LINEAR ELASTIC ACTUATOR OF A BIPED ROBOT "ROTTO"

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The paper presents a modified linear actuator for the biped robot "ROTTO". The elastic element of a special design is discussed as well. On the basis of the designed electromechanical system the force control structure is researched and the realization of an artificial spring with the prescribed rigidity and positioning with the given impedance is also investigated.

1. Introduction

The actuators with the serial elastic elements are been increasingly used in manipulators and walking robots nowadays. The elasticity allows not only storing energy, but also adds special characteristics to the actuator. The problem of a personal safety by casual contact with the industrial manipulators is the important issue. The solution is found in the control of the system impedance. The daunting problem of the walking mechanisms is a problem of the contact with the surface, where the big forces occur in short time intervals. The elastic element of the actuator allows the partial damping of the contact energy and gives the possibility to react on perturbation.

2. Linear elastic actuator

Design of an elastic element. The developed design of the elastic element, combined with the force sensor is shown on Figure 1. The modern composite materials allow to reach higher energy storage density in the elastic element by smaller masses. The main operating element is a flat coal-plastic spring 5. The deformation of the spring is measured by the Hall-sensor 4 placed in the magnetic field of the two neodymium magnets 3. The glass fibre plate 2 and the screw 1 serve to fix the actuator.

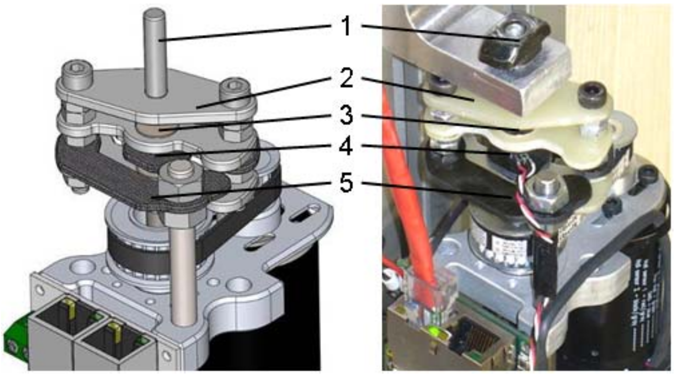


Figure 1. The CAD Model of the elastic actuator (left) and actuator of the robot (right).

<u>The force control.</u> The structure scheme of the force control system is shown on the Figure 2.

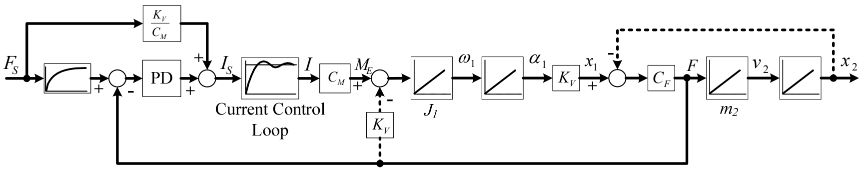


Figure 2. Structural scheme of the force control system, where CF – the coefficient of the spring rigidity (spring constant), KV – coefficient of the conversion of the rotational motion into the translational motion, CM – coefficient of the conversion from current to mechanical torque.

The force control system has a subordinate structure. There is only one inner control loop – the current control loop. Such approach allows to reach highest dynamical characteristics of the force control loop. Some successful attempts of using such structure are shown in the works of MIT-University [2].

The force control loop is controlled by the PD-regulator. The dotted feedbacks on the Figure 2 were not considered in developed PD-regulator. Such neglect doesn't bring any inaccuracy due to the high final speed of response of the force control circuit. These feedbacks are considered as a disturbances and don't cause any instabilities in the system. The step response of the force control loop is shown on the Figure 3. The first sequence is 15 ms by the bandwidth of the force control loop of 50 Hz.

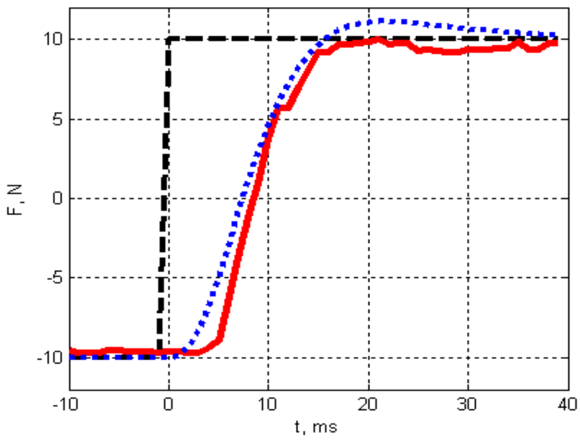


Figure 3. Step response of the force control loop: dotted line – modelling; solid line – experiment.

Position control with wishful impedance. The position control system is shown on the Figure 4. The above considered force control loop is the inner loop of the position control system.

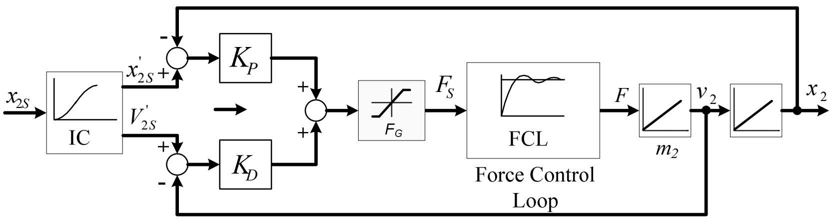


Figure 4. The position control loop.

The coefficient K_D determines the systems damping. The coefficient K_P and the value F_G are of the utmost interest. Changes of their values allow achieving the specific properties of the position control system by contact. For example, by setting a small value of coefficient K_P the behaviour of the system in contact is elastic (low impedance, artificial spring). Another task – a precise position control with force saturation in the contact point – can be achieved by setting of the higher value of coefficient K_P and the certain value of F_G. Such case is illustrated on Figure 5, where the end-position is not reached as a result of an impact with an obstacle.

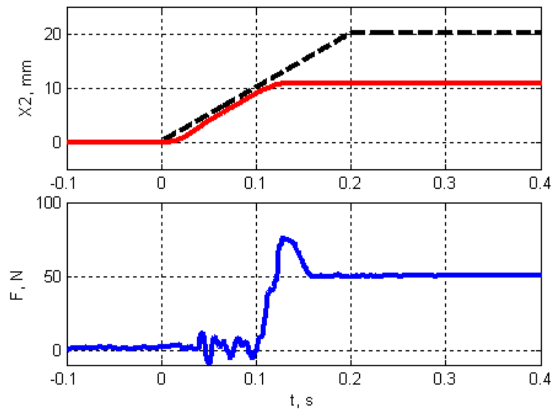


Figure 5. Impact with an obstacle by position control: dotted line – desired position; red line – actual position; blue line – force in the contact.

3. Control system of a compliant robot

3.1.1. *Mechanical construction*

Simple 2-Dimensional 2-DOF robot's leg (see Figure 6) was developed for the investigation of different stabilization algorithms as well as different gait algorithms. Simple robot's leg consists of foot, straight leg, heavy body and two linear elastic actuators with force/impedance control system. The prototype has several types of sensors, such as angle and velocity sensors in the motors, angle sensors in the joints and one inertial sensor in the robot's body.

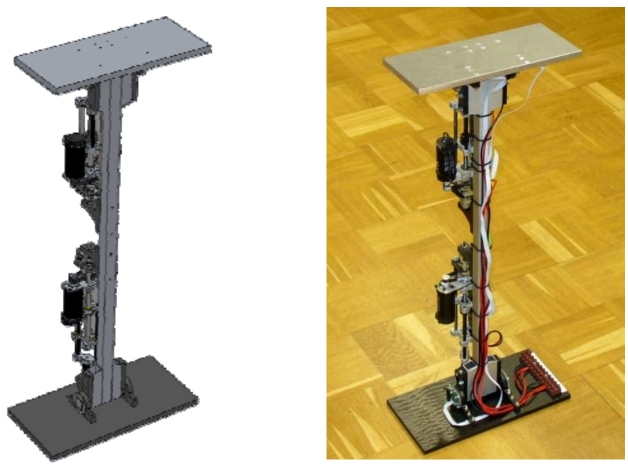


Figure 5. 2D 2-DOF robot's leg.

All dimensions, as well as all mechanical parameters such as bodies' mass, moment of inertia and parameters of actuator were chosen corresponding to those fitted to real two legged robot "ROTTO" (see Figure 6).

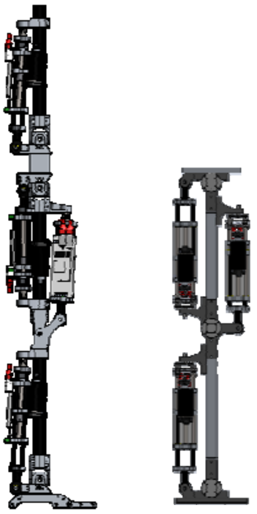
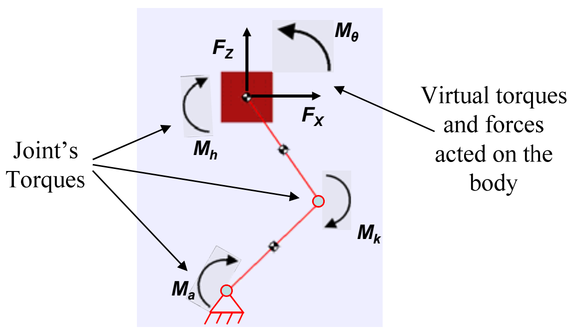


Figure 6. Real two legged robot "ROTTO" (left) and simple 2D robot's leg (right).

3.1.2. *Control system*

Two different control system approaches controlling of robot's leg were analyzed. One of the systems is based on so-called "Virtual Force Control" [5] approach. The structure systems of "Virtual Force Control" approach as well as the corresponding control system of robot's leg are shown on the Figures 7 and 8 accordingly.



$$\{M_a, M_k, M_h\} = J^T\{F_x, F_z, M_\theta\}$$

Figure 7. Approach of "Virtual Force Control".

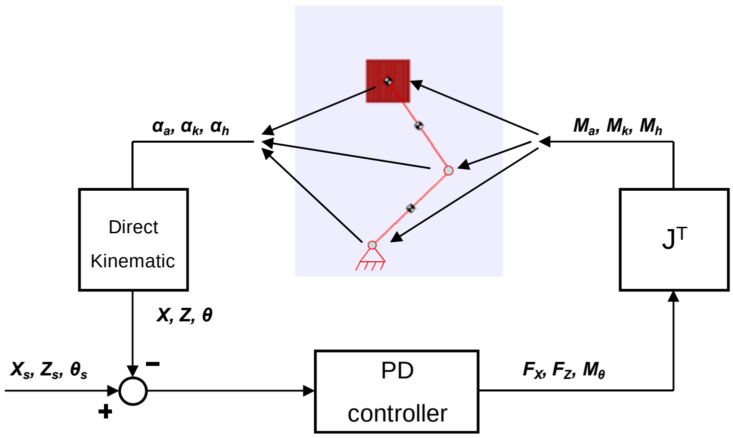


Figure 8. Position control system of robot's leg based on approach of "Virtual Force Control".

The structure of second control system is shown on the Figure 9. The main difference between these two control systems is in designing of controllers and different methods of recalculation of global physical values to the local ones and vice versa.

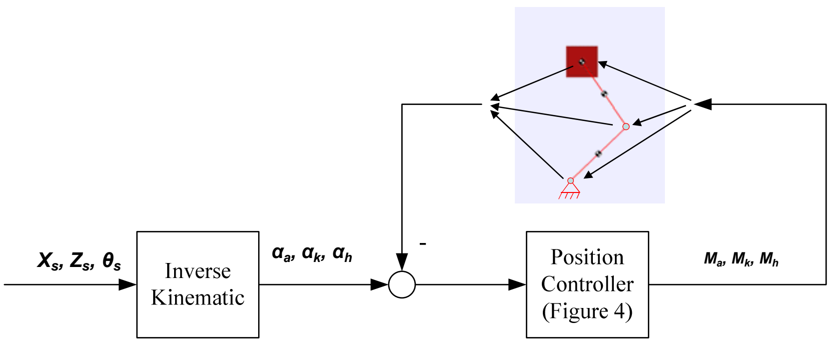
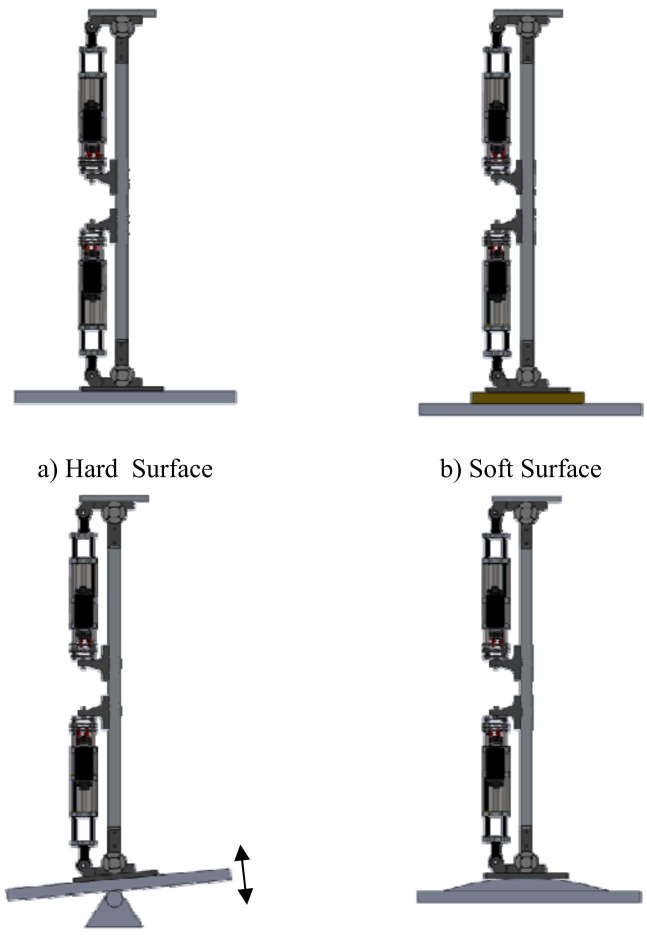


Figure 9. Position control system of robot's leg.

3.1.3. *Experiments and results*

Both control systems show a successful result by stabilization of simple robot as well as simultaneous motion in the 2D Cartesian coordinate system of main body of simple robot. The numbers of experiments (see Figure 10) were executed to proof the fast and at the same time robust control algorithms of robot stabilization. The applied control systems are able to stabilize robot's body independently of surface properties (hard, soft) as well as the slope angle of the surface. In all passed experiments robot's body was stayed stable independent to the external conditions (external forces) and type of surfaces.



a) Hard Surface b) Soft Surface

c) Movable Surface d) Cylindrical Surface

Figure 10. Schematic representation of passed experiments: on the hard, soft (synthetic foam), cylindrical surfaces, as well as on the extern moved surface.

Two different control approaches show a little distinction in performance between them. The control approach based on "Virtual Force Control" concept shows a little faster control reaction to the external disturbances, but at whole the both control approaches can be applied to stabilize as well as motion control of compliant robot. The choice between two described control approaches must be proceed from the tasks to whole robot control.

References

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