Neural Networks for the Control of Soccer Robots

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Abstract - In 1995 robot soccer was introduced with the purpose to develop intelligent, cooperative multi-robot (agents) systems. Robot soccer provides a good opportunity to test control strategies and methods of Multi-Agent-Systems. From the scientific viewpoint a soccer robot is an intelligent, autonomous agent which should carry out its task in cooperative, coordinated, and communicative way with other agents. The group behavior of agents and the behavior of a single agent should be explored. One of the single agent's behaviors is the motion control. The desired velocity of each wheel is generated and sent to the robot comparing the desired and actual position of the robot. The mostly used motion controller today is the digital PID-controller. In this paper as a "modern", intelligent control algorithm a neural network will be introduced and tested.

1. Introduction

Several years ago robot soccer was introduced with the purpose to develop the intelligent, cooperative multi-robot (agent) systems and as one of the first examples for robots in entertainment, leisure and hobby. Robot soccer offers a good opportunity to implement and test control and cooperation algorithms of Multi-Agent-Systems (MAS). From this viewpoint each soccer robot is an intelligent autonomous agent.

The whole robot soccer system (see Fig. 1.) consists of a host computer, players (three mobile micro robots), a vision system, communication modules etc. A color-CCD-camera, located 2m above the playground - size 1.50m x 1.30m - delivers picture to the host computer. The computer generates the motion commands based on the implemented game strategy and submits it to each robot by wireless communication. Based on the location of intelligence the robot system can be divided in,

- ⇨ remote-brainless systems
  The most intelligence is located in the host computer.
- ⇨ vision-based systems
  The robot is able to generate its motion behavior, like position control, collision avoidance etc.
- ⇨ robot-based systems
  Robot is moving autonomously. The host computer delivers only the position data of each object to the robots.

At the moment the most "intelligence" is located in the host computer.

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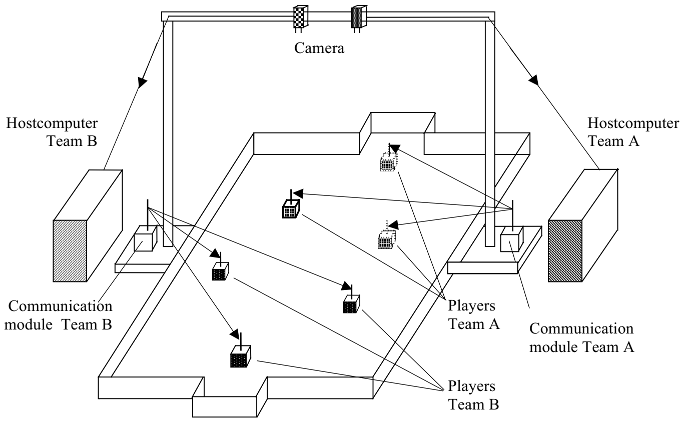

Fig. 1. Overall system

Usually a soccer robot is a two-wheel driven mobile robot, whose size may not exceed 75mm in each side of a cube. It consists of a mechanical part two wheels, two DC motors, a micro controller, a communication module and a power supply. It is a very good example for a mechatronic system. The behavior and efficiency of such a robot depends on the mechanical construction, control algorithm, and the performance and accuracy of the vision system.

2. Soccer Robot – ROBY-GO

The soccer robot at IHRT –"ROBY-GO" (see Fig. 2.) is a two-wheel driven mobile robot and is built in simple, compact and modular construction.

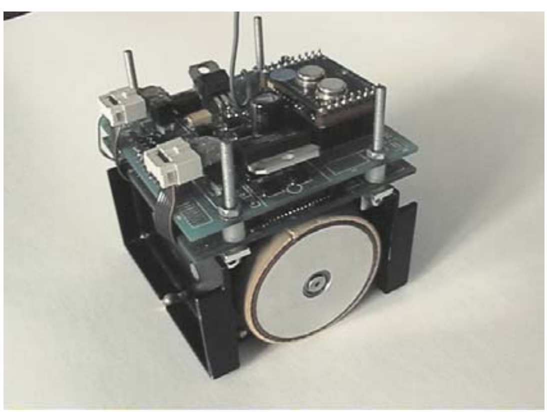

Fig. 2.Soccer robot ROBY-GO

Electronic part has a modular and open architecture and consists of two boards, one for microcontroller board and other for power electronic and communication. As a controller a C167-LM from Infineon (SIEMENS) is used. C167 is a 16-Bit CMOS microcontroller (25MHz) with on Chip CAN module. C167 contains CAN bus interface, there are possibilities to connect several microcontroller boards for different tasks, like sensors, etc.. This microcontroller has 4 channel PWM units.

ROBY-GO can reach maximum speed upto 2.5m/s. Each of two wheels is connected by a gear with a DC motor. Each DC motor receives a command value – desired speed - as input by the microcontroller generated PWM (Pulse-Width-Modulation) signal.

The behavior of a robot depends on the accuracy and dynamics of the vision system as well as the robot itself. From the communication module each robot receives reference velocity and reference angle velocity. New values are transmitted to the robots in constant time intervals of 33 ms. Values are calculated from known actual position and the goal position and goal velocity of the robot. So on host computer implemented algorithm for planning reference velocity curve serves also as a position controller. Very short time period in which the robot has to reach reference velocity enables another simplification. It can be supposed, that the robot reaches reference velocity in the moment or equivalently, that the robot is moving with constant velocity in the 33 ms time intervals, that is between points when it gets a new velocities from host computer. That assumption significantly simplifies path planning and also tasks of another modules implemented on host computer. The lowest sampling time that can be used for robot's velocity controller is 1 ms and is limited by encoder resolution. In the case of very complex control algorithm, also the computational power of the on-board processor could be limiting factor. Reference velocity curve is also calculated with the defined acceleration, separately for each of the wheels. Acceleration is set according to the actual and reference velocities of the wheels and available torque of the motors. In that way the actuator saturation and consequently increasing velocity errors are avoided.

3. A simplified Dynamical Model of the Soccer robot

The simulation study of a two wheel driven mobile robot is based on a dynamical model of the robot. Deriving the complete dynamical model faces many problems, specially determining complicated parameters of the model. One of them is inertia tensor matrix, especially when the parts are non-uniform and have a complicated shape. Additionally finding an appropriate friction model is also difficult because the friction can not be exactly measured. Therefore it is necessary to derive the model how the real robot will behave.

Simplified dynamical model of the robot :

$$m \cdot \ddot{x} = \frac{1}{r} \cdot \left(M_R + M_L \right) \tag{1}$$

$$J \cdot \ddot{\varphi} = \frac{a}{2 \cdot r} \cdot \left(M_R - M_L \right) \tag{2}$$

$$J = \frac{m \cdot a^2}{6} \tag{3}$$

$$M_R = M_{Rm} \cdot N \ ; \ M_L = M_{Lm} \cdot N \tag{4}$$

m is the mass of the robot and $\ddot{x}$ is the acceleration of the robot. $\ddot{\varphi}$ is the angular acceleration. The torque on left and right wheel (M_L, M_R) can be calculated with the torque provided by left and right motor (M_{Lm}, M_{Rm}) and the gear ratio (N). J is the amount of inertia under the assumption the robot is a homogeneous cube. r is the radius of wheel and a is the length of a robot's edge.

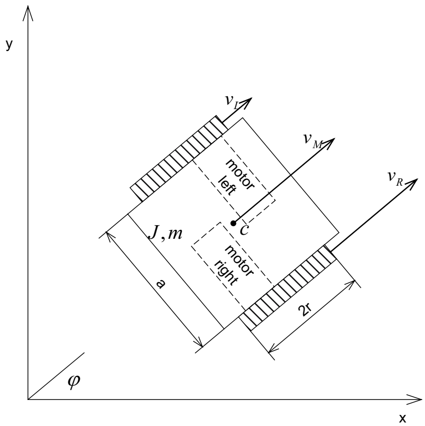

Fig. 3. Soccer robot

However getting an appropriate dynamic model of a robot near to real robot dynamics, some disturbance torque were added to the basic model. Disturbance torque should mainly compensate the absence of the friction in the simplified model, so it consists of a constant part referring to the Coulomb's friction and a velocity dependent part referring to the viscous friction Eq. (5).

$$M_d = 2 \cdot M_{dc} + k_{transl} \cdot \dot{x} + k_{rotat} \cdot \dot{\varphi} \tag{5}$$

Velocities of both wheels (V_L, V_R) which are necessary for implementation of velocity controller, can be calculated from following:

$$V_L = V_M - \frac{\dot{\varphi} \cdot a}{2}; \; V_R = V_M + \frac{\dot{\varphi} \cdot a}{2} \tag{6}$$

$$V_M = (V_R + V_L)/2 \tag{7}$$

For the simulations also a model of the DC motor (for example, Minimotor Type 2224 006SR) is necessary. A model with following linear equations is used:

$$M_m = K_M \cdot (I - I_0) \tag{8}$$

$$U = I \cdot R + K_E \cdot n \tag{9}$$

$$n = (60 * N * V)/(2 * pi * r) \tag{10}$$

M_m is the motor torque and is calculating with a torque constant K_M (6.92 mNm/A) and the current Eq. (8). I_0 is no load current (0.029 A). The terminal voltage U is calculated with back electro magnetic force constant, K_E (0.725 mV/rpm) multiplied with rotation speed n and with current and resistance R (0.94 Ohm). Left and right motor's input voltages U_L and U_R are the controller's outputs Eq. (9).

4. Model based Controller with Neural Network Disturbance Estimation

Presented control algorithm is based on a simplified dynamical model of robot and motors, stated earlier in the paper. However disturbances caused by unmodelled dynamics such as friction, time delays, and differences between actual and modeled inertia would be a reason for high velocity errors and performance that does not meet our demands. Problems are also frequent collisions between robots. For compensation of those disturbances a neural network is implemented in the control scheme. Combination (sum) of voltages calculated from the model and disturbance voltage estimated by neural network makes two reference voltages one for each motor of the robot. In the control scheme the actual acceleration and actual angular acceleration are necessary. Those actual values were replaced by estimated values ($\ddot{x}^C$, $\ddot{\varphi}^C$), calculated from reference acceleration ($\ddot{x}_r, \ddot{\varphi}_r$) and velocity error:

$$\ddot{x}^C = \ddot{x}_r + K_x \cdot \left(\dot{x}_r - \dot{x}_a\right) \tag{11}$$

$$\ddot{\varphi}^C = \ddot{\varphi}_r + K_{fi} \cdot \left(\dot{\varphi}_r - \dot{\varphi}_a\right) \tag{12}$$

$\dot{x}_a$: actual velocity, $\dot{\varphi}_a$: actual angular velocity

Implemented neural network is constructed with one hidden layer with a non-linear transfer function and an output layer with linear transfer function. 25 neurons in hidden layer were used. NN inputs are reference and actual velocity, reference angular and actual angular velocity of the robot and velocity errors of the wheels. Error vector of the output layer is calculated as linear combination of velocity error and acceleration error of the wheels. Learning algorithm is the same as the traditional backpropagation learning rule.

Robot's initial translational and angular velocity in the beginning of the simulation are set zero ($\dot{x} = 0$ m/s, $\dot{\varphi} = 0$ rad/s). The desired end velocity is 1 m/s and desired end angular velocity 5 rad/s. It is reached in 0.32 s. Equivalently the desired end velocity of right wheel is 1.19 m/s and end velocity of left wheel 0.81 m/s. Disturbance torque (M_d) were added to the model with the Coulomb's friction (M_{dc} = 0.0025) and the velocity dependent part to the viscous friction (k_{transl}=k_{rotat}=0.005) Eq. (5).

For simulated movement 30% of available torque reach for the reference trajectory. The gains for estimation of calculated accelerations were K_x = 10 and K_{fi} = 10.

Fig. 4 presents desired and actual velocity and desired and actual angular velocity of the robot. Corresponding errors are shown on Fig. 5.

Fig. 6 and Fig. 7 show results for each wheel of the robot. Maximal dynamical velocity error of robot is 0.009 m/s and maximal dynamical angular velocity error of robot is 0.66 rad/s. There is no steady state error.

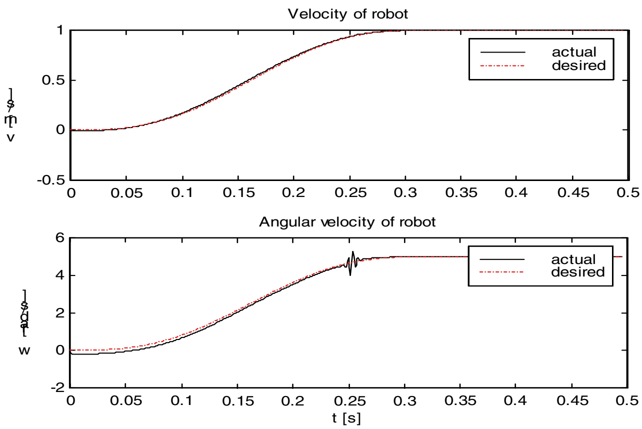

Fig. 4 Desired and actual velocity and angular velocity of robot

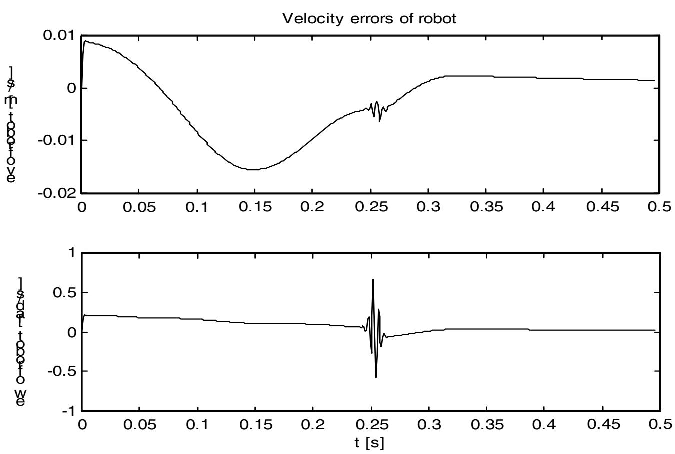

Fig. 5 Velocity and angular velocity error of robot

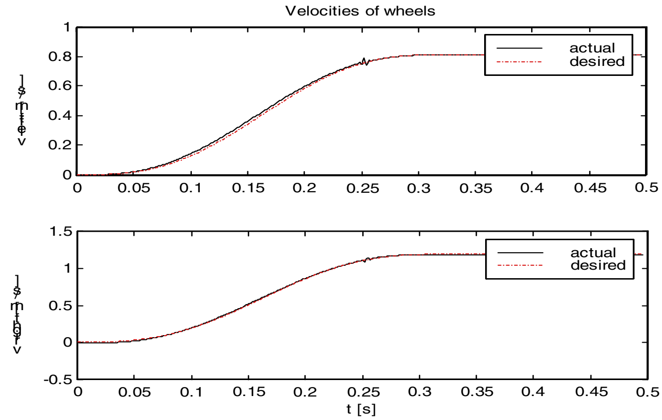

Fig. 6 Desired and actual velocities of wheels

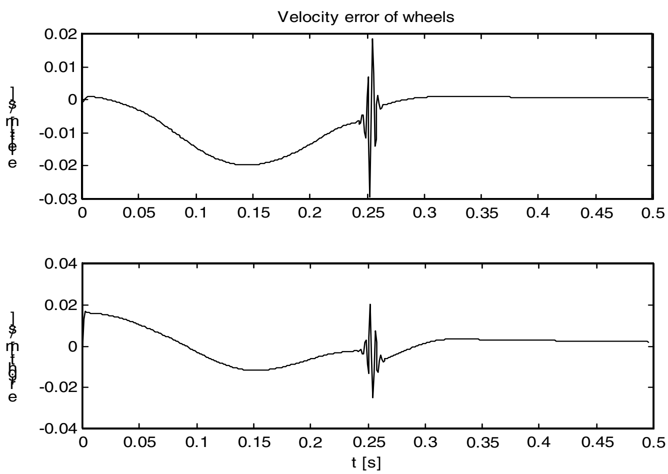

Fig. 7 Velocity errors of wheels

5. Conclusion

The research on robot soccer has various aspects, like

- The robot soccer is an interdisciplinary research theme including robotics, image processing, communication, cooperation, intelligent control and others.
- Robot soccer is a good tool for the entertainment and leisure as well as education.
- Robot soccer is a good test bed to implement and test the algorithms for Multi-Agent-Systems.

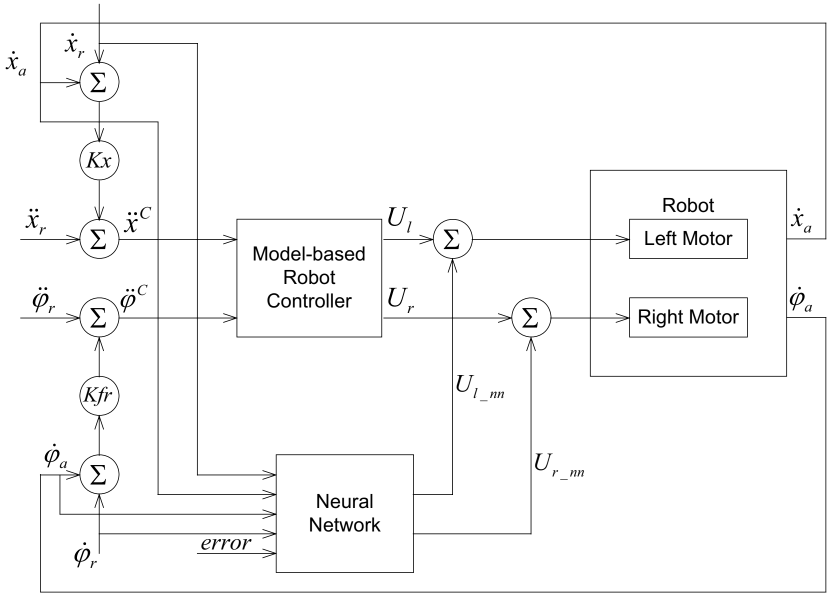

Fig. 8 Model based controller with neural network disturbance estimation

An adaptive velocity control algorithm for the control of soccer robots was presented in this paper. Controller is based on a derived dynamical model of the robot, which is upgraded with a neural network, that compensate unmodelled dynamics as well as other disturbances, that arise from frequent collisions between robots. Based on simulation the controller result in fast error convergence and no steady state error.

A robot can move with maximum speed approximately 2.5 m/s. The vision system can detect objects at constant frame rate (30 frames per second). The exact position of objects can not be calculated. It is necessary to predict future locations of the ball. For this purpose an extended Kalman filter (EKF) is implemented.

6. References

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