Fuzzy modelling of mobile autonomous soccer-playing robots - An educational approach with LEGO Mindstorms robots

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ABSTRACT

Soccer-playing robots are being used in education to foster understanding and interest in artificial intelligence, multimodal systems, engineering and science in order to solve complex problems through active learning comprehensive knowledge undergoing real-world applications. In 1997 the RoboCup Initiative started a broad international program of research and education, that has the aim to promote artificial intelligence and robot research by providing problems like soccer-playing robots or rescuing robots to be solved by integration of different technologies and collaboration of various resources. As the LEGO Mindstorms robotic construction kits are convenient in education, they are often used for RoboCup Junior competitions. To represent how fuzzy logic can be used in education, an example for moving a soccer-playing mobile autonomous robot based on LEGO Mindstorms is described.

INTRODUCTION

Over the past thirty years the "Epistemology and Learning Group" of the Massachusetts Institute of Technology (MIT) has searched for correlations between learning environments and learned skills. The idea of robotic construction kits is based on the research of Seymour Papert, who described the first steps of utilization of computers and robots in the learning environment of children in his book MINDSTORMS: Children, Computers and Powerful Ideas [Papert 1980].
Starting from the development of turtle robots and the child-friendly programming language LOGO, in 1998 the MIT and the LEGO company came out with the first LEGO Mindstorms robotic construction kits. Even though the product is primary centered to children and teenager, many adults are also attracted by the robotic construction kits. There are many active and creative online-groups that develop alternative programming environments and advanced construction techniques.
In this paper we describe the robotic construction kits and programming environments that we use in the course "Hamburg Robocup: Mobile autonomous robots play soccer" at the University of Hamburg as well as some examples of teaching fuzzy logic with LEGO Mindstorms robotic construction kits.

ROBOTIC CONSTRUCTION KIT AND PROGRAMMING

To understand the relevance of using robotic construction kits at universities, it is important to know the elements of robotic construction kits and how they can be programmed. In the following this is exemplified through the LEGO Mindstorms robotic construction kit, that consists of the following ingredients: a programmable RCX-brick (Hitachi H8/3292-microcontroller with 16 KB ROM and 32 KB RAM), light sensors and touch sensors, motors, many common LEGO bricks, an infrared sender to transmit data to a computer, the programming environment Robotics Invention System (RIS) and a construc-

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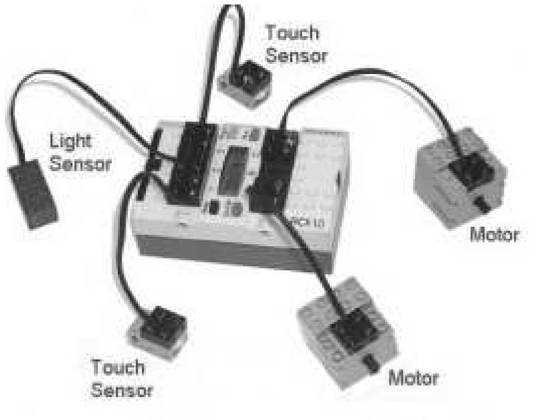

Figure 1: RCX-brick with sensors and motors

tion handbook. The RCX-brick contains three inputs for sensors, three outputs for motors or lamps, five spots for programs, a LCD-display, four control buttons, a speaker and an infrared interface. Fig. 1 shows an RCX-brick with two motors, a light sensor and two touch sensors.

The Robotics Invention System (RIS) is a graphic-based programming environment that works with blocks. Each block stands for one instruction. To program the robot the blocks are joined per Drag and Drop in form of a chain. Running the program the blocks are executed in sequence of the block chain. To read the values of the sensors while executing the program, parallel block chains can be used.

Beside the software RIS, that is part of the LEGO Mindstorms robotic construction kit and that is directed to children and teenager without programming skills, the active LEGO online-groups developed some other possibilities for advanced programmers to work with the robotic construction kits. Most of this software can be found as freeware in the internet. Here are some examples of other programming environments that was used in the course “Hamburg Robocup: Mobile autonomous robots play soccer” at the University of Hamburg:

ROBOLAB: works with kind of advanced flowcharts, based on LabVIEW, was developed especially for use in schools

RCX Command Center: with the programming language Not Quite C (NQC), a language similar to C, programs can be written text-based

LEGO Java Operating System (lejOS): an implementation of a Java Virtual Machine (JVM)

Other enhancements can be found in [Baum 2000, Baum et al. 2000, Erwin 2001, Knudsen 1999].

HAMBURG ROBOCUP: MOBILE AUTONOMOUS ROBOTS PLAY SOCCER

Over the past years the utilization of robotic construction kits in schools was analyzed and appreciated in many studies [Christaller et al. 2001, Müllerburg 2001], but in the context of universities they are often depreciated as toys and as a consequence as irrelevant for teaching students [Koch 2003]. Using “real” robots has often the disadvantage that they are very expensive, so that many students have to share one robot. Additionally it can be difficult to motivate students to work with robots and to teach the basics of robotics because the orientation time of a complex robot system often requires weeks or months. To avoid those problems, we decided to use robotic construction kits in the undergraduate course “Hamburg Robocup: Mobile autonomous robots play soccer”. The goal of the class is to work with mobile autonomous robots, so that the students develop and understand the complexity of non-linear systems. Additionally soft skills like communication, teamwork and project-management are supported.

In the course “Hamburg Robocup: Mobile autonomous robots play soccer” the students have the exercise to construct and program a robot that plays soccer considering the rules of RoboCupJunior - the pupil league of RoboCup [Kroeger et al. 2000, Lund 1999, Lund et al. 1999, Lund and Pagliarini 2000, Stone and Veloso 1998]. RoboCup is a broad national and international program of research and education, that has the goal to promote artificial intelligence and intelligent robot research by providing problems to be solved by the integration of different technologies and the collaboration of various resources.

During the course contests are realized to test the performance of the robots. At the beginning some problems crop up: the robots don't find the ball, the robots aim at the wrong goal, etc. But most of the students are stimulated by those

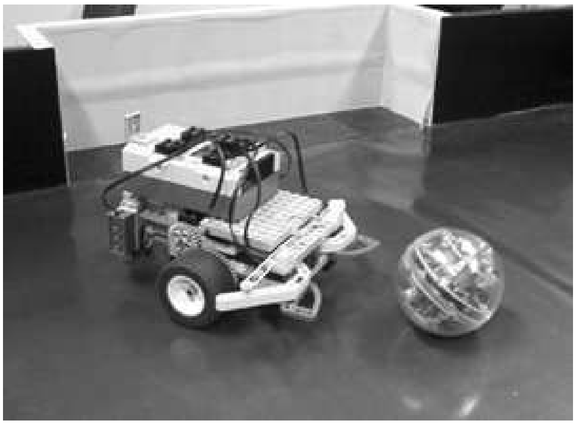

Figure 2: Soccer-playing mobile autonomous robot

problems to extend their work. One approach to deal with the fuzzy dynamic behavior of the robots - modelling the robots with fuzzy logic - is described in the following section.

FUZZY MODELLING OF MOBILE AUTONOMOUS SOCCER-PLAYING ROBOTS

Modelling a robot with Fuzzy logic is one example of a computer science branch that can be taught effectively by mobile autonomous robots. Fuzzy statements that are recognized by the students during the work with the robots can be precisely expressed with Fuzzy logic. Fig. 2 shows a soccer-playing LEGO Mindstorms robot on the playground. While the students work with the robots they find out that the robots do not move straight forward although both motors run with the same performance. In this situation fuzzy logic can be very helpful to solve the problem. The students learn by means of linguistic variables of the mobile robot to determine the membership function of the linguistic variables and to draw up rules to describe the dynamic behavior of the soccer-playing robots.
To represent how fuzzy logic can be used in a control system, in the following an example for moving a soccer-playing mobile robot based on LEGO Mindstorms, is discussed. For a brief introduction into fuzzy logic see [Möller 1995].
The position of the robot movement is determined by some linguistic variables: the direction angle, denoted as α, the distance from the object, which is for a soccer-playing robot the ball, denoted as x and the direction of the mobile robot movement, denoted as β, that is determined by the angle of the wheels steering position. For a given initial robot position within the specific area, the soccer playground, the goal for the mobile robot is to move toward the center of the ball. The desired final position is to let the robot moving the ball on a track toward the goal. α, β and x are the respective linguistic variables for this purpose. To each of these linguistic variables, a set of linguistic values can be assigned as shown in Table 1, 2 and 3:
As shown in Fig. 3, a range of numerical values can be assigned to each linguistic value of a linguistic variable. Each graph, called a membership function, indicates the degree to which an input value belongs to a particular linguistic value. Such a degree of membership ranges from 0 to 1. The value 0 indicates no membership, and the value 1 represents full membership. Hence a value between 0 and 1 represents a partial membership.
The rules have to be defined, describing the dynamic behavior of the soccer-playing robot. In general, each rule produces some output linguis-

Distance x	Input variable
RST	right side of track toward goal
CT	center of track toward goal
LST	left side of track toward goal

Table 1: Distance variables

Dir. angle α	Input variable
ND	north direction toward the goal
ED	east direction toward the goal
SD	south direction toward the goal
WD	west direction toward the goal

Table 2: Direction angle variables

Wheels angle β	Output variable
TR	turn right toward the goal
SF	straight forward toward the goal
TL	turn left toward the goal

Table 3: Wheels angle variables

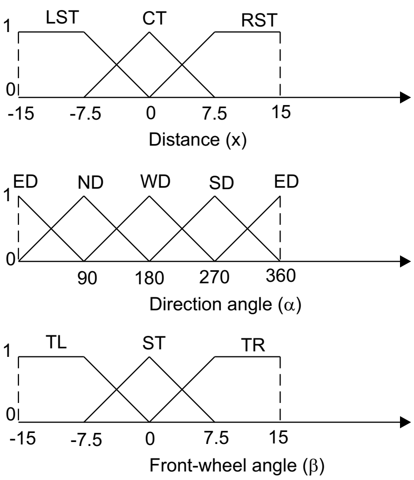

Figure 3: Membership functions for the distance x, direction angle α and wheels angle β

	RST	CT	LST
ND	TL	SF	TR
ED	TL	TL	SF
SD	TR	TL	TL
WD	SF	TR	TR

Table 4: FAM set of rules

tic values based on some input linguistic values. In the case of the mobile robot, some of the rules can be defined as

$if\ \alpha = ND\ and\ x = LST\ then\ \beta = TR$
$if\ \alpha = ND\ and\ x = CT\ then\ \beta = SF$
$if\ \alpha = ND\ and\ x = RST\ then\ \beta = TL.$

These rules can be extended to consider all the possible values for α; thus there will be 12 rules in all, which can be represented in the fuzzy associative memory (FAM), shown in Table 4.

For given input values for x and α, the fuzzy-logic controller can determine an output value for β. For this purpose, for each input value the fuzzy controller determines the membership degree of its corresponding linguistic values. As a next step, for each rule, as shown for example in Table 4, the minimum of the membership degrees of its antecedents is chosen as a membership degree for the rules consequent, which is considered as a weight for the rules consequent. When there is more than one membership degree for a consequent, the MAXIMUM operator is chosen for that consequent. Hence the membership degree is assigned to each linguistic value. If a crisp output is required from the fuzzy rule base rather than the fuzzy output set, a process called defuzzification is used to compress this information. The crisp output is generally obtained using a mean of maxima or a center of gravity defuzzification strategy. The most widely adopted method for defuzzifying a fuzzy set A of a universe of discourse Z, is the centroid defuzzification or center of gravity method, which is based on the centroid of area z_{COA}

$$z_{COA} = \frac{\int\limits_Z \mu_A(z) z dz}{\int\limits_Z \mu_A(z) dz} .$$

where $\mu_A(z)$ is the aggregated output of the membership function and z_{COA} is the control output, which equals the fuzzy centroid of A, where the limits of integration correspond to the entire universe of discourse Z of angular values of the steering wheel(s) velocity values.

The center of gravity method, COG, provides a weighted average of all linguistic output values. A simplified calculation is as follows:

$$COG = \frac{\sum\limits_{i=1}^{n} c_i * L_i}{\sum\limits_{i=1}^{n} L_i} .$$

where the L_i are the weights of linguistic output values and the c_i are the weighting factors.

As an illustration of the information process between the fuzzification and defuzzification, Fig. 4 shows the signal flow through a continuous fuzzy-logic system using the center of gravity defuzzification method. There exist p multivariate fuzzy input sets and q univariate fuzzy output sets.

Example 1: Let the starting point of the mobile robot be at direction x = -10.0, and the direction angle $\alpha = 90^o$. For these initial values the membership degree of the linguistic input values are for the distance $x = -10.0$: $\mu_{RST} = 0$; $\mu_{CT} = 0$; $\mu_{LST} = 1.0$, and for the direction angle $\alpha = 90^o$: $\mu_{ND} = 1.0$; $\mu_{ED} = 0$; $\mu_{SD} = 0$; $\mu_{WD} = 0$. Combining distance and direction, as shown in the fuzzy associative memory in Table 4, with the respective membership degree μ_i for each rule consequently results in the membership matrix, shown in Table 5.

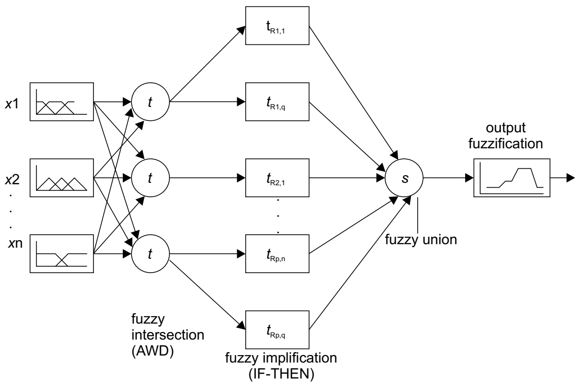

Figure 4: Information flow through a continuous fuzzy system with p multivariate fuzzy input sets and q univariate fuzzy output sets

	RST	CT	LST
ND	1	0	1
ED	0	0	0
SD	0	0	0
WD	0	0	0

Table 5: Membership degrees for each FAM rule based on the initial conditions

The system output-value calculation can be evaluated by using the center of gravity method, and the MAX operator, while there is more than one membership degree. In this formula the maximum degree of each of the four membership degrees is chosen, 1 for TR, and 0 and 0 for ST and TL, respectively. Based on these degrees we receive the mobile robot system output value as follows:

$$COG = \frac{(20 * 1) + (-20 * 0) + (0 * 0)}{1} = 20 \; .$$

That is, that the wheels of the mobile robot will turn right with an angle of 20^o. The robot moves for a short distance and then the process repeats for the new position.

Example 2: Let the slope of a terrain range between -45^o and $+45^o$, which can be divided into several memberships in between large negative and large positive. We will further assume that the terrain can vary between very rough, rough, moderate, and smooth, and the output speed of the fuzzy-logic system may range between 0 and 15 mph, divided into very slow, slow, medium, fast, and very fast. The rules of the fuzzy-logic mobile robot system are as follows:

if slope is large-positive and terrain is very-rough then speed of the robot is very-slow
if slope is large-positive and terrain is rough then speed of the robot is slow
if slope is large-positive and terrain is moderate then speed of the robot is medium
if slope is large-positive and terrain is smooth then speed of the robot is high
if slope is positive and terrain is very-rough then speed of the robot is slow
if speed is positive and terrain is rough then speed of the robot is medium
if slope is positive and terrain is moderate then speed of the robot is slow
if ...

CONCLUSION AND PERSPECTIVE

As shown in this paper soccer-playing robots can easily be used in education to foster understanding and interest in domains such as artificial intelligence, multimodal systems, engineering and science. Hence we have used soccer-playing robots for learning by doing education of soft computing methods. We have reported about our experience with fuzzy logic.
Our future work is focused on the expansion of soft computing methods to soccer-playing robots based on neural networks, genetic algorithms and image processing. Moreover we plan to use SONY Aibo robots for comparison the soft-computing methods of the different platforms with respect to easy implementation, better search strategies and adaption to machine learning. It is planned to report our results at international conferences and distribute new results via our website.

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