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Control of a cost oriented humanoid robot

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Abstract: The teen-sized humanoid robot "Archie" is developed by the Intelligent Handling and Robotics Department (IHRT) at the Technical University of Vienna. The main idea behind "Archie" is to develop a Cost Oriented Humanoid Robot (COHR) to assist humans in their daily life tasks. Currently, the robot consists of 18 degrees of freedom and is able to perform basic human-like walking motions. According to the scope of TECIS this robot is an excellent example for "Cost Orientation".

Until now the control of the joints was carried out by industrial controllers. These are expensive, heavy and have only limited possibilities for the implementation of advanced control algorithms. Therefore a new hard- and software control concept for the motors and the joints was developed. In order to find appropriate controller parameters the dynamic behavior of the joints is analyzed by means of a nonlinear system identification using a Hammerstein model. The result of the system identification shows that the dynamic behavior of the joints is PT1 element with two nonlinearities, a dead zone and a nonlinear gain. Therefore a "piecewise linear" PI controller – the gain depends from the velocity – will be implemented on a COA processor. Finally an outlook on further works will be described.

Keywords: Robots, Control, Identification, Cost Orientation

1 INTRODUCTION

This paper deals with the controller design of the teen-sized humanoid robot "Archie" developed by the Intelligent Handling and Robotics Department (IHRT) at the Technical University of Vienna. The main idea behind "Archie" is to develop a Cost Oriented Humanoid Robot (COHR) to assist humans in their daily life. Currently, the robot consists of 18 degrees of freedom and is able to perform basic human-like walking motions (Kopacek; 2013).

All of the 18 joints of the robot are actuated either by a brushed or brushless DC-motor and are controlled by a commercial micro-controller using the standard three-cascaded control architecture for the current, velocity and position control. These controllers will be now replaced by an on board microcontroller.

The overall stability of the robot depends above all on the accurate performance of the position and velocity commands sent to each joint. Therefore, the dynamic behavior of the joints consisting of a DC-motor and a gear set is investigated in detail.

A mathematical model of the underlying physical system was developed by experimental system identification by means of a grey box model of the joints. Since the joints have a nonlinear behavior a Hammerstein model is estimated. The results of the system identification show that the dynamic behavior of the joints is dominated by two static nonlinearities, a dead zone and a nonlinear gain.

In order to deal with the static nonlinearities the gain scheduling function of the micro-controller is used. The gain scheduling algorithm automatically chooses the proportional and integral controller gains depending on the reference velocity input. The various gains are stored in a gain scheduling table (Schörghuber, 2012).

Finally, the tuning of the joint controllers is tested on the real robot by applying the actual trajectories used for the robot's walking motion. The results of this test show that the use of the gain scheduling function enables the micro controller to follow precisely the position and velocity commands.

2. SYSTEM IDENTIFICATION

The determination of the dynamic behavior is carried out by experimental system identification. As an example serve the output of the right knee joint to specific test signals. Most joints of the robot are actuated by brushless DC-motors and have an identical structure. Therefore, the results of the system identification of one joint are similar for all others.

The basic knee joint is controlled by a micro-controller which is also responsible for the commutation of the brushless DC-motor and the control of the adjacent mechanical structure by

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using the position and/or velocity feedback obtained from the digital Hall sensors mounted on the DC-motor. For the system identification the control mode of the micro-controller is switched to the open loop mode. This open loop system structure is necessary to receive the genuine response of the system to any input test signal.
For the first pre-identification single step signals will be used to determine the basic system structure according to its step response. Later, randomly distributed multi-step signals will be used to identify the nonlinear dynamics of the joint. As a first step, a grey box model of the robot's knee joint will be established (1).

$$G(s) = \frac{K \cdot b}{1 + \frac{J}{b} \cdot s} \tag{1}$$

with
J…..overall moment of inertia (rotor, gears, lower leg)
b…..friction coefficient
K…..gain
Therefore K.b is the resulting gain and J/b the time constant of the transfer function of a first order lag (PT 1) element.

This simple transfer function is the basis mathematical form of the grey box model for the joint plant with the parameters time constant and gain. For the grey box model models of the three subsystems including the still unknown free parameters: brushless DC-motor, harmonic drive gear and the adjacent mechanical structure, i.e. the right lower leg of the robot are necessary. Then, the particular models of each subsystem will be merged to obtain a grey box model of the joint (Schörghuber; 2015).

Furthermore equation (1) shows that the friction coefficient is involved in the gain and the time constant of the transfer function of the joint. As already mentioned this demonstrates once more that a variable friction coefficient influences the dynamics of the joint substantially.

As mentioned before, the joint plant shows closely the characteristic step response of a first order lag element (PT1-element) with dead time. The characteristics of the first order lag element can be observed by the global proportional behavior and by the escalating rise of the output signal.

The estimated linear transfer function is not able to predict the real system behavior with sufficient accuracy. The linear transfer function neglects the static nonlinearities of the real system in terms of the dead zone and the nonlinear gain.

One way of dealing with a nonlinear system is linearizing the system in certain working points. For these working points an accurate linear transfer function can be found, representing the real system behavior only in the particular working point.

The linear transfer function in a certain working might also be valid with a minor inaccuracy within a certain interval around the working point. The length of this interval depends on the structure of the nonlinearity and on the tolerable inaccuracy of the model.

Table 1 shows the linear transfer functions of the joint plant for selected working points (Schörghuber; 2015).

Table 1: Linear transfer functions for certain working points

Input step size	Linear transfer function
$I_{Step} = 1$ [A]	$G(s) = \frac{191.56}{1 + 0.064237 \cdot s}$
$I_{Step} = 1.5$ [A]	$G(s) = \frac{324.24}{1 + 0.09705 \cdot s}$
$I_{Step} = 2$ [A]	$G(s) = \frac{484.32}{1 + 0.12527 \cdot s}$

Summary:

- Most of the robot's joints show a nonlinear transmission behavior.
-The nonlinear behavior is static and consists mainly of a dead zone and a nonlinear gain.
- The nonlinear behavior is most likely caused by friction nonlinear dependent on the velocity caused by the gear set and by the nonlinear dynamic of the DC-motor.

3. CONTROL

The system identification has shown that the joint plant shows a dead zone characteristic, making it difficult for the brushless DC-motor to operate at very low velocities. This problem is most likely caused by the friction of the gear set and cannot be resolved by the controller. The sole way to cope with dead zone nonlinearity is to design the trajectories for the various joints in such a way that very low velocities are avoided wherever possible. Table 2 shows a summary of the specifications of the velocity controller (Kopacek et.al.; 2014).

Table 2: The velocity controller

Velocity Controller	
Controller type	Piece-wise linear PI-controller using gain scheduling
Sampling time [msec]	TS = 180
Proportional gain	Dependent on the velocity
Integral gain	Dependent on the velocity
Rise time	Dependent on the velocity
Overshoot	none
Settling time	Dependent on the velocity