Improvement of the walking robot dynamic stability using the DSmT and the neutrosophic logic

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Abstract: This paper presents an innovative algorithm for improvement of the walking robot dynamic stability, using the Desert Smarandache Theory (DSmT) and the neutrosophic logic set. Starting from the hybrid force-position control, by applying the Robot Neutrosophic Control (RNC) method we extend the fuzzy control for walking robot stability motion on uneven terrain and in unstructured environments. Results analysis through virtual experimentation for motion control of a mobile walking robot proves that the neutrosophic logic leads to performance improvement of real time control through robustness, adaptation to robot's environment, efficient control and fast and clear identification of robot states.

Keywords: Hybrid Force Position Control, Walking Robot Control, Sliding Control, Fuzzy Control, Neutrosophic Logic, Switching Logic

I. Introduction

Studies of hybrid force-position control by Raibert & Craig [1] were analyzed by An and Hollerbach [3], which proved the conditions in which this type of control becomes unstable and improved by Zhang and Paul [2].

In the last years, several researchers used different switching techniques between the control laws needed at certain times in motion of the robot. P.R. Ouyang, W.J. Zhang and M.M. Gupta used in 2006 [18] an adaptive method to switch between different gain values used in tracking control on a motion trajectory for serial manipulators. In a different papers from 2011, G.P. Moustris and S.G. Tzafestas [19] used a fuzzy switch, outside the control loop, for switching from a reference trajectory to another for the motion control of a mobile robot.

G.L. Nicolás, C. Sagüés et. all in 2008 a switching control based on the epipolar geometry [20] presented which has the purpose to switch between different captured images by a mobile robot for to compute its trajectory up to target. These switching techniques and many others [21-23] were used mainly to switch between reference values or between constant values for a certain control law.

The Robot Neutrosophic Control (RNC) method by Vladareanu for the hybrid force-position dynamic control [10] in which was applied neutrosophic logic developed by Smarandache from University of New Mexico USA and Dezert-Smarandache theory (DSm) and the further applied research [10-14] led to developing a new and original switching method, based on DHFPC method by Vladareanu [4, 7, 8, 22] and neutrosophic logic by Smarandache [10, 15, 24-27]. Because the input data of a control system can be often ambiguous or contradictory, we used this new control technique which uses the probability of truth, falsity and uncertainty computed through the modeling process of raw data received from certain sensors with the role of system observers.

This paper presents a new innovative hybrid control solution by using RNC method [10], the neutrosophic logic and DSmT (Dezert Smarandache Theory). We aim to improve the hybrid force-position control [5, 6, 9] through adding the dynamic allocation of the Sk selection matrix, which will be applied to robot joint control. This technique can be compared with a switch between different states. The switch will take decisions according the sensor input data, and will provide as output ***n+m*** vectors, that will make filtering between the force control laws on ***n*** DOF and the position control laws on ***m*** DOF for the robot joints.

II. Dynamic control of the mobile walking robot

Starting from the classic diagram by Raibert and Craig [1], in which the selection matrix S filters the control type in an offline way, the RNC (robot neutrosophic control) method was developed to allows quasi-simultaneous work of several intelligent control laws and techniques through decisions in real time related to the values the selection matrix S. For this we used neutrosophic logic and set, that proved the efficiently for decide between certain status or options according to sensor's input.

The dynamic control is achieved through the SMC (Sliding motion control) method [13, 16, 17, 23], because it ensured a clear and efficient transition between the pendulum state to the phase of walking and supporting the robot's weight, and provide robustness for dynamic components which may appear at the time of the contact with the support surface. Moreover, the robot's weight support phase required knowing and adding the dynamic elements (forces, inertias) in the joint control decision. To note that the sliding motion control law which ensures the stability in following a trajectory, will be able to compensate the robot weight during walk and will also keep the robot at a certain height for the phases where the leg will support the entire robot's weight and during forward motion.

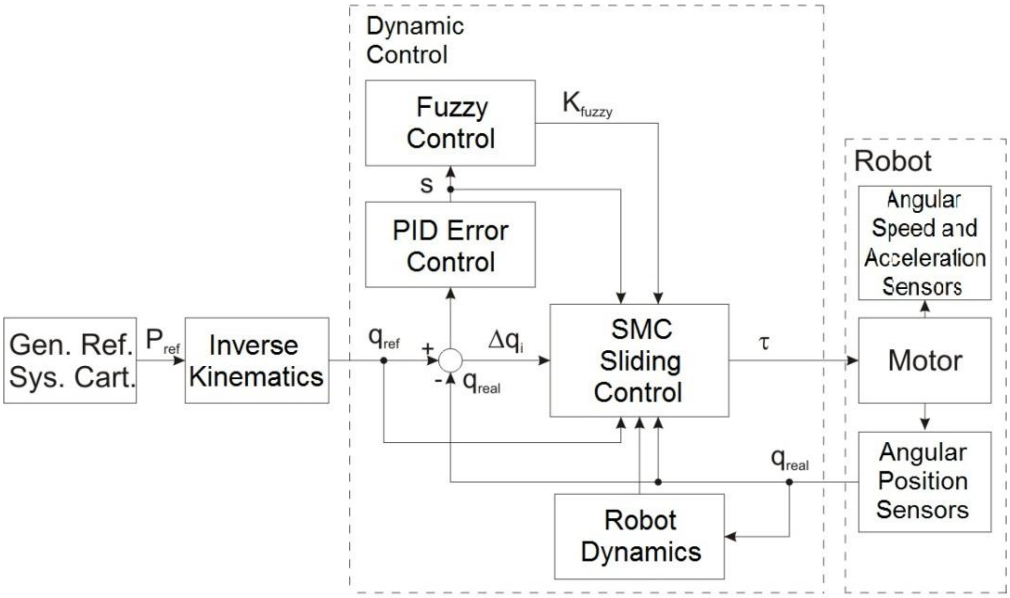

Fig.2 Dynamic control diagram of the mobile walking robot

The dynamic control diagram of the mobile walking robot is presented in figure 2, with the dynamic equations of the Fuzzy-PID-SMC method [13, 16]. As in kinematic control, we use the same data for the Cartesian reference, data which are transformed in joint space values by the inverse kinematic robot's function. The positioning error is computed by the functions based on "s" parameter and the fuzzy gains, inside the Fuzzy-PID-SMC control method. This control law uses robot's dynamic parameters, which are an important part of the dynamic control method. The result of these computations is formed by a vector of size equal to the number of robot's controlled degrees of freedom, and contains the torque reference for the robot joints.

A simple function for the dynamic diagram is given below:

$$\tau_{ctrl} = SMC\ \ \Delta q, S, K_{fuzzy}, Rob_{Din}$$

The τ_{ctrl} function computed the control torque for the joint motors using the robot's parameters and the dynamic information, where Δq is the angular joints positioning error, S is the selection matrix, K_{fuzzy} is the fuzzy gain for the robot axis respectively Rob_{Din} contains the robot's dynamic parameters. Because the dynamic control diagram provides a joint space control, it was necessary to introduce the inverse kinematic function. One can see that this control method doesn't use the joint's angular speed and acceleration as we would in a kinematic based controller, and only an angular positioning error.

III. Neutrosophic law for choosing the selection matrix

Having the two control methods (kinematic and dynamic) we can define the switching method that will choose between them. In this paper we prove the efficiency of using the neutrosophic logic in taking the switching decision for the hybrid force-position control for the simulated mobile walking robot.

In the first phase is required to decide which control method must be chosen to obtain robot motion stability. The diagram from figure 3 presents the way of reaching this decision for one leg. First we read the sensor data, which initially are at the starting point of the simulation, for which we know that the angular position, the angular speed and acceleration are zero.

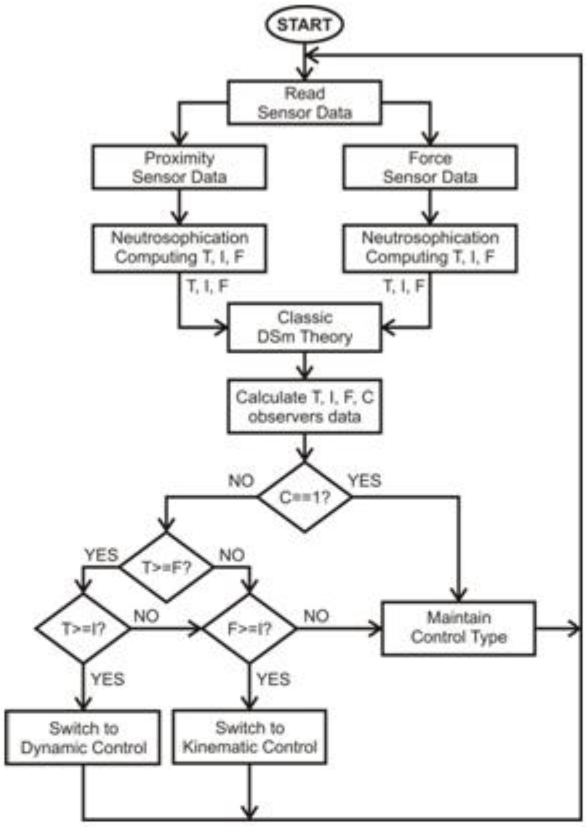

Fig. 3 Decision diagram with neutrosophic logic

The signals generated from sensors are sent to the neutrosophication functions, one for each type of sensor. The probabilistic information is provided to RNC module so that a certain motion law will take over the robot control. The probabilistic data of truth, uncertainty and falsity are processed according to the sensor's input and certain experimental parameters added by the robot's designer, for to be achieve the required tasks. In our case, having a proximity and force sensors mounted on the down side of the robot's foot, we desire to establish the robot state, in which the robot's leg is, so that the chosen control law will be optimal for controlling the robot's motion for the specific work state. The next step is to apply the classic DSm theory, to compute the probability parameters of Truth, Uncertainty, Falsity and Contradiction. Using these parameters, we go to the deneutrosophication phase in which we decide to maintain or change the robot's control law.

In the case when the sensors provide contradictory information, we can't decide the state of the robot's leg in the environment and we'll keep the current control law [13]. If the information are not contradictory, we check the other parameters. For that we considered that the percentage of truth will be for switching to the dynamic control and the percentage or falsity will be for switching to the kinematic control. By comparing the two probabilities, if the percentage of truth is greater or equal to that of falsity, we will check if this one is higher than value of the uncertainty. If both comparisons are true, then we will switch to the dynamic control law of the robot's leg. If the value of truth percentage is lower than value of the falsity percentage, we will compare the percentage of falsity with the one of uncertainty. If this one is higher or equal than the percentage of uncertainty, then the neutrosophic switching law will commute to the kinematic control.

For both cases of probability comparison of truth and falsity, if these values are lower than the probability of uncertainty, then the control law will not be changed and will be maintained until a new decision is made. Checking the uncertainty value has also the purpose to lower the *chattering* effect due to the fast switching between the two types of control, because the probability value of uncertainty will always be higher near of the transition state of the robot. Based on the function „Go to dynamic control" and „Go to kinematic control", we determine the S_k matrix. Thus, the switching control laws is performed in real time, at the time prior sending the data to the engine control.

IV. Results and conclusions

By using the RNC method with the improved hybrid control from figure 2, we developed a control system for the mobile walking robots. The control laws are applied according to the decision generated by the neutrosophic logic and the received data from the sensors. Figure 4 presents the graph which was obtained from the decision diagram of neutrosophic logic in which the switch from the control laws is decided by the neutrosophic logic according to RNC method.

Using this decision we obtained the positioning data for the robot legs presented in the following figures, where the robot was controlled quasi-simultaneous in position and force by kinematic and dynamic control laws for moving the robot on uneven and unstructured terrains, with a total run time of 10 seconds.

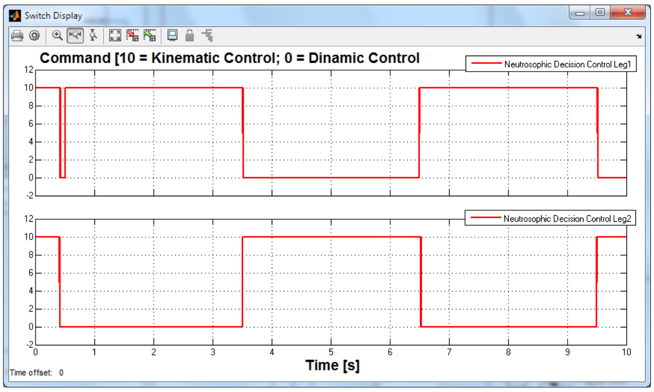

Figure 4 – Neutrosophic decision for robot's legs

Figures 5, 6 and 7 present the positioning on the Cartesian axis of the biped mobile walking robot's foot. Comparing with kinematic positioning, one can observe that in the robot's weight support phase, the positioning on OX direction is lowered due to the dynamic controller, but the error on OZ axis is slightly larger and constant.

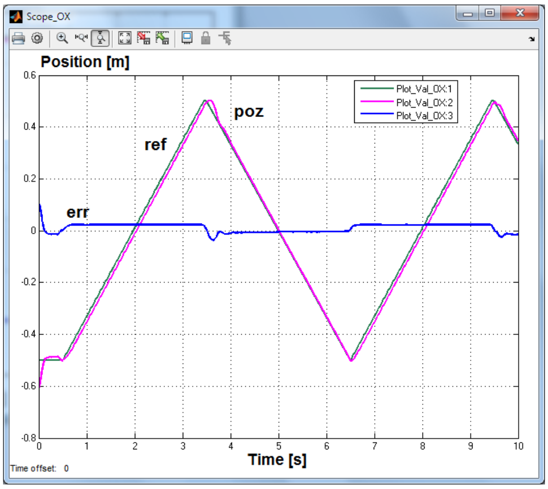

Figure 5 – Robot's foot positioning on OX axis using RNC method

This means that the forward speed is the one needed because the error on OX axis in very close to zero, and the OZ axis error is positive, resulting a lower distance between the support surface and the robot's main body due to the fact that the robot's foot must support the entire robot's weight. The positioning errors can be better observed in figures 8 and 9, in which we observe error peak values on the horizontal positioning when the robot foot touches the support surface, due to the fact that the robot is in motion.

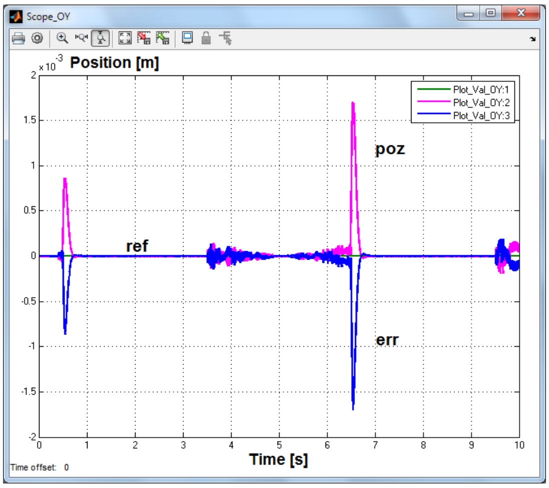

Figure 6 – Robot's foot positioning on OY axis using RNC method

More over, we observed positive and negative the peaks for the positioning error on the vertical axis when the robot foot leaves the support surface and the robot's weight doesn't act on the legs' joints, and also when the leg begins to touch the support surface [13], because in that moment, the weight of the robot and inertial forces act instantaneous on the robot foot.

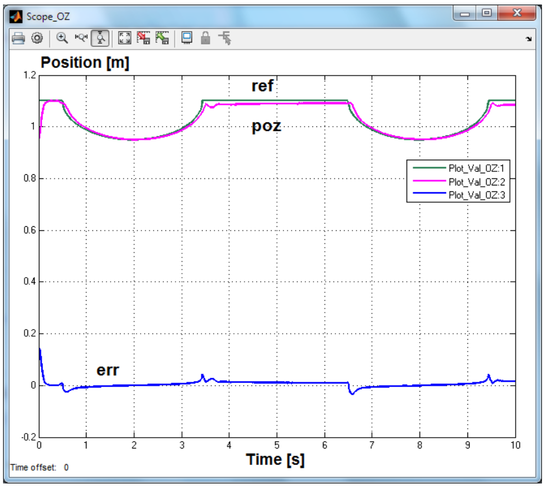

Figure 7 – Robot's foot positioning on OZ axis using RNC method

Finally, the Dezert-Smarandache theory and the neutrosophic logic or set applied according to RNC method was used successfully to improve the classic hybrid force-position control. Thereby, we developed a new method an innovative algorithm regarding the improvement of the walking robot dynamic control which adapt the control laws according to the system's states.

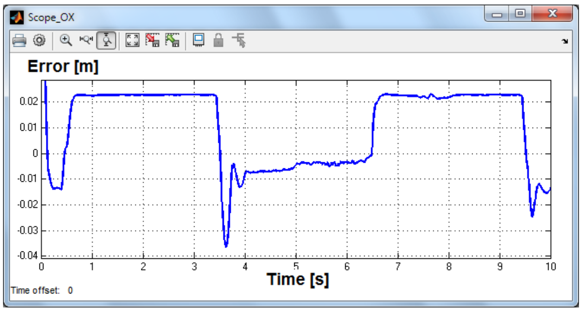

Figure 8 – Positioning error for leg 1 on OX axis using RNC method

The main advantage of this control method is to allow the robots to use intelligent control laws adapted the work environment and according the measured data through sensors. In this way, the robot has the possibility of changing the control method according to the robot's goal.

The position or force control decisions carried out in real time through the neutrosophic switching laws, which not possible to achieve by the classic hybrid force-position control laws because the selection matrix S is computed in the design phase, is another advantage of the RNC method.

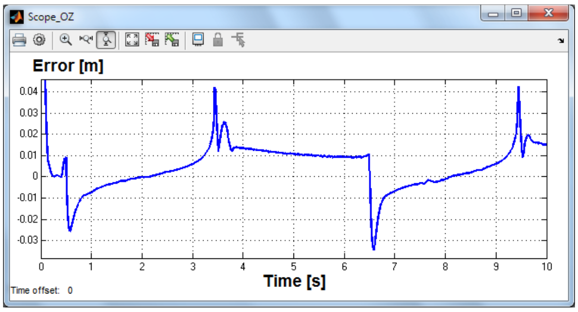

Figure 9 - Positioning error for leg 1 on OZ axis using RNC method

In order to implementation of the high performance hybrid control method is very important that prior to commissioning the robot all the control laws required for to fulfil different robot tasks will be validated. Moreover, as the robot status number increases, because this depends on the number of available observers, increases the degree of complexity for the laws of the neutrosophic switching. For this purpose researches are being conducted to develop a ***Versatile Intelligent Portable Robot Platform – VIPRO***, competitive with other similar virtual application platforms CDA, CAM, CAE, Solid Works or MatLab Simulink, COMSOL, Lab View, but additional to these platforms, it will allow to design, test, and experiment any advanced intelligent control methods, integrating classical control system in modelling and simulation of the robot.

Acknowledgment. This work was supported in part by the Romanian Academy and the FP7 IRSES RABOT project no. 318902/2012-2016.

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