Analysis of Multi-Agent Collaborative Systems

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Abstract

A tool for the analysis of Multi-Agent Collaborative Systems is presented and demonstrated on an example of robot soccer system. The tool enables automatic filtering and selection of game sequences which are suitable for the analysis of the game. Fuzzy logic is used since the data gathered by a camera is highly noisy. The data used in the paper was recorded during the game Germany - Slovenia in Hagen. The dynamic parameters of our robots are estimated using the least squares technique. Meandering parameters are estimated and an attempt is made to identify the strategy of the opposing team with the method of *introspection*.

Keywords: Fuzzy logic, Identification, Robot navigation, Robot soccer

1 Introduction

Robot soccer is an ideal testing ground for Multi-Agent Collaborative Systems involving various technical solutions and scientific methods. In competition systems, such as robot soccer, the analysis of a game is useful for the detection of faults in the program and enables the applied algorithms to be improved. The analysis is performed based on data recorded during the game. The output of the vision system is recorded for subsequent analysis. Most robot soccer programs consist of two main parts, both of which may malfunction: the vision and strategy components. In this paper we will focus on the analysis of the strategy , which is done "manually" with the help of an off line computer aided interactive tool. Performing such an analysis is important from the competitive point of view and may be helpful for the elimination of bugs and faults in own strategy as well as for the detection of weak points in the opposing team and for the preparation of the strategy to be used in forthcoming duels.

The tool employed should automatically performed the identification of critical situations for off line analysis. This paper deals with the application of identification methods to the detection of critical situations which may be of interest for the subsequent analysis. Actually the identified parameters are kinematic parameters, but they are closely connected with the applied strategy; e.g. the time needed to kick the ball mainly depends on the speed attainable by the robot soccer player, but if the robot is unable to avoid obstacles and becomes stuck, the time mainly depends on the ability to free itself. So the well known classical identification and parameter estimation methods are unsuitable for such purposes. Modern algorithms based on artificial intelligence, such as those using fuzzy logic, are capable of coping with the nonlinearities which are an essential of robot soccer.

This paper is organized as follows: Fuzzy logic as a basic tool in decision making process will be introduced briefly in the Section 2. Data filtering using fuzzy techniques is discussed in Section 3 Analysis of the game, i.e. partitioning the game into sequences and the classification of these sequences according to the situation using fuzzy rules will be explained in Section 4. Next, the identification of the robot's dynamic parameters based on the data recorded during the game between Germany and Slovenia in Hagen on November 11, 2001 will be discussed. This data will also be referred to Section 6 where firstly a meandering factor is determined automatically for every sequence and then the method of introspection is used for evaluating both ones, own and the opponent's strategy.

2 Fuzzy logic - the mathematical tool used for solving problems

Fuzzy logic provides a means of expressing mental models in a compact mathematical form. The intuitive and heuristic nature of the human mind, which is actually quite imprecise, can be incorporated into formal models which can used to support the planning and decision making processes. Fuzzy logic is used in the described tool for solving different problems. One is the filtering of the recorded data and the other is the identification of those sequences of the game which are interesting for analysis.

Fuzzy logic has extended the classical mathematical models involving differential and difference equations, to a broad class of models that are more easily understandable. Fuzzy adaptive systems may be viewed as a framework for solving the problems associated with nonlinear system control. In recent years, a lot of effort has been put into the fuzzy identification of complex industrial plants, which can not easily be theoretically modelled.

Accurate nonlinear white-box models based on first principles, usually cannot be obtained at a reasonable cost. Therefore, data driven methods for black-box identification that require only little prior knowledge are of considerable interest. Fuzzy logic-based models can be used as general function approximations and can provide accurate prediction models for a large class of nonlinear systems.

3 Data filtering

The data (the positions of the robots and the ball) obtained by the camera and the vision module is highly noisy. On the other hand, the robots are highly manoeuvrable, so a sampling time of 40 ms, as used with our camera is quite low. So filtering with a digital low pass filter is not advisable as it may deform the dynamic model of the robot. Moreover, outliers and spikes, which cannot be removed by ordinary (e.g. Butterworth - type) filters, represent a significant problem. So fuzzy logic filters are used to remove the spikes.

Takagi Sugeno type rules where the consequence is crisp, are used and they are as follows:

R^1 :

if $\boldsymbol{\Delta} position(i,k)$ **is** $High\_positive$
and $\boldsymbol{\Delta} position(i,k+1)$ **is** $High\_negative$
then $position(i,k) = position(i,k-1)$

R^2 :

if $\boldsymbol{\Delta} position(i,k)$ **is** $High\_negative$
and $\boldsymbol{\Delta} position(i,k+1)$ **is** $High\_positive$
then $position(i,k) = position(i,k-1)$

R^3 :

if $\Delta position(i,k)$ **is** $High\_positive$
and $\Delta position(i,k+2)$ **is** $High\_negative$
then $position(i,k)$ *is* $position(i,k-1)$;
$position(i,k+1) = position(i,k-1)$

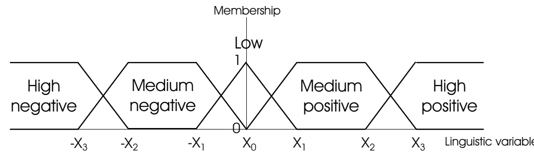

Figure 1: Membership functions for linguistic variable $\Delta position$

R^4 :

if $\Delta position(i,k)$ **is** $High\_negative$
and $\Delta position(i,k+2)$ **is** $High\_positive$
then $position(i,k)$ *is* $position(i,k-1)$;
$position(i,k+1) = position(i,k-1)$

where

$$\boldsymbol{\Delta} position(i,k) = position(i,k) - position(i,k-1)$$

and i is the number of the robot. The membership functions for the linguistic variable $\boldsymbol{\Delta} position$ are given in Fig. 1. Several parameters of the membership functions were tested; the best results were obtained with $x_2 = 0.9\ m/s$ and $x_3 = 1.1\ m/s$

4 Analysis of the game

In the proposed analysis tool the first step in the analysis of a robot soccer game is the partition of actions into sequences. A sequence is a fragment of the game between two successive ball kicks. Firstly each fragment of the game (called an event or activity) is classified according to several criteria such as its dynamics. The activities are classified as being either static, where two or more robots are clustered together around the ball or one robot is pushing the ball against the wall, or dynamic. Dynamic activities are further classified into activities near the wall and activities where the wall does not represent an obstacle. In the method used for the detection of the ball kick and in all classifications, a knowledge based fuzzy classification is used. Some of the fuzzy rules used for the classification of the activities are given as follows:

R^5 :

if $\min_i\{Dist\_Robot\_Ball(i,k)\}$ **is** Low
then $Activity\_type(k)$ *is* **Ball_Kick**

R^6 :

$$\begin{array}{ll}
\textbf{if} & \min\limits_{i,j,i\neq j}\{Dist_between_Robots(i,j,k)\}\ \textbf{is}\ Low \\
\textbf{and} & \max\limits_{i}|\Delta position(i,k)|\ \textbf{is}\ Low \\
\textbf{and} & \mathbf{Dist_Robot_Ball(i_{min},k)}\ \textbf{is}\ Low \\
\textbf{then} & \quad Activity_type(k) \quad = \quad \textbf{Static}
\end{array}$$

R^7 :

$$\begin{array}{ll}
\textbf{if} & \min\limits_{i}\{Dist_Robot_Wall(i,k)\}\ \textbf{is}\ Low \\
\textbf{and} & \min\limits_{j}\mathbf{Dist_between_Robots(i,j,k)}\ \textbf{is}\ Low \\
\textbf{and} & \max\limits_{i}|\Delta position(i,k)|\ \textbf{is}\ Low \\
\textbf{and} & \min\limits_{i}\{Dist_Robot_Ball(i,k)\ \textbf{is}\ Low \\
\textbf{then} & \quad Activity_type(k) \quad = \quad \textbf{Clinch}
\end{array}$$

R^8 :

$$\begin{array}{ll}
\textbf{if} & \min\limits_{i}\{Dist_Robot_Wall(i,k)\}\ \textbf{is}\ High \\
\textbf{and} & \min\limits_{j}\mathbf{Dist_between_Robots(i,j,k)}\ \textbf{is}\ High \\
\textbf{then} & \quad Activity_type(k) \quad = \quad \textbf{Free_run}
\end{array}$$

The membership functions shown in Fig. 2 are used for the linguistic variables **Dist_Robot_Ball**, **Dist_between_Robots** and **Dist_Robot_Wall**. This part of the tool is not fully realized yet, in fact only the rules R^5 and R^8 have been realized so far with the parameters given in table 1. Also the orientation of the robots has yet to be taken into consideration.

Activities are joined together into sequences. A sequence is a set of successive activities of the same type, with the type of activity determining the type of the sequence. Sequences are further classified into short and long ones. Again a knowledge based fuzzy classification is used and some rules are given as follows.

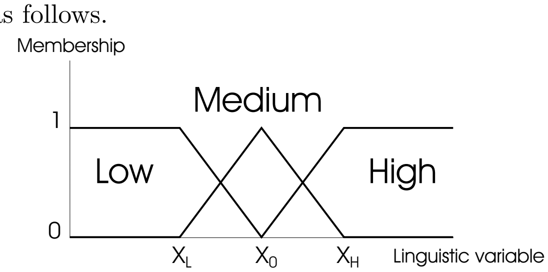

Figure 2: Membership functions.

Table 1: Parameters of the membership functions.

Membership function	$x_0[m]$	$x_H[m]$
Dist_Robot_Ball	0.055	0.075
Dist_Robot_Wall	0.035	0.055
Dist_between_Robots	0.075	0.110

R^9 :

$$\begin{array}{ll}
\textbf{if} & Activity_type(k)\ is\ Sequence_Type(k-1) \\
\textbf{then} & \quad Sequence_Type(k) = Sequence_Type(k-1) \\
\textbf{else} & \quad Finish_Current_Sequence; \\
 & \quad Start_New_Sequence; \\
 & \mathbf{S}equence_Type(k) = Activity_type(k)
\end{array}$$

Long sequences in the middle of the playground are suitable for the automatic identification of parameters.

5 Identification of Robot's dynamic parameters

The movement of the robot in radial and circular directions can be approximated using linear transfer functions of the form

$$\begin{aligned}
G_p(z) &= \frac{B(z^{-1})}{A(z^{-1})}z^{-d} \\
&= \frac{b_1 z^{-1} + \ldots + b_n z^{-n}}{1 + a_1 z^{-1} + \ldots + a_n z^{-n}}z^{-d}
\end{aligned} \tag{1}$$

where n is the order of the system and d is the delay. By transforming the transfer function (1) in the time domain, the output (radial and circular velocity, respectively) can be written in the following vector form

$$y(k) = \psi^T(k)\theta + v(k) \tag{2}$$

where the vectors ψ and θ are defined as

$$\begin{aligned}
\psi^T(k) &= [-y(k-1), \ldots, -y(k-n), \\
&\quad\ u(k-d-1), \ldots, u(k-d-n)] \\
\theta^T &= [a_1, \ldots, a_n, b_1, \ldots, b_n]
\end{aligned} \tag{3}$$

The corresponding model can be written in the form

$$\hat{y}(k) = \psi^T(k)\hat{\theta} \tag{4}$$

where

$$\hat{\theta}^T = [\hat{a}_1, \ldots, \hat{a}_n, \hat{b}_1, \ldots, \hat{b}_n] \tag{5}$$

is the estimate of the parameters. By defining the error of the model

$$e(k) = y(k) - \hat{y}(k) \tag{6}$$

the basic equation for the least squares estimate is obtained. The estimate in the least squares sense is

$$y(k) - \psi^T(k)\hat{\theta} = e(k) \tag{7}$$

$$\hat{\theta} = [\mathbf{\Psi}^T\mathbf{\Psi}]^{-1}\mathbf{\Psi}^T\mathbf{y} \tag{8}$$

Only **Free_run** sequences are used for identification. Obviously, only the dynamic parameters of the home robots can be estimated, since the commands for the opponents' ones are not known. Data recorded during the game between Germany and Slovenia in Hagen on November 11, 2001 is used, and the resulting transfer functions for the radial and circular velocities are

$$G(z) = \frac{0.08446z^{-1} + 0.7618z^{-2} - 0.5218z^{-3}}{1 - 0.1934z^{-1} - 0.2827z^{-2} - 0.1892z^{-3}} \tag{9}$$

and

$$G(z) = \frac{0.07063z^{-1} + 0.3725z^{-2}}{1 - 0.2826z^{-1} - 0.1956z^{-2}} \tag{10}$$

respectively.

6 Analysis of the strategy

Robot soccer is in principle a well defined system, however there is also some uncertainty to be considered such as the strategy of the opposite team. So a gray box model seems to be applicable for such purposes.

In each sequence,the player who wins the race for the ball and kicks it (in sequel this player will be referred to as the winner), is identified. Suitable sequences are then classified according to scenario. Typical scenarios are:

- At the beginning of the sequence two or more robots including the winner are clustered together in a group (hustle). The winner gets free of this group and kicks the ball after a **Free_run**.
- The winner kicks the ball during an unrestrained run.
- The winner is moving at the beginning of the sequence, but standing still when the ball reaches him (typical for the goalkeeper).

For the classification of the different scenarios, the sequence of sequences is deciding. For each of these scenarios, some parameters can be identified, such as meanders in an unrestrained free run, the ability to get out of a hustle, etc. This part of the tool is not realized yet. Only meandering in a free run is estimated, as shown in table 2 where the data from the game Germany - Slovenia is used once again.

Actually the identification of the opponent's strategy is the final goal of our tool. For this purpose the method of *introspection*, a well known method in psychology, is used. The basic principle of this method is the question: *What would I do if I were in my opponent's shoes?* With this method, first the principle and the dynamic model of the robots is tested with our own strategy using our own robot which is closest to the ball (this was our strategy in the game, which was used for the analysis). Actually, this provides a means of verifying the method.

The results of the method are shown in Figs. 3 to 5. In all of the figures Slovenia is playing from left to right, since our software is oriented like this. The original path of the robot and the resultant path after the application of our strategy (the same as during the game) are depicted by $\times$ and $+$ respectively. Good coincidence of both paths can be established. This justifies the proposed method of introspection. In figures also the animation can started by pressing the corresponding button, the time scale of the animation can be adjusted using the slider and the strategy to be used can be selected.

After verification the same method is applied to the robots of the opponent team. The same sequences are used as with verification and shown in Figs. 6 to 8. It can be stated that our strategy was superior to that of our opponents. This was confirmed by the result of the two games (2:11 and 2:15 respectively).

7 Conclusion

A tool which can be used for the analysis of a robot soccer game was presented. The tool enables automatic filtering and selection of game sequences which are suitable for the analysis of the game. Fuzzy logic is used since the data gathered by a camera contains much noise. The data recorded during the game Germany - Slovenia in Hagen, on November 11, 2001 is used. The dynamic parameters of our own robots are estimated using the least squares technique. Meandering parameters are estimated and an attempt is made to identify the strategy of the opposing team with the method of *introspection*. The tool is not completed yet, and

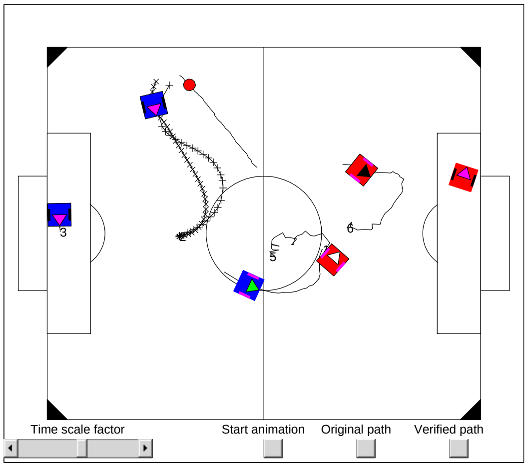

Figure 3: Verification 1. sequence

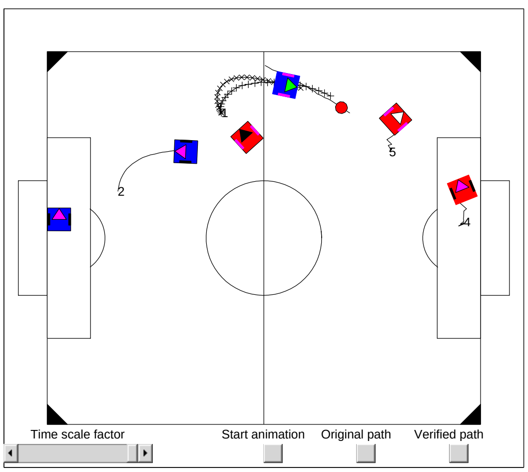

Figure 4: Verification 2. sequence

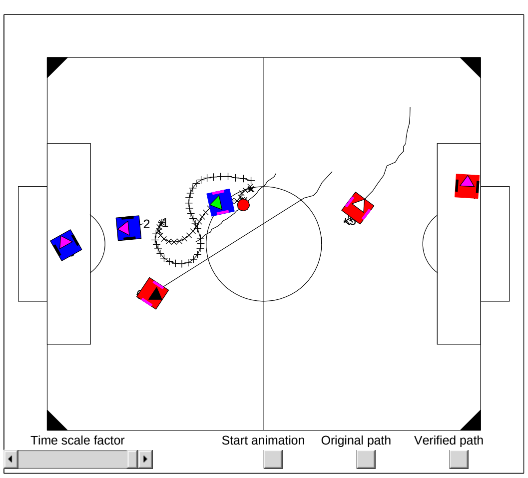

Figure 5: Verification 3. sequence

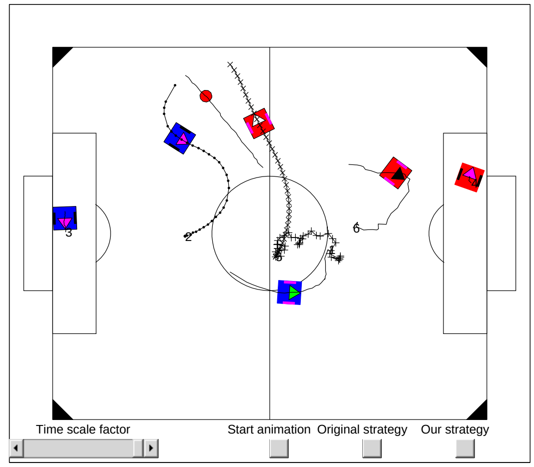

Figure 6: Introspection 1. sequence

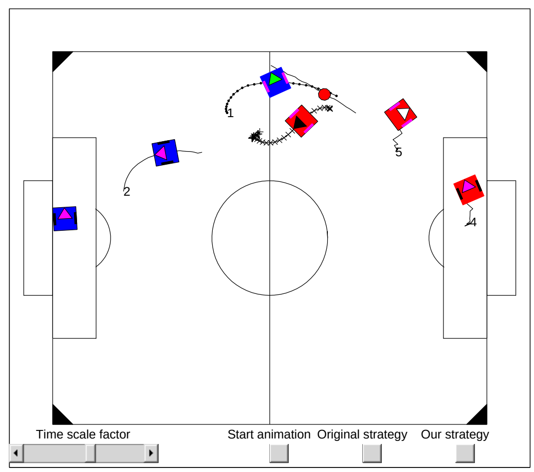

Figure 7: Introspection 2. sequence

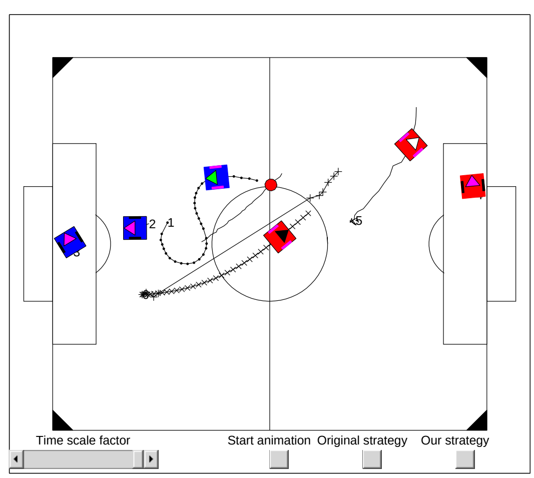

Figure 8: Introspection 3. sequence

much work remains to be done, e.g. to improve the rules used for the automatic selection of sequences.

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Table 2.: Estimation of the meandering factor.

Sequence No. : 1 Sequence Type : Free_Run Sequence duration: 1.52 s The winner is: 2 The distance attained by the ball: 0.4263 m Average speed: 0.28046 m/s						
Robot No. 1-3=Slovenia, 4-6=Germany	1	2	3	4	5	6
The path accomplished by robots:	0.47373	0.71714	0.08142	0.04956	0.65398	0.58651
Optimal path accomplished by robots:	0.35014	0.52914	0.07310	0.02010	0.22375	0.22326
Meander factor:	1.35297	1.35529	1.11378	2.46574	2.92278	2.62708
Sequence No. : 2 Sequence Type : Free_Run Sequence duration: 3.28 s The winner is: 6 The distance attained by the ball: 1.0744 m Average speed: 0.32757 m/s						
Robot No. 1-3=Slovenia, 4-6=Germany	1	2	3	4	5	6
The path accomplished by robots:	1.39420	0.95137	0.08724	0.73534	2.01726	1.67217
Optimal path accomplished by robots:	0.56434	0.24595	0.02928	0.36059	0.54602	0.28087
Meander factor:	2.47047	3.86815	2.97945	2.03925	3.69445	5.95362
Sequence No. : 3 Sequence Type : Free_Run Sequence duration: 0.96 s The winner is: 1 The distance attained by the ball: 0.34091 m Average speed: 0.35511 m/s						
Robot No. 1-3=Slovenia, 4-6=Germany	1	2	3	4	5	6
The path accomplished by robots:	0.44600	0.34321	0.01480	0.29426	0.24299	0.17907
Optimal path accomplished by robots:	0.38223	0.30390	0.00273	0.10859	0.11554	0.00517
Meander factor:	1.16684	1.12937	5.43163	2.70980	2.10309	34.6638