Using Self-Organizing Maps to Control Physical Robots with Omnidirectional Drives

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Abstract— **In many application areas, robots most suitably employ classical PID controllers and the like. In the field of autonomous mobile robots, however, further adaptation features are required in order to adapt to dynamically changing environmental conditions. In recent contests, the particular research area of soccer-playing robots, called RoboCup, has observed the emergence of omnidirectional driven robots. Such drives consist of three independently controllable motors with which a robot can simultaneously perform both translational movements and rotations, which yield a significant advantage in soccer games. This paper describes how a Kohonen-feature-map-based neural network is able to learn the required capabilities and how to adapt to changing environmental conditions.**

I. INTRODUCTION

RoboCup [9] is an initiative that aims at developing human-competitive soccer robots. In order to focus on different research issues, RoboCup distinguishes between the following four leagues (ordered from small to large): simulation, small-size, mid-size, and human size. The robots in these leagues not only differ in size but also in their capabilities, such as general complexity, processing power, employed cameras, motor power, autonomy, etc. The annual national and international competitions [7], [12] have clearly indicated that robots with omnidirectional drives exhibit better performances than rather conventional ones, which traditionally utilize only two motors and an optional steering-wheel.

Section II illustrates a small-size robot with an omnidirectional drive. Such a drive consists of three independently controllable wheels, and allows the robot for simultaneously doing both driving in any direction and turning around its own axis. Given a moving direction and a rotation speed, the "engineering problem" consists in finding three appropriate motor speeds.

Almost any robot can employ conventional controllers, such as a PID (proportional-integrate-differentiate) controller, known from classical control theory [2]. In the particular field of autonomously soccer-playing robots, however, classical controllers exhibit the following limitations: the range of operation is rather small (i.e., valid only in the neighborhood of the pre-specified point of operation), adaptivity to changing demands, and being rather sensitive with respect to changes in the total weight, wheel-to-floor friction, etc. Due to these limitations, this paper explores the usage of well-known self-organizing feature maps [3], [10]. Section III presents the employed control architecture in full detail.

As indicated above, this paper aims at developing a controller for a physical robot. Rather than resorting to pure simulations, all the experiments were done on a physical robot. In order to allow for experimental replications, Section IV summarizes the experimental setup.

The results presented in Section V indicate that the chosen control architecture is at least suitable for the task at hand. Despite its operability, the employment of self-organizing feature maps also allow for ongoing dynamic adaptations, as opposed to some one-time offline parameter learnings. This, in turn, allows the robot to adapt to changing environments. In fact (see, for example, [5]), the environmental conditions, i.e., light, wheel-to-floor friction, etc., do significantly change during contests as well as from contest to contest. Finally, Section VI concludes with a brief discussion, which includes an outline of ongoing as well as future work.

II. THE ROBOT

The robot has been developed in several student projects [11] and has undergone several developmental stages. A pre-assembled version of the current model is depicted in Fig. 1, and is of size 18 cm in diameter and of weight 2.0 Kg. It is equipped with three motors, with wheels attached to it of 55 mm in diameter. With a pulse-width modulator and 12 batteries with a total of 14.4 V and 3 Ah, the robot's maximum speed is as fast as 3 m/s. Each motor axis has a wheel encoder attached to it, which provides 256 ticks per round. Due to the "gearbox", this leads to approximately 1024 ticks per wheel round. In addition, the robot utilizes a Motorola microprocessor board [8] with an attached DECT wireless radio module, which allows for a wireless robot-to-PC connection.

The particular wheel construction, as illustrated in Fig. 2, exhibits very high friction along its natural direction but vanishing friction along the wheel axis. This property allows for three wheels being mounted with angels[1] $\varphi_1 = 30^\circ, \varphi_2 = 150^\circ$, and $\varphi_3 = 270^\circ$, respectively, as can be seen in Fig. 3.

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[1] All angles are measured counter clockwise relative to the y-axis.

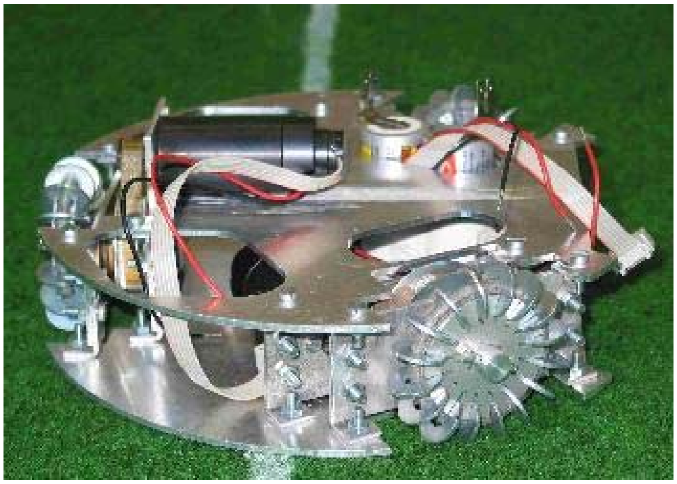

Fig. 1. The physical robot (pre-assembled).

The speeds (rotation speed times circumference) associated to them are denoted by $v_1, \ldots, v_3$. This (omnidirectional) drive construction allows the robot to be moving in any direction φ with any speed and any additional rotation speed r. That is, the robot can simultaneously control both translation and rotation independently of each other. This capability saves valuable time (with respect to the soccer games), since the robot does not have to turn and move sequentially.

III. THE CONTROLLER

The controller's general task is to derive the three wheels' speeds $v_1, \ldots, v_3$ from the desired moving direction φ, the speed v, as well as the rotation speed r. Based on the robot's morphology (Fig. 3), basic kinematics show that the rotation speed $r{=}0$ vanishes only if the sum of all motor speeds $\sum_i v_i{=}0$ also vanishes. Given a rotation speed $r{=}0$, the robot's moving direction is then the *vectorial* sum, i.e., vectors $\vec{V_i}$ with length $||\vec{V_i}|| = v_i$ and angle φ_i. These relations between v, r, φ, and $v_{1\ldots3}$ allow for reverse engineering the desired motor speeds $v_{1\ldots3}$.

Fig. 2. The wheel.

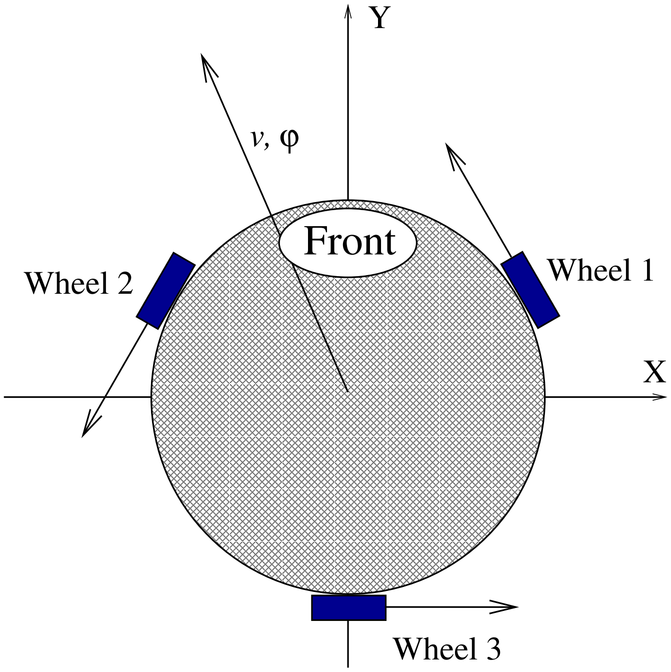

Fig. 3. The robot has three wheels, which are mounted with angles $\varphi_1{=}30°$, $\varphi_2{=}150°$, and $\varphi_1{=}270°$. Depending on the wheels' speed settings $v_{1\ldots3}$, the robot is moving with speed v at an angle φ and additional rotation speed r.

Classical control theory would solve the given task by, for example, using some sine/cosine equations and PID controllers (for a thorough introduction, the interested reader is referred to [4]). This might be well working in many application areas. In the field of autonomously soccer-playing robots, however, this approach exhibits some non-negligible limitations, which are due to the following reasons: the wheel-to-floor friction is not constant, the wheel fabrication does have significant tolerances, and the robot's weight depends on the actual equipment. This obviously requires constant online adjustments (see, also, Section VI).

Due to the problems summarized above, this research resorts to adaptable controllers that are based on neural networks. A first straight forward approach would be to employ a monolithic controller that derives the three motor speeds $v_{1\ldots3}$ from v, φ, and r. But the robot's particular morphology as well as previous experiences [6] in the area of self-organizing control architectures suggest to decouple the moving direction φ from the rotation speed r. Thus, the controller as shown in Fig. 4 employs a self-organizing extended Kohonen feature map [3] to determine normalized motor speeds to $v^{'}_{1\ldots3}$. Subsequent processing stages rescale and shift these speeds $v_i = v \times v^{'}_i + r$ to obtain the desired translation as well as rotation speeds v and r. respectively. Finally, internal PID controllers regulate the internal pulse-width modulation.

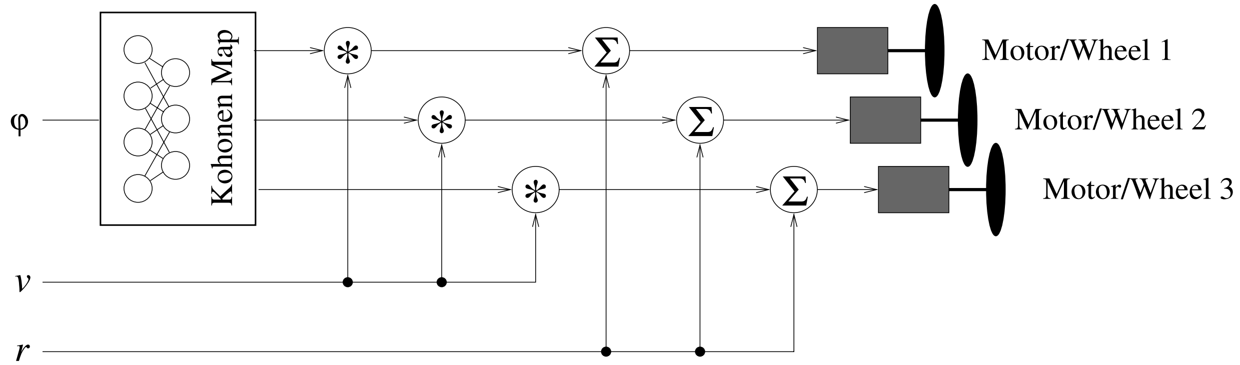

Fig. 4. The controller: From a given translational moving direction φ, a Kohonen feature map determines three motor speeds which are multiplied with the desired speed v and updated by an additional desired rotation speed r.

IV. METHODS

In the first stage, the controller's Kohonen map must be trained such that the provided speeds $v_{1\ldots3}$ correspond to to desire direction φ. To this end, 30 randomly generated triples $v_{1\ldots3}$ were applied to the motors. The resulting driving direction was measured by hand leading to a set of 30 quadruples $\{(v_1^{(j)}, v_2^{(j)}, v_3^{(j)}, \varphi^{(j)})\}$. Since all directions are equally likely, the associated angles (normally denoted by w_i) of the map's neurons where uniformly distributed over the range $0{\leq}\varphi{<}2\pi$ and kept fixed during their entire lifetime. Then, only the outputs of an extended Kohonen map with 20 neurons was trained for 10 epochs with a learning rate of λ=0.3. Since the neurons' locations were kept fixed, a neighborhood of 1 with a constant strength of 0.3 was used. The resulting Kohonen map was copied to the controller. Moreover, by keeping the learning rate at λ=0.3, the feature map preserves its plasticity for ever.

V. RESULTS

The following experiments were done with the robot that was described in Sections II and equipped and trained with a neural network controller as discussed in Sections III and IV. The results show that the employed Kohonen map is able to suitably control the omnidirectional drive. The observable deviation from the target angle deviates approximately between -2 and 2 degrees.

The observable deviation is suitably small but somewhat higher than expected. However, this deviation will be further regulated by the system (not by the controller itself) as follows: The camera and image recognition system usually employed in robocup recognizes the difference and subsequently compensates for this deviation.

Dear reviewer, please note that doing these experiments with a physical robot is a severe bottleneck. We will be providing further results by the deadline for camera ready papers, in case the paper will be accepted. Furthermore, we will be investigating whether the observable deviation is due to the Kohonen feature map or due to the measuring procedure. We apologize for the current shortcoming and highly appreciate you understanding.

VI. DISCUSSION

This paper has described a robot that is able to autonomously play soccer. In order to adapt to dynamically changing environmental conditions, the robot was equipped with a Kohonen feature map. And the experiments have indicated that the chosen approach is appropriate.

Future research will be devoted to the following extensions: In RoboCup, a camera is utilized by an image processing software to determine the locations of all robots. The very same program can be used to derive the resulting moving directions as well as rotation speeds. This information will be used to constantly update the controller's Kohonen feature map.

The second extension will be devoted to improving the robot's behavior in case of drastic changes in the moving direction φ. Currently, it takes a while (about a second or two) until the robot is able to change from one direction to another especially in case of large changes $\Delta\varphi$. The observable behavior is mainly due to the robot's mass and partly due to the employed PID wheel controllers. A second one-dimensional Kohonen map will be generating a compensation angle α that depends on the difference $\varphi^t - \varphi^{t-1}$ between two consecutive time steps $t{-}1$ and t. The sum of the desired moving direction φ and the derived compensation angle α will be fed into the controller as described above.

ACKNOWLEDGEMENTS

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[5] The RoboCup rules: `http://www.itee.uq.edu.au/~wyeth`.
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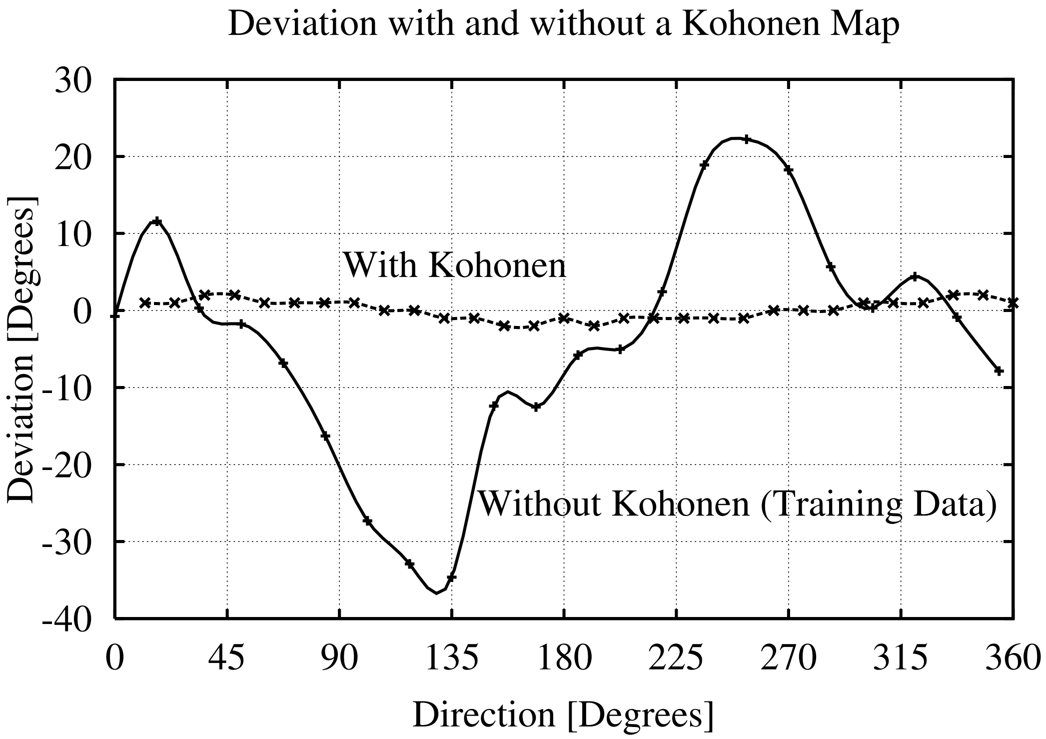

Fig. 5. This figure shows the resulting deviation of the robot after training the Kohonen feature map.

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