LOW-LEVEL CONTROL SYSTEM OF A NEW BIPED ROBOT "ROTTO"

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The paper presents a low-level control system of a new biped robot "ROTTO". The Software-in-the-Loop and Rapid Control Prototyping frameworks, which have been used for robot development, are presented. An industrial Ethernet-based real-time communication protocol is introduced and the communication ability between the robot-side hardware and PC-side control system is investigated.

1. Introduction

The control system of fully or partly autonomous biped robot is almost always controlled by embedded system. Commonly the embedded systems are designed to control complex plants such as engines, satellites, vehicles, spacecrafts, and of course CLAWAR. They generally require a high level of complexity within the embedded system to manage the complexity of the controlled plant.

Development and test of complex real-time embedded systems require many steps from modeling and simulation of the plant till the implementation of the source code in the real hardware. Hybrid techniques, that are used more and more often nowadays, are the Software-in-the-Loop (SiL) and the Rapid Control Prototyping (RCP). We use these methods while developing and testing the biped robot.

Thus the technical purpose of this work is to develop the biped robot with the possibility of the dynamical walking, as well as to develop such control system that allows simple and rapid development of the complex control algorithms. The purpose of this work is the development of control algorithms for the desired mechanical interaction with environment. Moreover, flexible communication bridge for real-time communication between real control system and real robot is presented as well.

2. Biped robot “ROTTO”

To perform above stated requirements a biped robot “ROTTO” (see Figure 1) has been developed and constructed. The robot mechanics, sensor and control systems guaranty the ability of dynamical walking, measurement and control of support reactions as well as control and forecast of robot motion stability. The real-time communication bridge based on industrial Ethernet protocol EtherCAT was developed. It guarantees the communication between robot onboard electronic and robot control system with sample time of 1ms.

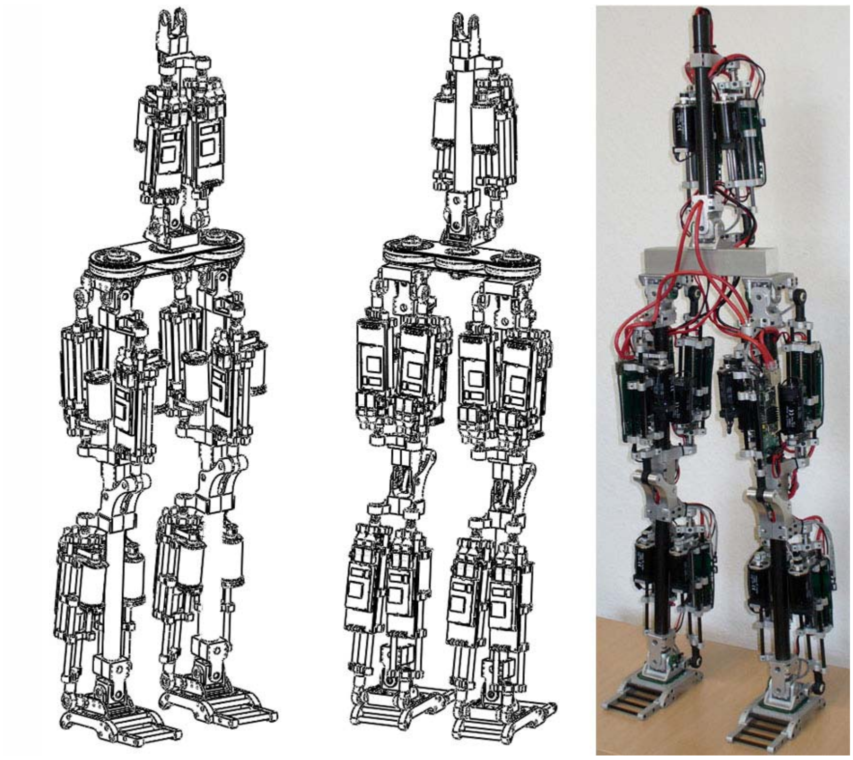

Figure 1. CAD construction (left); real biped robot “ROTTO” (right).

The robot construction has more than 15 DOF (Degree Of Freedom) similar to what human being provides. Each leg has 6 DOF. The robot actuators are the linear drives, with maximal power 290W. Sensor system of the robot consists of components that are standard for biped robots and it includes:

- absolute magnetic encoder installed in each robot joint;
- incremental position sensor, two current sensors and two limit switches installed in each of the actuator module;
- six-component force sensor mounted in each leg's shank;
- high precision tri-axis inertial sensor installed on the robot body.

3. Hardware control system

Control system with real-time decentralized data gathering and processing builds the kernel of robot system and makes it possible to develop of control algorithms with help of hybrid simulation. The control system implemented with the robot is already at industry level and is based on typical real-time communication EtherCAT. The developed hardware (see Figure 2) consists of netX communication processor from Hilscher. The time diagram of communication process is explained in the [2]. Detailed presentation of decentralize Single-Chip controller based on the netX processor is shown on Figure 3.

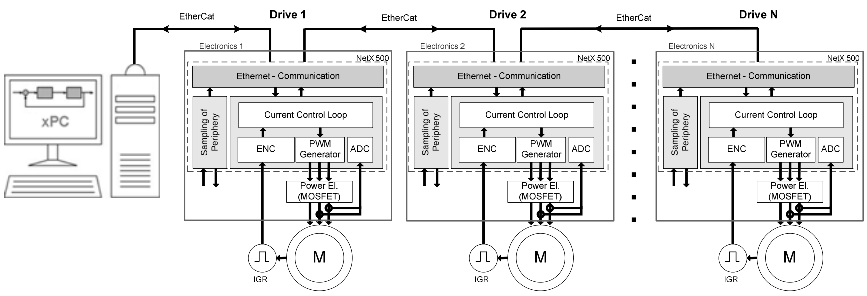

Figure 2. Flexible communication system based on netX processors.

The main feature of the EtherCAT communication protocol [2] is the exchange of the data in the loop Master-Slave-Master with one solid telegram. Received information from sensors (RD) is saved to the transfer buffer of the EtherCAT slave. After that it will be sent with the next closest transfer packet (Packet n+1) and will be actual on the n+2 work period.

The standard PC is used as a control computer (Host PC). Therefore the jitter time (Tjitter) in the communication system due to large number of hardware peripheries is occurred. Practically all of hardware peripheries are tuned off in the BIOS of PC to minimize jitter time. The maximal jitter time in our communication system is less than $15\mu s$.

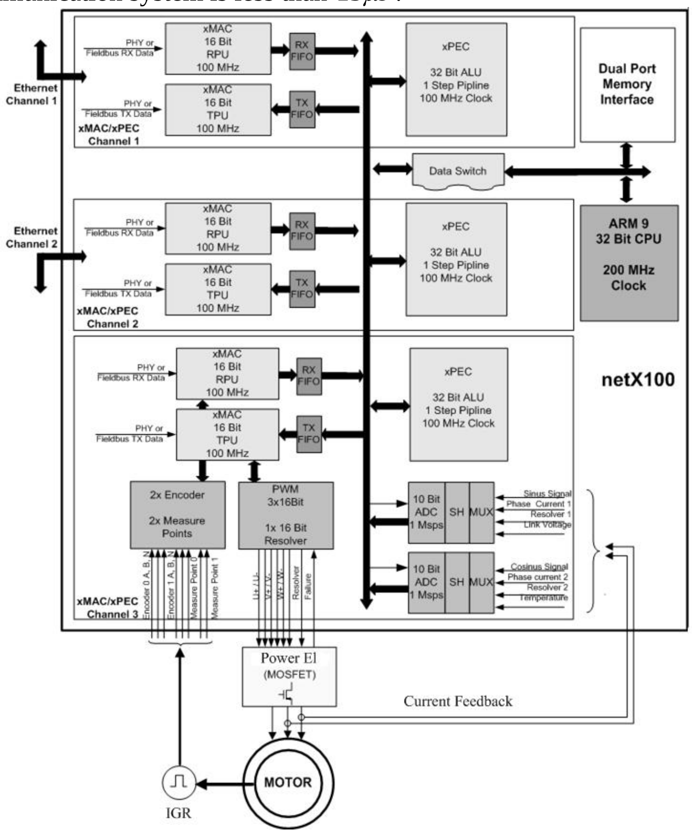

Figure 3. Decentralize Single-Chip controller based on netX processor.

4. Actuator control system

The current control loop is shown on Figure 4. Current control loop is implemented in the netX/xPEC. The current control is calculated synchronously with the PWM module with 28 kHz cycle. The control signal (reference current value) and the sensors signals (motor position, velocity and so on) are exchanged between netX processor and external control PC (with xPC-Target real-time OS) using an EtherCAT communication protocol. Sensors signals are used as the feedback signals for the position/velocity control loops (Figure 5). The sample time of the position/velocity control loops depends on the power of control PC. In our case (3GHz processor from Intel) sample time is equal 1ms and can be decrease to 0,5ms.

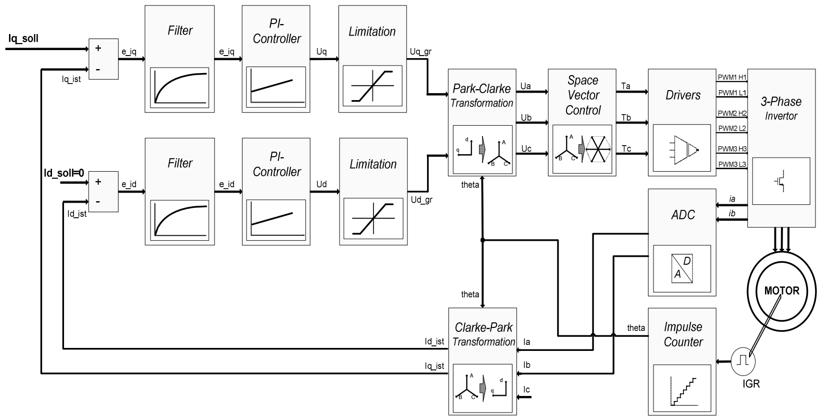

Figure 4. Current control loop in the netX/xPEC.

Phase currents (i_{a_ist}, i_{b_ist}) are measured in the netX by the way of sampling of intern ADC module and are recalculated from coordinate system ABC in coordinate system DQ using Park-Clarke transformation:

$$\begin{aligned} i_D &= \frac{3}{2}\left[i_A \sin(\varphi) + i_B \sin\left(\varphi - \frac{2\pi}{3}\right) + i_C \sin\left(\varphi + \frac{2\pi}{3}\right)\right] \\ i_Q &= \frac{3}{2}\left[i_A \cos(\varphi) + i_B \cos\left(\varphi - \frac{2\pi}{3}\right) + i_C \cos\left(\varphi + \frac{2\pi}{3}\right)\right] \end{aligned} \quad (1)$$

The control error between reference and real current is controlled by the PI controller:

$$\frac{U}{e_i} = P_{Cont} + I_{Cont} \cdot \frac{1}{1 - z^{-1}} \quad (2)$$

The control voltage is transformed from the coordinate system DQ in coordinate system ABC using the inverse Clarke-Parke transformation:

$$\begin{aligned} U_A &= i_D \sin(\varphi) + i_Q \cos(\varphi) \\ U_B &= i_D \sin\left(\varphi - \frac{2\pi}{3}\right) + i_Q \cos\left(\varphi - \frac{2\pi}{3}\right) \\ i_C &= i_D \sin\left(\varphi + \frac{2\pi}{3}\right) + i_Q \cos\left(\varphi + \frac{2\pi}{3}\right) \end{aligned} \quad (3)$$

The velocity and position control loops are developed in the Matlab/Simulink and are compiled to the control PC using Real-Time-Workshop-Tools [7]. The velocity and the position control loops are shown on the Figure 5.

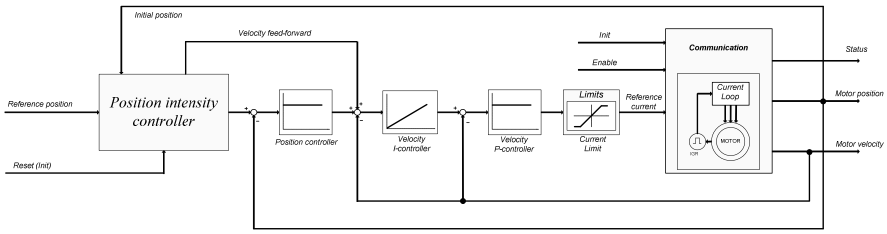

Figure 5. Position/velocity control loops.

The accuracy and the correctness of the Permanent Magnet Synchronous Motor (PMSM) control depend on the correct determination of the rotor position. Therefore following algorithm has been developed to determine the exact position of the rotor:

1. reference currents are *id_ref* = 5A, *iq_ref* = 0A for rotor positioning along the flux axis D;
2. one second pause for the exact positioning;
3. reset of the IGR's counter;
4. start the current loop, in other words wait for the reference value of *iq_ref*, the reference value of *id_ref* is equal 0A.

The ensure correct work of position control loop on the step reference signals the second order position intensity controller (Figure 6) has been developed.

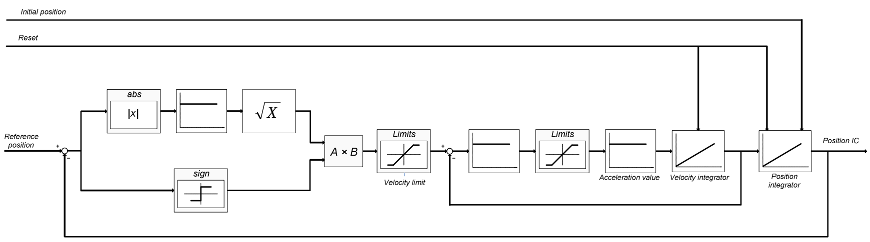

Figure 6. Position intensity controller.

The experimental results of position/velocity control loops as well as current control loop are shown on the Figure 7. Experiments have been carried out on the linear drive without any loads. The position reference signal has been applied as the step signal.

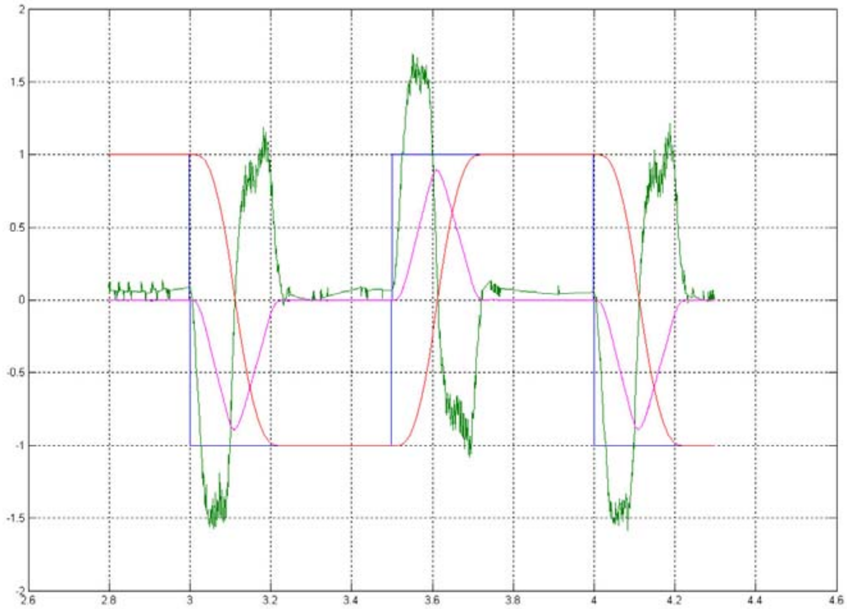

Figure 7. Experimental results: blue – reference position (±10 revolutions); red – actual position (±10 revolutions); magenta – velocity (±13000 rpm); green – current (±3,6A).

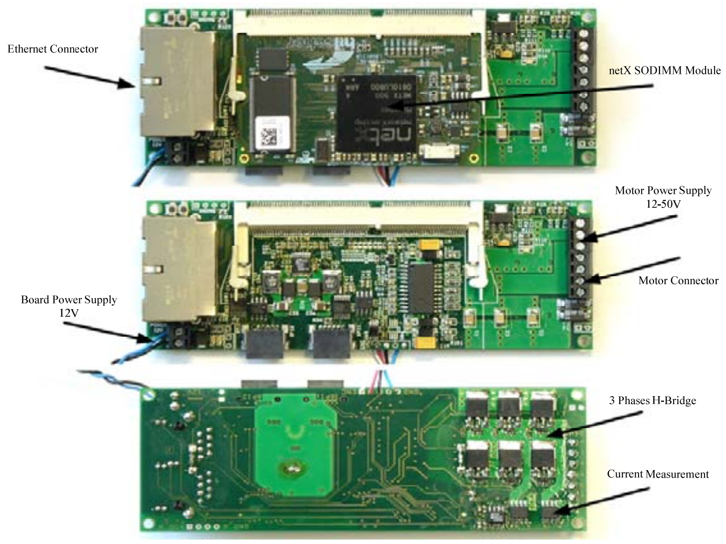

Figure 8. Decentralize control electronics of the biped robot "ROTTO".

5. Conclusion

The control electronics (Figure 8) as well as the all control architecture and algorithms for the biped robot “ROTTO” have been developed and showed satisfactory results. The control electronic consists of two boards: the small one netX SODIMM module, and the second one with power electronics. The control algorithms as well as communication between on-board electronics and external control PC have been successfully tested on a large number of experiments as well as by the static walking of biped robot “ROTTO”.

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