teams from all over the world was carried on in order to build rescuing and seeking robots (Hanshi-Awaji Earthquake, Fig.1b) divided in two sub-projects: one for multi-agent simulation and virtual robot, and the second focused on developing the real robot.

Real time control robots with remote network control with human operators’ ability play an important part in hazardous and challenging environments where human life may be exposed to great dangers such as support and repair in nuclear contaminated area, fire and earthquake disaster areas. An important amount of research led to the development of different robots with sensing abilities, transport and manipulation of different applications. Developing mobile and remote control autonomous robots, which can help people in order to perform search and rescue operations in nuclear contaminated environments, fires and earthquake disaster areas, is a priority and a complex task^{1,2}.



a) Military robot for bomb diffusing



b) Hanshi-Awaji Earthquake

Fig. 1. Autonomous mobile robots in case of dangerous landmine or natural disasters

The VIPRO platform, presented in paper, brings the virtual robots to the real world and creates an international innovative robot platform, based on virtual projection method by Vladareanu-Munteanu, IMSAR patent³, which allows developing mechatronic systems of mobile robots in virtual environments and communicating with real robot systems through a high speed interface^{4,5}. The result is development of an intelligent, portable, versatile platform VIPRO which allows the improvement of robot motion and stability performances in a virtual and real environment on unstructured and uneven terrains. Using VIPRO platform will allow efficiently building of mobile robots endowed with Robot Neutrosophic Control (RNC), Robot Extensics Control Interface (eHFPC) and Robot Haptic Control (RHC) Interface, etc. in addition to other similar products on the market.

2. The VIPRO Platform Strategies

The VIPRO Platform allows the development of a complete research tool for the robot mechanical modelling of 3D virtual environment, virtual platform for the robot modelling and simulation, planning strategies, robot motion developing, image processing, robot adaptive intelligent control and behaviour based control.

Robotic simulation is essential in developing control⁶ and perception algorithms⁷ for robotics applications. A 3D virtual platform for mobile robots must correctly simulate the dynamics of the robots and to avoid the objects in the environment, thus allowing for a correct evaluation of robot behaviours in the environment. Moreover, real-time simulation is important in order to correctly model interactions among the robots and between the robots and the environment. Since the simulation accuracy requires significant computing power, it is often necessary to make the approximations for obtain the robot real time control.

Mechanical modeling of motion. The Robo-Cup version of the NAO (H21 model) has 21 joints, resulting in 21 degrees of freedom (DOF)⁸. See Figure 2 for a complete schematic overview of the NAO robot. The movement of each joint can be described by a rigid body equation¹. Two different types of contacts can be distinguished. The first is a contact caused by bumping into another rigid body or into the world. The other type of contact is caused by having a joint defined between two rigid bodies.

Motion planning. A Motion Editor for testing, debugging and to realize new motions was developed. For some predefined motions, such as standing up of the robot was used a method based on main-condition. One motion network is defined as a DFSA (Determinist Finite State Automata).

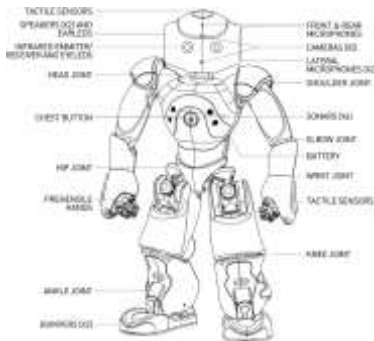


Fig.2 The NAO Robot (Aldebaran Robotics)

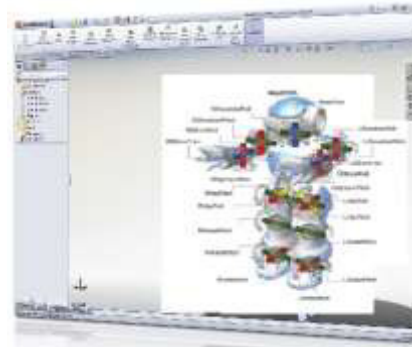


Fig.3 The 3D representation of the NAO robot

Each node describes the state of the robot (actuators) and each line describes the transition between two states (Figure 3) following the occurrence of certain events, such as receiving information from sensors^{7,8}.

The VIPRO intelligent control interfaces adapted to the surrounding environment were developed as alternative to classic AI, where the intelligent behaviour was built in a top-down manner. Using this concept, the robot used the motion networks and real time control that simulates the artificial intelligence, adding the control complex laws in order to improvement the stability of the mobile autonomous robots^{9,10}. For this purpose a strategy was used for dynamic stabilization and balance of the walking robot through applying the patent “Method and device for real time robot control in virtual projection” known as the Vladareanu-Munteanu method. This was integrated in the development of controlling.

In order to build the virtual platform, a software development tool was selected based on analysing the available solutions, for to modeling and respectively simulation of the 3D objects, robots and the environments in which they are moving. Control interface and components integration have been achieved using the web services compatible with SOA (Service Oriented Architecture) architecture and/or REST (Representational State Transfer). The services technology for modelling, control and simulating the robots was implemented successfully in Microsoft Robotics simulator^{11,12}.

Validation of the robot’s mechanical structure and simulation was done using the NAO robot. As seen in Figure 3, the NAO robot has 21 DOF. It has the advantage of being small and the manufacturers deliver it with a control software for the end-user. We have used this robot aiming to model a bipedal robot in 3D virtual platform, to test the interaction between the physical and virtual system and to validate VIPRO performance operation.

The VIPRO has the additional purpose to develop the platform for DHFPC (Dynamic Hybrid Force-Position Control) that will lead to the study of mobility and stability of mobile robots, the 3D design of the simulation environment, controlled through the intelligent control methods: extension theory¹³⁻¹⁶ or^{18,19}, neutrosophic logic (DSmT)^{20,21}, fuzzy^{9,21}, neural networks², Petri Nets modelled with Markov chains^{4,6}, methods for dynamic balance control¹⁴ or ⁶, hybrid force-position control method^{6,9} or ¹².

3. Building of the open architecture system

The architecture of the VIPRO control system, applied in open architecture^{2,3} or ^{5,9}, is presented in Figure 4, in which SCMC is the classic control system, which drives the servo-actuators MS1, MSm,-with „m” being the number of the robots degrees of freedom-, and receives signals of TM1-TMm measure.

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 which receives the X_{R^P} and X_{R^F} , position and force reference and a X_{R^S} 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.

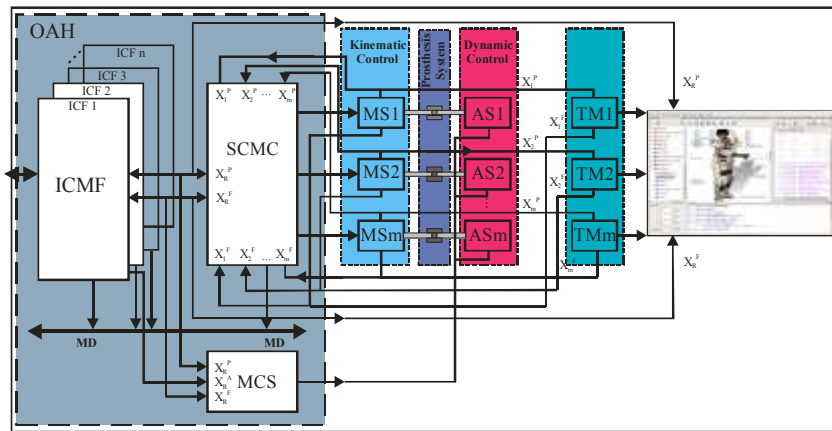


Fig.4. Virtual projection method by Vladareanu-Munteanu applied to VIPRO Platform

The novelty of the virtual projection method by Vladareanu-Munteanu allows a complex control for the dynamic walking robots, real time hybrid control for positioning and joint trajectories of robot legs, the feed-back forces and walking robots dynamic control to increase stability and mobility. The main advantages of the method consists of real-time robot balance control, gait control and predictable motion control providing increased mobility and stability in order to achieve higher performance according to the robot walk developing new technological capabilities of the control systems.

In order to carry out new capabilities for walking robots, such as walking down the slope, by avoiding or passing over the obstacles, it is necessary to develop high-level intelligent algorithms, because the mechanism of walking robots stepping on a road with bumps is a complicated process to understand, being a repetitive process of tilting or unstable motion that can lead to the overthrow of the robot. The chosen method that adapts well to walking robots is the ZMP method^{6,9}. A strategy was developed for the dynamic control of walking robot gait using ZMP and inertial information. This, includes pattern generation of compliant walking, real-time ZMP compensation in one phase - support phase, the leg joint damping control, stable stepping control and stepping position control based on angular velocity of the platform.

4. The optimization of intelligent control methods using the VIPRO Platform

The optimization of intelligent control methods allows the mobile autonomous robot to adapt to uneven ground, through real time control, without losing its stability during walking^{2,3} or⁵. The VIPRO platform architecture, in correlation with the virtual projection method, was developed in Figure 4. In this article are presented three intelligent control interfaces (I.C.), implemented by using the versatile, intelligent and portable robot platform VIPRO.

4.1. Robot Neutrosophic Control (RNC)

The proposal is to build a module which uses the neutrosophic logic to fusion the information provided by robot's sensors in order to find the most accurate sensors' results^{9,16} or²⁰. These results are later used in robot's decision-making process. Hybrid position and force control of industrial robots equipped with compliant joints must take into

consideration the passive compliance of the system. The generalized area where a robot works can be defined in a constraint space with six degrees of freedom (DOF), with position constrains along the normal force of this area and force constrains along the tangents.

On the basis of these two constrains there the ariables X_C and F_C represent the Cartesian position and the Cartesian force exerted onto the environment. Considering X_C and F_C expressed in specific frame of coordinates, its selection matrices S_x and S_f can be determined, which are diagonal matrices with 0 and 1 diagonal elements, and which satisfy relation: $S_x + S_f = I_d$, where S_x and S_f are methodically deduced from kinematics constrains imposed by the working environment^{5,10} or²⁰.

For the fusion of information received from various sensors, information that can be conflicting in a certain degree, the robot uses the fuzzy and neutrosophic logic or sets^{3,20}. In real time a neutrosophic dynamic fusion is used, so an autonomous robot can take a decision at any moment. For the combination of the information we can use the information fusion theories (Dezert-Smarandache Theory, Dempster-Shafer Theory, Smets's Transferable Belief Model) and different fusion rules, among them the Proportional Conflict Redistribution, the Hybrid Rule, etc. We can also use fuzzy logic/set and neutrosophic logic/set for designing a model of combining robot sensor's information using the neutrosophic logic operators (N-norm and N-co-norm, which are generalizations of the fuzzy T-norm and T-co-norm).

Robot neutrosophic control (RNC) by *Vladareanu-Smarandache* method through applying the neutrosophic logic and the Dezert-Smarandache Theory (DSmT) represent a new theory which merge the fuzzy theories and information fusion²⁰.

4.2. Robot Extenics Control Interface

The robot extended control interface (ICEx) integrates the Extenics real time control method through the application of Extenics theory for solving contradictory problems.

Extenics is a science dealing with modeling contradictory and antithetic problems. Extended system control allows the optimization of the control process through the application of Extenics theory, metrics and dependence function in the extended space defined by Extenics logic. The founder of Extenics is Prof. Cai Wen from Guangdong University who in 1983 laid the basis of this theory^{3,14}. Extenics has been researched by numerous other academics, with significant contributions being brought by Prof. Sandru from the Politehnica University Bucharest and Prof. Smarandache from the University of New Mexico, USA, both members in the VIPRO research team. Significant obtained results consist in generalizing from the 1-dimensional case to the n-dimensional case of certain indicators fundamental to Extenics theory in general^{15,16} or¹⁸.

The contradictory force-position problem regarding real time control of the robot motion using the VIPRO platform has been designed using **extended hybrid force-position control (eHFPC)** for robots and mechatronic systems developed by Vladareanu et al^{5,16,21}.

Real time functioning consists of implementing in the principal design of the extended robot control interface (ICEx) in Figure 5. The scientific foundation is based on Extenics theory in defining the extended position distance $\rho(X, X_o)$, the extended force distance $\rho(F_a, X_{F_o})$, the dependence function $K(X, X_o, X_{CR})$ of the current position signal X in relation to the standard positive interval of the reference position X_o and the transitive positive position interval X_{CR} , respectively the dependence function $K(F_a, X_{F_o}, X_{FCR})$ of the force signal F_a in relation to the standard positive interval of the reference force X_{F_o} and the transitive positive force interval X_{FCR} . Thus, an extended transformation is done through a relation which includes an extended dependence function in the universe of discourse U by using an extended position distance $\rho(X, X_o)$ and an extended force distance $\rho(F_a, X_{F_o})$.

The eHFPC architecture with explicit control using force and position sensors. The robot extended control interface (ICEx) developed by integrating the Extenics real time robot control method (eHFPC), presented in Figure 12, is aimed at solving the contradictory hybrid force-position control problem of the movement of robotic and mechatronic systems.

This is conceptually obtained by replacing the logic values of 0 and 1 in the selection matrices S_x and S_f , depending on the force-position sequences with Cantor logic, with dependence function values using extended distance, followed by the extended domain transformation for position S_{K_x} , respectively for force S_{K_f} , generating a new selection matrix and correlation coefficients for position, respectively for force, accomplishing explicit control in force and in position

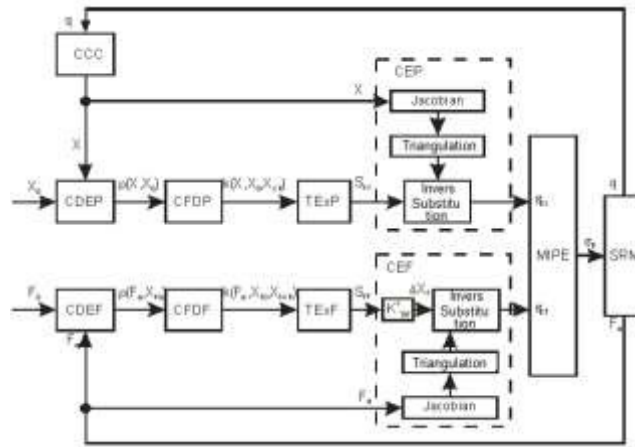


Fig.5. System Architecture eHFPC with Explicit Control

Thus, a module for computing the extended position distance CDEP receives the current position signals X processed by the Cartesian coordinates computation module CCC through direct kinematics for the robotic mechatronic system SRM and, according to the experimentally defined standard positive position reference interval X_0 , calculates the extended position distance $\rho(X, X_0)$, which it sends to the position dependence function computational module CFDP. The extended position distance $\rho(X, X_0)$, according to extenics theory, is calculated as the distance from a point, in this case the current position signal X , to an interval, in this case the standard positive reference position interval X_0 . The data is similarly processed for the computation of the extended force distance CDEF, which works quasi-simultaneously with the computational module of the extended position distance CDEP.

The implementation methodology of this advance hybrid force-position control method for robotic and mechatronic systems consists of experimental determination of the standard positive DSP domain and the transitive positive DTP domain for each control component, applying the transformation to the force and position signals taking into account their real position in relation to the standard positive DSP domain, resulting in a transformed force and position error representing an optimized function for hybrid force-position control in a metric generated by extended distance and the dependence function from extenics theory. The universe of discourse has been configured so as to allow a negative transition domain DTN, defined by the points for position c_x and d_x , respectively c_f and d_f for force, so that when passing these points the force and position errors will be limited to not allow for controller saturation, with all its negative effects.

4.3. Robot Haptic Control (RHC) Interface

The disadvantages of known robot control solutions for motion and navigation on irregular terrain and uncertain, unstructured or undefined environments, consist of the inability to control the rigidity of the leg sole joints and robot segment joints when detecting unevenness, depending on the robot environment map and do not ensure remote control by the human operator, who can see the robot environment map and simultaneously feel the damping of the robot leg movement, with the aim of generating the haptic Cartesian positions for robot motion adaptation to the actual conditions of the terrain and environment.

The innovative solution developed and patented for haptic robot control¹⁷ allows the robot to “feel” the terrain on which the mobile autonomous robot moves by the **modification in rigidity** of the leg sole joints and of the segment joints when detecting unevenness depending on the rigidity K_{X_c} associated to the leg sole joint position of the robot X_c on the robot environment map. Modifications in rigidity are realized from the time the leg sole touches the terrain until complete contact of the leg sole segment. **The human operator** has the possibility to remotely control

the robot movement, through two parameters, one visual and the second haptic, respectively seeing the robot environment map and simultaneously to feel remotely the dampening of the robot leg movement when using the haptic device stick. Depending on the type of manipulation of the haptic device, the human operator generates the haptic Cartesian positions X_{CH} to ensure the robot motion is adapted to the uneven and unstructured terrain in crisis situations or natural disasters where human lives may be at risk.

In order to generate the robot environment map, images are processed from a CCD camera, stabilized for the various robot motion directions. This is done by processing the signals received from a 3D gravitational transducer (TGR3D) and a magnetic compass (TBM), resulting in an interface of the 3D robot environment map with a stable image to the robot movement. Each point in the robot environment map is associated with the rigidity of the robot leg sole joint position X_C , named associated rigidity K_{X_C} . **The movement damping** at contact between the uneven terrain and the robot leg sole is obtained by computing from position control to force control from the moment the tip or the posterior of the leg sole touches the terrain, depending on the robot walking scheme, until complete contact of the leg sole segment is made.

Changing the robot walking scheme is a biologically inspired technical solution, conforming to human walking, and consists in touching the terrain with the tip of the leg sole and damping movement until complete contact of the leg sole segment, for uneven and unstructured terrain, as opposed to regular walking, which consists of touching the terrain with the posterior of the leg sole and damping movement until complete contact of the leg sole segment is made, for smooth terrain. **Visual robot motion control by the human operator** is achieved through a haptic map of the robot environment, which copies the graphic 3D interface of the robot environment map (HMR) remotely sent through the communication modules.

Haptic control of the robot movement by the human operator is achieved through a haptic device which allows the human operator to feel the damping of the robot leg movement and generates the Cartesian reference positions of the robot movement, called haptic Cartesian positions X^{H}_{CH} , for adapting robot movement to uneven and unstructured terrain. **The telemetry module (TL)** allows the measurement of the distance to the leg sole segment by using an optic scanning device.

The device for haptic robot control (DCRH) interacts with both the robot (RO), from which it receives the signals generated from the sensors mounted on the robot and runs the actuators on the robot movement axes, as well as with a human operator (OU), who receives visual information from the haptic map of the robot environment, with the aim that the human operator feel, during hand-operated manipulation of the haptic device stick, the reaction force due to the reaction associated to the position of the leg sole joint X_C and the position error due to the terrain contact force ΔX_F .

5. Results and conclusions

The paper presents new concepts and approaches for the development of a versatile intelligent portable robot (VIPRO) platform through an original method of virtual projection, in which the robot motion control is done through intelligent interfaces using Robot Neutrosophic Control (RNC), Robot Extenics Control Interface (eHFPC) and Robot Haptic Control (RHC) Interface. The overall goal is to develop a 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, building 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.

In comparison to the global level existing solutions and the enormous research done in developing the different types of robots with sensory, transport and manipulation capabilities, the VIPRO platform has the advantage of providing innovative elements related to robot control, such as Neutrosophic Logic or Extenics Theory and also of being an universal, intelligent, portable solution, thus improving the performance of movement and stability in virtual and real environments for mobile autonomous intelligent robots and in particular for search and rescue robots.

The focus is on the three areas which imply creating the virtual environment of the walking robot motion, in each case, with obstacle avoidance, image processing and motion on unstructured terrains by keeping it in a balanced state. The result is a novelty VIPRO prototype platform, which will be able to be marketed in competition with

other similar virtual simulation platforms with applications in mechatronics, called virtual instrumentation, CDA, CAM, CAE, Solid Works, etc., which is very reliable in powerful modeling but only in a virtual environment or the MatLab, Simulink, COMSOL, Lab View platforms, which allow extensions for real time data acquisition and signal processing, but none of which allow the design, testing and experiment of intelligent control methods in the absence of the mechanical structure using of the classical robot real time control system.

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