DESIGNING VISION BASED AUTONOMOUS DOCILE-X MOBILE ROBOT FOR REAL-TIME APPLICATION TO SOCCER BEHAVIORS

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Abstract:
This paper aims at developing a real-time, robust, and reliable behaviors for an omnidirectional soccer robot, can be used in crowded dynamically-changing environments. The soccer robot system consists of highly coordinated operations and movements so as to fulfill specific objectives, even under unfavorable situations. The associated issues are position control, velocity control and sensing information in addition to the need for imitating the human-like decision. The proposed method considers not only the kinematics of the robot but also its dynamics. Moreover, a control structure is designed and several behaviors for a soccer robot are proposed. Image processing, recognition and target following algorithm are illustrated through experiments.

Keywords*: autonomous soccer robot, control structure, image processing, decision behaviors, Kalman filter*

1. Introduction

From the standpoint of soccer robot systems, a soccer game is a good example of the problems in real world, which can be moderately abstracted. We have chosen soccer as one of the standard problems for the study on soccer robot systems. Robotic soccer is an active research domain in Artificial Intelligence (AI) and robotics research [1, 2].

The robotic soccer provides a good test bed for evaluation of various theories, algorithms, and intelligent system architectures. Through the research for accomplishing this task, a number of technical breakthroughs for AI and robotics are expected to be solved. So far, various problems have been solved with new theories and algorithms for controlling [3], planning and so on.

Additionally, it is an attempted to foster AI and intelligent robotics research by providing a standard range of technologies that can be integrated and examined. Generally, contemporary robotic systems involved large amounts of expensive, special purpose hardware for motor control system, velocity control, position control and local information sensing [4]. A fundamental ability of an autonomous soccer robot is to plan collision-free trajectories from a start to a goal position among a collection of stationary/moving obstacles. This paper describes a vision based autonomous mobile robot and its control structure, which can be easily operated. The important features of this soccer robot system are that this platform consists of driving, visual sensing, sensors, motor control, communication and decision behaviors. The last characteristics is essential in the system to perform well when using it under unfavorable situation.

To evaluate the developed system, some behaviors for playing soccer and visual segmentation method and tracking algorithms based on color information have been implemented.

2. System Specification

The control structure of this system was designed in such a way that simplifies its usage not only in a variety of task but also on different hardware platforms.

The robotic soccer, which has been designed is much simpler than the complex and expensive autonomous soccer robot but still it has the entire standard components and functionality in order to fulfill the research assumption data and learning outcomes. In this system, the robot has its own driving mechanism, communication part and a microcontroller board. The computational part controls robot's velocity according to the command data received from a host computer. All calculations of vision data processing, strategies, position control of robot and so on are done in the host computer.

2.1. Design Architecture of Soccer Robot

The design philosophy is to realize autonomous soccer robot with various functions, so that they can be used not only in soccer game but also in a lot of other applications as well. The designed soccer robot has body frames and CMOS-type devices are used to power consumption. The complete robot size is

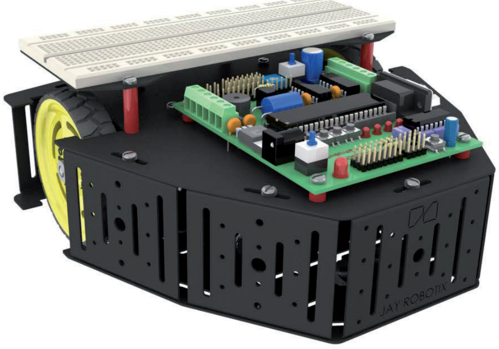


Fig. 1 (a). Autonomous soccer robot [6]

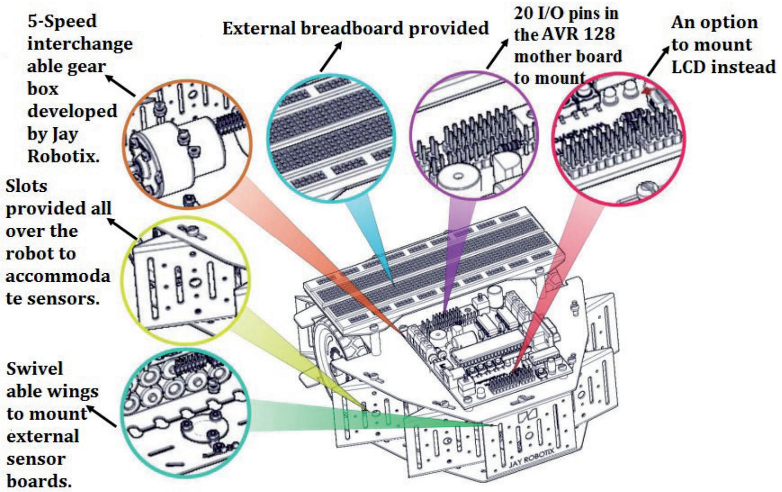


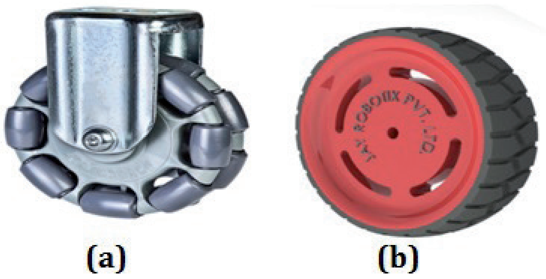
Fig. 1 (b). Architecture view of the soccer robot [6]

within 8 cm^3. The microcontroller, three side IR sensors and the caterpillar moving mechanism make it possible to control the robot's motion with obstacle avoidance and other intelligent behaviors.

It is design in such a way that it will be useful in other applications as well. The design philosophy of commercially accessible Docile-X autonomous soccer robot (in Figure 1(a) is shown in Figure 1(b).

2.2. Driving Design

The driving system of the mobile robot allows it to move successfully in the various tasks and therefore, must provide adequate speed, acceleration and maneuverability. Two different driving systems were considered in this work: an omnidirectional driving system and a differential driving system [11].



(a) (b)

Fig. 2. Two different driving wheels [17, 6]

The robot is modeled as a rigid body on wheels, operating on a horizontal plane. The total dimensionality of the robot chassis on the plane is three: (a) two for position in the plane, (b) one for orientation along the vertical axis – orthogonal to the plane [19]. The global reference frame is given by the inertial basis {O, XI, YI} and the robot local reference frame is given by {P, XR, YR}. The position of the P is the global reference is given by coordinate x and y, and the angular difference between the global and local frames is given by θ.

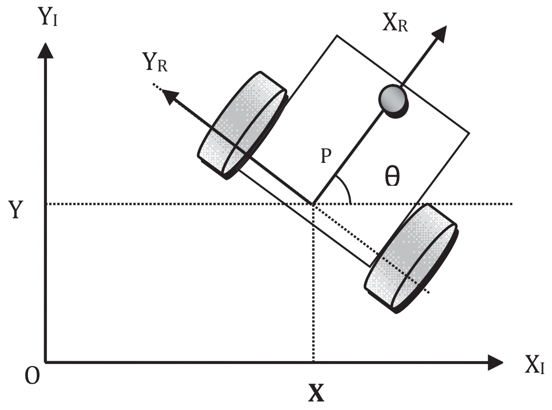


Fig. 3. Representing robot pose

The pose and velocity is describe by

$$\varepsilon_I \triangleq \begin{bmatrix} x \\ y \\ \theta \end{bmatrix},\ \dot{\varepsilon_I} \triangleq \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix},$$

respectively.

The mapping between the velocity in the global reference $\{O, X_I, Y_I\}$ and the velocity in the robot local reference frame $\{P, X_R, Y_R\}$ can be accomplished using orthogonal rotation matrix:

$$R(\theta) \triangleq \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix},\quad R^T R = R R^T = I\,.$$

This matrix can be used to map the motion in the frame $\{O, X_I, Y_I\}$ to motion in the frame $\{P, X_R, Y_R\}$

$$\dot{\varepsilon_R} = R(\theta)\ \dot{\varepsilon_I} = R\ (\theta) \cdot \left[\dot{x}, \dot{y}, \dot{\theta}\right]^{T}, \qquad (1)$$

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[1] The Docile-X mobile robot has been designed in the Jay Robotix Pvt Ltd (R&D) Lab, Hyderabad, India.

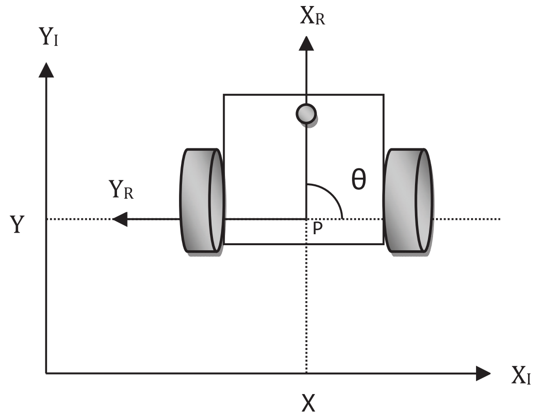

Fig. 4. Representing robot pose and velocity

$$\varepsilon_R = R\left(\frac{\pi}{2}\right)\varepsilon_I \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \dot{y} \\ -\dot{x} \\ \dot{\theta} \end{bmatrix}. \qquad (2)$$

2.3. State-space Model of Soccer Robot

The science of robotics is about synthesizing motion- in the environment, using a robot. To synthesize motion, we need to understand what it is (i.e. structure) and how to describe it – an overview of basic techniques for describing motion. The mobility analysis of the mobile robot can be reformulated in to state-space form. Mobile robot can move unbound with respect to its environment:

a) there is no direct way to measure the robot's pose instantaneously,
b) robot motion must be intregrated with time,
c) leads to inaccuracies of the motion estimation due to slippage.

The goal of the kinematic model of the state-space representations is to describe the behavior of the wheeled robots and for control design. The kinematic modeling is used to established the robot speed [20], $\dot{\varepsilon} = [\dot{x}, \dot{y}, \dot{\theta}]^T$ as a function of wheel velocity $\dot{\varphi}_i$, steering angle β_i, steering speed $\dot{\beta}_i$ and geometric parameter of the robot. The robot pose and speed in global frame:

$$\varepsilon_I \triangleq \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}, \ \dot{\varepsilon}_I \triangleq \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}.$$

The transformation R between two frames:

$$\dot{\varepsilon}_R = R(\theta)\dot{\varepsilon}_I, \ \dot{\varepsilon}_R = R(\theta)^{-1}\dot{\varepsilon}_I.$$

The velocity in the local coordinate frame:

$$\dot{\varepsilon}_I \triangleq \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \vartheta \\ \omega \end{bmatrix},$$

where ϑ is the linear velocity and ω is the angular velocity. The transformation between two frames shown in Figure 5.

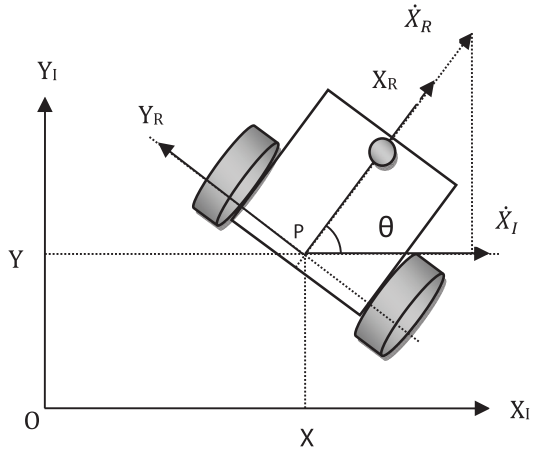

Fig. 5. Differential drive with velocity mapping

The $\dot{X}_I$ velocity component,

$$\dot{X}_I = \dot{X}_R \cos\theta$$

Whatever type of robot, the velocity vector $\dot{\varepsilon}(t)$ is restricted to belong to a distribution Δ_c define as,

$$\dot{\varepsilon}(t) = \Delta_c \triangleq span\{col[R^T(\theta)B(\beta_s)]\} \qquad (3)$$

Where the columns of the matrix $B(\beta_s)$ constitute a basis of the null space $N(C_1 * (\beta_s))$.

2.4. Sensing System

There are several methods for robot to reckon its position: (1) the location of the robot in the environment; (2) the location of the objects; (3) whether the robot has the object or not. The most standard method, somewhat indirect, but a useful way is done by vision camera. Despite its usefulness of getting precise location and orientation of the objects on the field, its relatively long processing time inhibits the user from using the vision system alone.

Seven IR sensors on the three sides of the soccer robot are used for obstacle detection (in Figure 6).

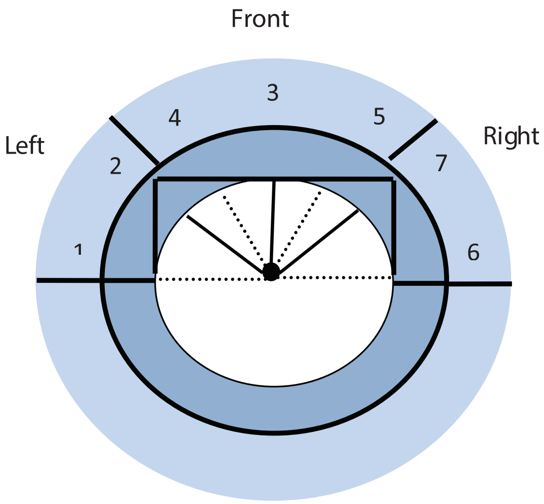

Fig. 6. Sensors for obstacle detection and their ranges

The obstacles in such discrete distances as 18 (very far), 10 (far), 5 (close) can be detected by just one pair of sensors. Linguistic sensing makes it easy to realize artificial intelligence approach.

2.5. Communication

According to the soccer game rules, robot must not be wired, so RF-digital communication system is necessary. The robot uses the full duplex-mode RF-digital communication. The communication between robots facilitates performing the design objectives. Communication deadlock may happen when the amount of information increases, so communication strategy and protocol was carefully designed.

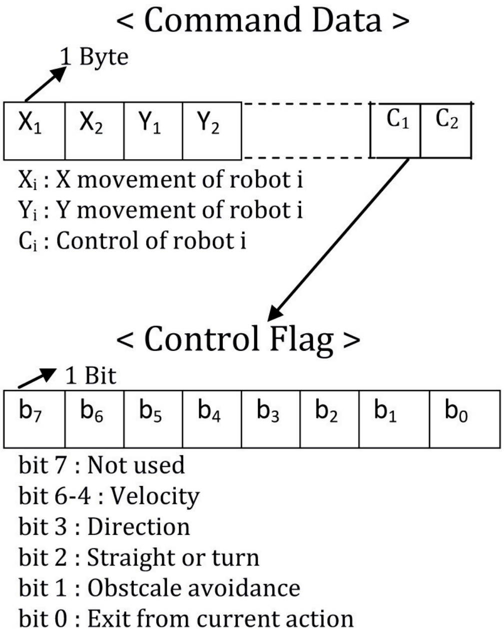

Fig. 7. Communication protocol for vision-based soccer robot system

Figure 7 shows the communication protocol used to command robots from the host computer through RF modem for the vision-based soccer robot system. Three bytes assigned for robot of which two bytes are used to movements in x and y directions. The third byte is used as a flag representing 'robot's velocity', 'direction', 'straight or turn', 'enable obstacle avoidance' and 'exit from current action'. Because of size limitation, the robot may not be show fully autonomous behaviors with the current technologies. The vision system [10] will be helpful to improve the performance and the intelligence of the total system. In the vision-based soccer robot system, it should have the capabilities to do some processing on strategies as well as for calculating locations of the object (i.e., ball) and the robot.

2.6. Vision-based Soccer Robot System

The vision-based soccer robot system can be considered as a system at an intermediate level between the remote-brainless and the robot-based system. In the vision-based system, the robots should have functions such as speed control, position control, obstacle avoidance and so on. The host computer processes vision data and calculates the position of the robot and the object (i.e. ball) and processes various behaviors according to strategies and sends commands to the robot using RF-modem. The robot makes his move according to these commands keeping away from obstacles. The robot has to have sensors for position control (encoders) and obstacle avoidance (IR sensors).

Basically in this soccer research, we looked at the various positions of the camera [8]. Generally, the position can be divided into:

- Global vision where the camera is positioned overhead and should cover the whole environment.
- Local vision, popularly known as onboard camera on the robot soccer, where the camera is positioned on the robot itself and also moved with the robot too.

The visual sensing in a soccer robot system plays an important role in acquiring visual information and recognizing it [21]. The soccer robot can detect and following the object, based on the images taken by the on-board camera. Camera must cover wide range of view. Since the robot soccer has such sensing capabilities, it can find an object by moving its camera head without moving its body. The host computer processes vision data on the position of the object (i.e. ball) and robot and forwards the same to the robot. The robot decides its own behavior autonomously using the received vision data, its own sensor data and strategies. This can be considered as a distributed control system.

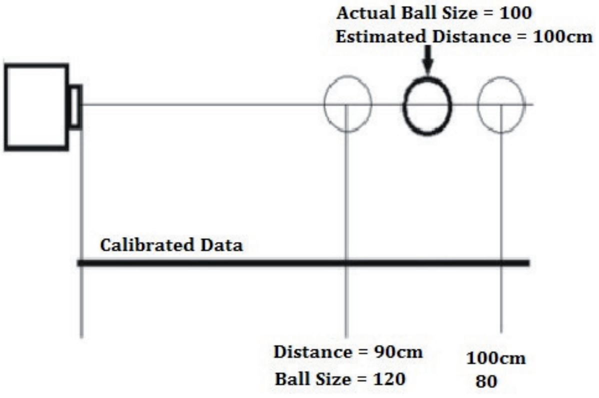

Fig. 8. Monocular vision depth estimation

2.6. Control Structure

In the soccer robot system when robot position, orientation and distance from the object (i.e. ball) are known, algorithm determines what robot should do [7]. Taking in to account, the task of the design system is necessary to determine the effectors and receptors and also determined the number of task assign to them (take into account the transmission delays and the necessary computational delays). The control system needs to define initial condition for each of behaviors along with transition function and terminal condition [18]. Two behaviors can be considered in soccer applications: a) tracking an object using the moving camera, b) detecting obstacle using sensors.

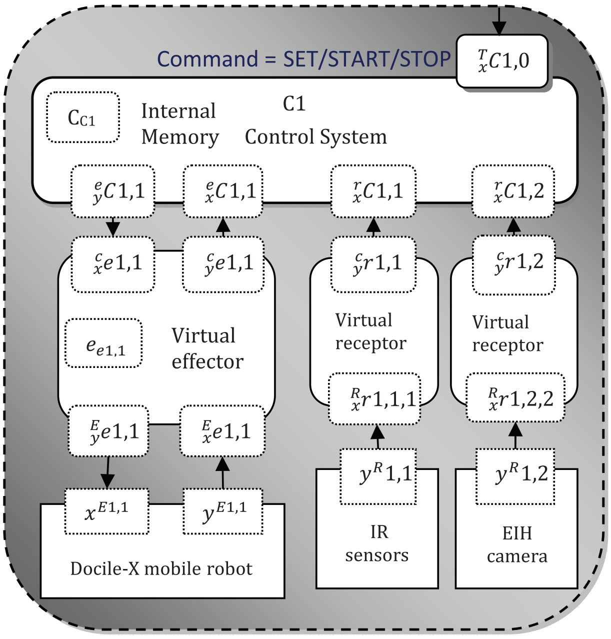

Fig. 8. Structure of control system agent [22]

There are two receptors in our agent, as there are two sets of real receptors, (1) IR sensors, (2) EIH camera. The virtual receptor that interfaces the IR sensors with the controller converts the readings of all the seven sensors in a form that controller understands. Similarly the virtual receptor that interfaces the EIH (Eye-In Head) camera with the controller converts the reading from the camera to real angles that is interpreted by the controller.

Virtual Receptors Buffer:

- ${}^{c}_{y}r1,1$ – [t_s] = word containing the status of all seven IR sensors,
- ${}^{c}_{y}r1,2$ = current orientation of the agent in radians,
- ${}^{R}_{x}r1,1,1$ – [t_s^F, t_s^L, t_s^R] = output of the sensors,
- ${}^{R}_{x}r1,1,2$ – [${}^{C}I_{RGB}$] = retrieve camera image.

The virtual effector that interfaces controller and real effectors of our robot perform two functions, instead of it receives from the current position, computes change in position of the robot caused by the effector (wheel) during the sampling time gap and provides the data to the controller, the virtual receptors also compute rotation of either wheels and provides appropriate current and regulate the wheels to the required velocities based of the desired linear and angular velocities provide by the controller.

Virtual Effectors Buffer:

- ${}^{c}_{x}e1,1$ = [V_{des}, W_{des}] – desired linear and angular velocities,
- ${}^{c}_{y}e1,1$ = change in position,
- ${}^{E}_{x}e1,1$ = current position readings,
- ${}^{E}_{y}e1,1$ = signal corresponding to the desired rotational speed of the wheels,
- $e_{e1,1}$ = change in position along the current direction of the soccer robot.

Control system receives data from the virtual receptors & transmission buffer and sends control signal to the virtual effectors. Following are the control system buffers:

- ${}^{T}_{x}C1,0$ = commands received (SET or START/STOP) in the form of single word,
- ${}^{e}_{x}C1,1$ = current planner position of the soccer robot (in terms of *X* and *Y* co-ordinates),
- ${}^{e}_{y}C1,1$ = desired velocities (linear and angular) of the soccer robot,
- ${}^{r}_{x}C1,1$ = IR sensors status word,
- ${}^{r}_{x}C1,2$ = orientation of the soccer robot data obtained from vision sensing system,
- C_{C1} = internal memory data – contains the current planner postion of the soccer robot.

2.7. Behaviors of the Agent

From the problem statement, it is deduced that there is only one agent in our system, i.e. the soccer robot with the given specification, which is going to perceive its environment and acts upon that environment, having an internal imperative to realize a certain task. This agent is an embodied agent, which is capable of perceiving its environment through receptors (IR sensors and EIH camera), acts upon that environment through effectors (wheels), having an internal urge (control system) to attain a certain goal (to reach the given goal point).

The following behaviors of the agent are defined:

(a) Idel: This behavior is shown by the agent under any of the three conditions:
  1. When the agent is powered on, until it receives START and SET command.
  2. When the agent is given STOP command.
  3. Once the agent reached the goal.

In this behavior, all the other behaviors are muted/terminated. This behavior supersedes all the other behavior of the agent.

(b) Turn along vertical direction (TAV): This behavior is shown by the agent under the following conditions:
  1. When the agent receives START command and the robot is at (0,0) and Y (goal) < X (goal) & (Y (goal) – Y (current)) ≠ 0. Or
  2. When the current orientation of the agent is aligned along X direction and the front IR sensors hits a obstacle and none of the other sensors are activated. Or
  3. When ((X (goal) – X (Current)) is 0 and ((Y(goal) – Y(current)) is not equal to zero and none of the sensors are activated.

(c) **Turn along horizontal direction (TAH):** This behavior is shown by the agent under the following conditions:
  1. When the agent recieves START command and the robot is at (0,0) and (X (goal) – X (current))< (Y (goal) – Y (current)) & (X (goal) – X (current)) ≠ 0. Or
  2. When the current orientation of the agent is aligned along Y direction and the front IR sensors hits a obstacle and none of the other sensors are activated. Or
  3. When ((Y (goal) – Y (Current)) is 0 and ((X(goal) – X(current)) is not equal to zero and none of the sensors are activated.

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[2] The study of the control system has been adopted from the topic 'Robot Programming Method'.

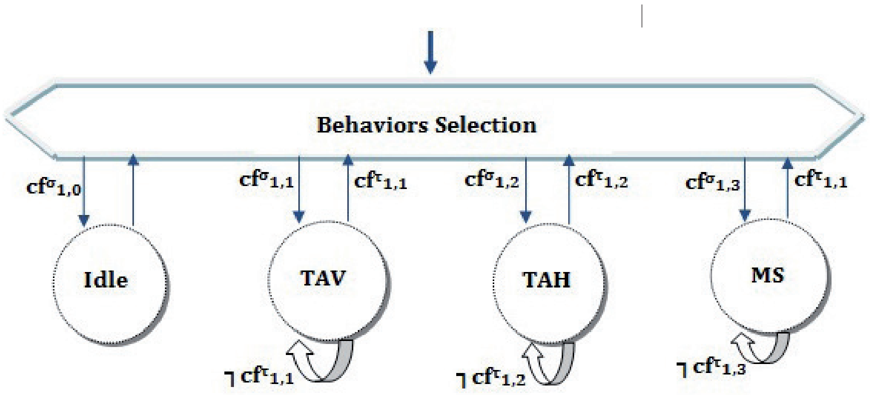

Fig. 9. Finite state automation of agent's behavior

(d) **Move straight (MS)**: This behavior is shown by the agent when none of the other states are true.

Initial conditions and terminal conditions of the agent (i.e. soccer robot) for the above behaviors are calculated from the following (in Figure 9), are derived in the mathematical equations,

1. **Initial conditions**:

$cf^{\sigma}_{1,0}$: (Ygoal = Ycurr ∩ Xgoal = Xcurr) U
(command = STOP)

$cf^{\sigma}_{1,1}$: $(Y_{goal} < X_{goal} \cap \text{command} = \textbf{START} \cap \neg X_{curr} \cap \neg Y_{curr} \cap Y_{goal} - Y_{curr} \neq 0) U (\alpha = 0 \cap t_{front} = 1 \cap \neg (t_{right} U t_{left})) U (\neg (X_{goal} - X_{curr}) \cap (Y_{goal} - Y_{curr} \neq 0) \cap \neg (t_{front} U t_{right} U t_{left}))$

$cf^{\sigma}_{1,2}$: $(X_{goal} < Y_{goal} \cap \text{command} = \textbf{START} \cap \neg X_{curr} \cap \neg Y_{curr} \cap X_{goal} - X_{curr} \neq 0) U (\alpha = \frac{\pi}{2} \cap t_{front} = 1 \cap \neg (t_{right} U t_{left})) U (\neg (Y_{goal} - Y_{curr}) \cap (X_{goal} - X_{curr} \neq 0) \cap \neg (t_{front} U t_{right} U t_{left}))$

$cf^{\sigma}_{1,3}$: $\neg cf^{\sigma}_{1,2} \cap \neg cf^{\sigma}_{1,1} \cap \neg cf^{\sigma}_{1,0}$

2. **Terminal conditions**:

$cf^{\tau}_{1,0}$: command = **START** U $(X_{goal} \neq X_{curr} U Y_{goal} \neq Y_{curr})$

$cf^{\tau}_{1,1}$: command = command = **STOP** U (i = N)

$cf^{\tau}_{1,2}$: command = **STOP** U (i = N)

$cf^{\tau}_{1,3}$: command = **STOP** U $(t_{front} U t_{right} U t_{left}) U \neg (X_{goal} - X_{curr}) U \neg (Y_{goal} - Y_{curr})$

3. A Novel Image Processing Algorithm

In this section, we introduced a novel approach for image processing algorithm, which identifies the ball, wall and goal from image gathered in real time vision [8]. In many fields of robot vision applications, the camera platform may be mobile such as vehicle and airplane platform. Because of the camera movement, the images captured by the mobile platform will be changed in translation and rotation, which causes many difficulties in the applications like image displaying, image understanding and target tracking. Therefore, detecting and compensating the global image movement is very important task.

3.1. Color-based Image Processing

An image is considered as a raw data, which we need to process by some image processing method until we get the correct information that is required. Processing the image is a very complex task [9,10]. Fortunately, there are many computer vision libraries that simplify image processing algorithms. In this work, we used OpenCV (Open Computer Vision) packages for image processing to deal with it. Even though an image that is obtained in real time vision, the concept behind the process is the same in which the obtained vision is divided in to multiple frames, and each frame needs to be processed. Each frame is then considered as an image and is processed as a still image. Based on the single still image concept, each image is compared to identify the object of interest. There are many color based object detection methods, which have been researched. We choose in this work '*Y-U-V*' color format.

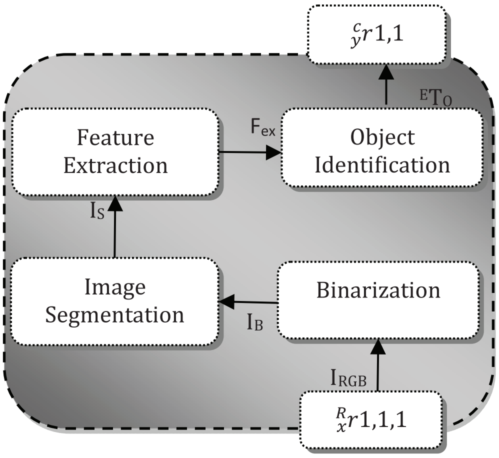

Fig. 10. Visual receptor transition function

The robustness of the object recognition for a specific color format is crucial for the robot soccer. It is impossible to use RGB color space to recognize the objects with specific color. In general, it is possible to use *Y-U-V* color format in different lighting variations. For the *Y-U-V* image format [4], three components are separated into three planes. The *Y-U-V* is different from *RGB*. The *RGB* contains the image information of three large color channels, and the *Y-U-V* deals with one brightness or luminance channel *Y* and two color or chrominance channels C_r and C_b, respectively. When $Y\ C_r C_b$ data is being packed as a *Y-U-V* packing, the C_r component is packed as *U*, and the C_b component is packed as *V*. Each C_r or C_b contains the information of four neighboring pixels (a two-by-two square of the image). For instance: $C_r O$ belongs to *Y'00*, *Y'O1*, *Y'10*, and *Y'11*. Note that the *Y-U-V* and *RGB* can be converted.

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3 The basic idea of emboided agent's behaviors has been studied from this paper http://staff.elka.pw.edu.pl/~czielins/hab.pdf

The upper bound of the Y-U-V band-pass thresholds is indicated as (YU_j, UU_j, VU); the lower bound of the Y-U-V band-pass thresholds is indicated as (YL_i, UL_i, VL_i). The formulas to determine the Y component band-pass thresholds are indicated in equation (4) to (6). Where i is also the index of interested objects, YM_j is the mean value of component Y for object i. $Y\varepsilon_i$ is the tolerance value of component Y for object i. The U and V components can also be determined in the following manner,

$$YM_i = (\textstyle\sum_{i=0}^{10} Y\, i,j)/10, \tag{4}$$

$$YU_i = YM_i + Y\varepsilon, \tag{5}$$

$$YV_i = YM_i - Y\varepsilon_i. \tag{6}$$

The color characteristics then return and the established of Y-U-V ranges directly to the color definition, Figure 10 shows accurate result,

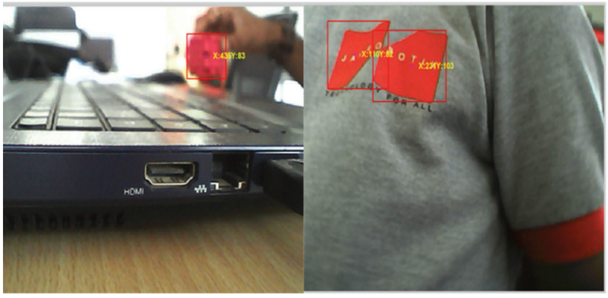

Fig. 11. Color based object using monocular vision

In order to obtain more accurate results in future, we are also drawing our interest on clustering methods. Clustering techniques seek to divide a set of data into groups or clusters [12]. This is also used to determine the location and size of the robots, once segmentation is completed.

4. Trajectory Tracking

However, when it comes to tracking an object with a soccer robot, the image processing can be done using many methods/algorithms. The most commonly used algorithms are listed below:

1) Kalman Filter,
2) CAM shift (Continuously adaptive Mean),
3) Optical Flow.

The proposed soccer robot is capable of working with the above mentioned three methods. Our work adopted the Kalman filter method [14]. Introduced by Kalman back in 1960 in his famous paper titled "A new approaches to filtering and prediction problems". Kalman filter (KF) has been extensively researched especially in the area of autonomous navigation and assisted guidance, specifically in robotics. It is described as "optimal" because it considers all information that can be provided to estimate the current value of the variable of interest, by using:

- Knowledge of the system and measurements' devices dynamics;
- The statistical description of the system noises, measurement errors and uncertainty in the dynamics models;
- Any available information about initial conditions of the variables of interest.

In the field of soccer robot, many papers have been published and it has been widely researched. Used in vision processing and localization, KF is the algorithm of choice, sometimes along with other algorithms to improve the efficiency [15]. Some of the research articles have focused on the use of KF in multi-object tracking where the process of tracking multiple moving objects was implemented successfully.

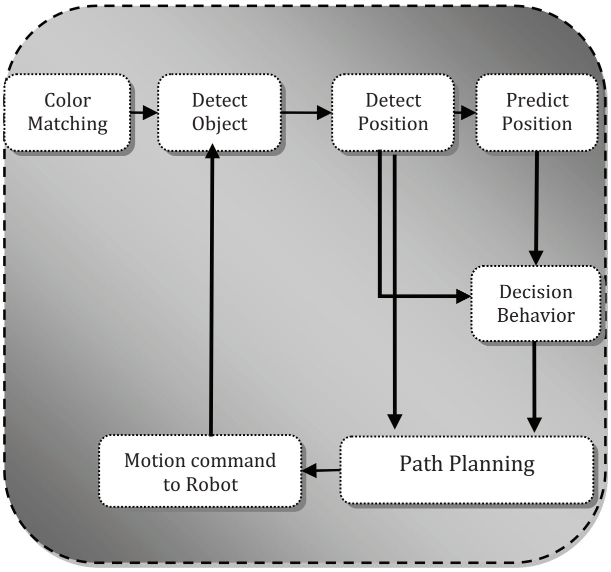

Fig. 12. Trajectory tracking scheme

The Kalman filter works by estimating a process using feedback information. Firstly, the filter estimates the process state at time k and obtains measurement feedback. To pictorially represent the equations involved in this cycle, it can be divided into two groups: "Time update" equations and "Measurement update" equations. The "Time update" equations are for projecting the current state forward in time and the error covariance gives the *a priori* estimates for the next time step. The "Measurement update" equations are responsible for the feedback, e.g. for incorporating a new measurement into the a-priori estimate to obtain an improved a posterior estimate.

Figure 13 shows the block diagram of a Kalman filter. A brief explanation of this figure has been given in research article [16]. Representing in a mathematical equation based on Figure 13 are as follows:

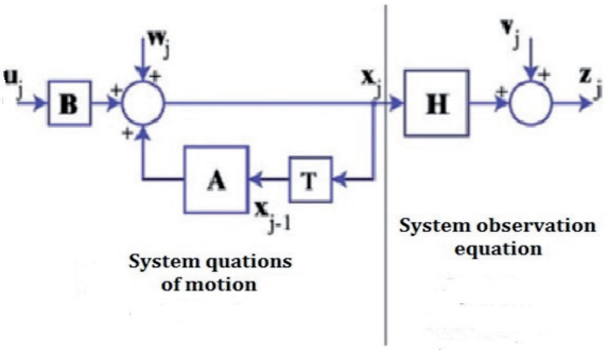

Fig. 13. Block diagram of a discrete time system

System equation of motion:

$$x_j = A.x_{j-1} + B.u_j + w_j. \quad (7)$$

System observation equation:

$$z_j = H.x_j + v_j. \quad (8)$$

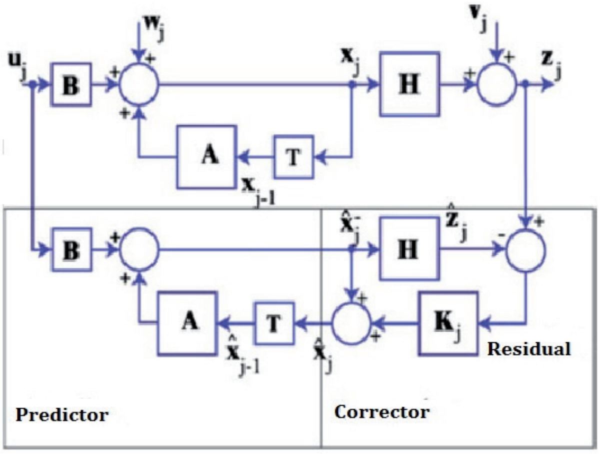

Fig. 14. Block diagram of Kalman filter

The block diagram for Kalman filter is as in Figure 14 where the equation are given by:

The "Time Update" or predictor equation is

$$\hat{x}_j^- = A.\hat{x}_{j-1} + B.u_j. \quad (9)$$

The "Measurement Update" or corrector equation is

$$\hat{x}_j = \hat{x}_j^- + K_j\left(z_j - H.\hat{x}_j^-\right). \quad (10)$$

In this manner, the robot soccer strategy can be further executed.

5. Decision Behaviors

5.1. Move Behavior

Move behavior consists of two operations performed sequentially, rotating and running. This is the simples scenario in which there are no obstacles in between the start point and goal point. For this scenario, strategy that can be adopted: possible strategy for this scenario is first orient the agent towards the goal point and simply move in a straight line tracking the position in real time till the goal point is reached.

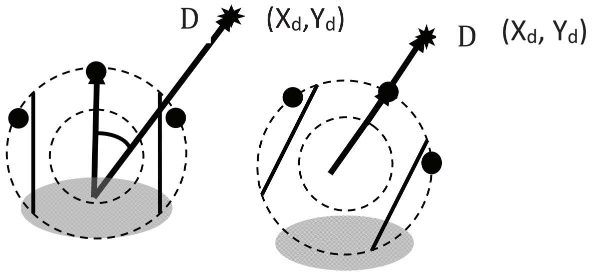

Fig. 15. Move behavior

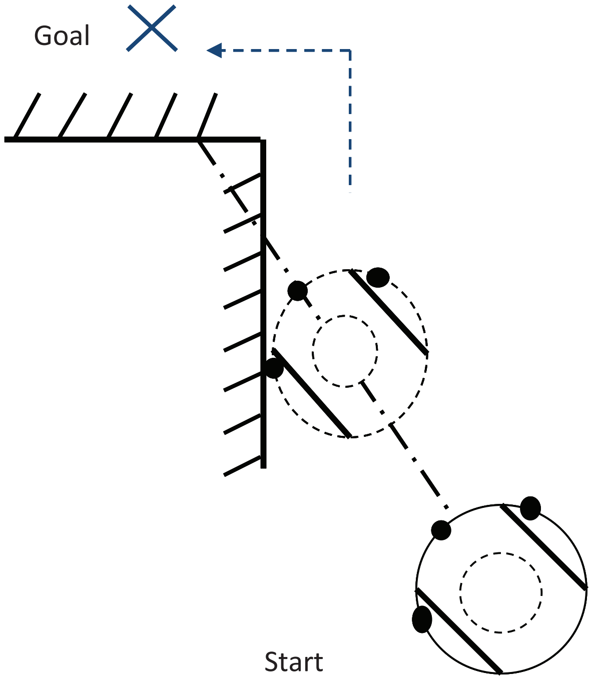

Fig. 16. Obstacle avoidance behavior (scenario 1)

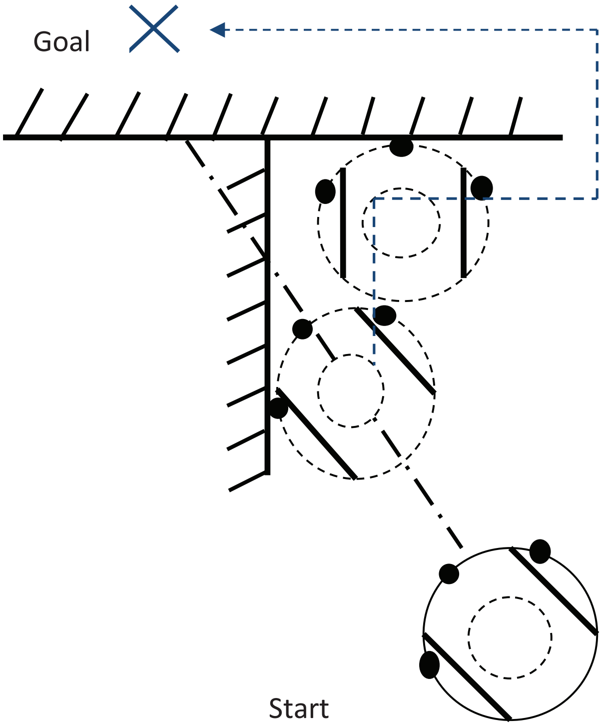

Fig. 17. Obstacle avoidance behavior (scenario 2)

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4 The detailed explanation of all equations has been given in: Welch G., Bishop G., *An introduction to the Kalman filter*, UNC+Chopel Hill, TR 95-041, July 24, 2006.

5 This experiments has been tested in Jay Robotix R&D laboratory, India.

6 The diagram (in Figs. 15, 16, 17) of the robot is changed for better understanding of decision behaviors using sensors.

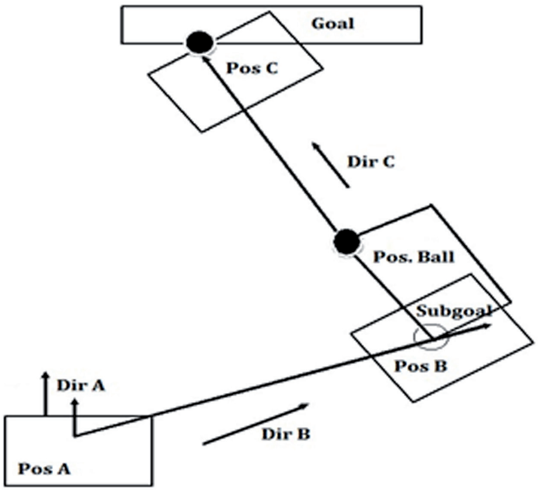


Fig. 18. Attack procedure of the robot soccer

5.2. Obstacle Avoidance Behavior

The robot has IR sensors to detect obstacles as shown in Figure 6. The seven sensors detect obstacles in the front, right-hand or left-hand sides. In this behavior, we proposed two best scenario that can be adopted for which the control system has been designed: we placed a perpendicular wall or obstacle on the straight line (either vertical or horizontal) connecting start and goal points as shown in Figure 16, we placed a cross wall or obstacle in the straight line connecting the start point and goal point, respectively.

Strategy adopted in the scenario 1, i.e. if there is a wall or obstacle, the agent (i.e. soccer robot) has to follow the wall or obstacle in the direction of the goal until the obstacle ends and then loop the original strategy with the current point as the starting point.

Strategy adopted in scenario 2, i.e. if there is a cross wall (in Figure 17), the agent (i.e. soccer robot) has to follow the wall throughout the direction of the goal until the obstacle ends and then loop the original strategy with the current point as the starting point as same as the scenario 1.

6. Experiments

To experimentally measure the efficiency of the proposed algorithm, the robot has to move its predefined path in the robotic soccer environments, leaving the ball in a known location.

The methods and approaches proposed in this paper has been tested and verified in our laboratory. Note that the lightning condition was poor and inconsistent during the experiments. The experimental result described in this paper that the proposed algorithm has almost constant processing time and independently of the environments around the robot soccer. Based on the practical experiments, the conversion equation are shown in (11) and (12),

$$D_p = 0.000377D_i^3 - 0.19231D_i^2 + 14.0578D_i - 489.286, \quad (11)$$

$$D_i = 8.09 \times 10^{-6}D_p^3 - 0.00798D_p^2 + 1.50981D_p + 21.9831. \quad (12)$$

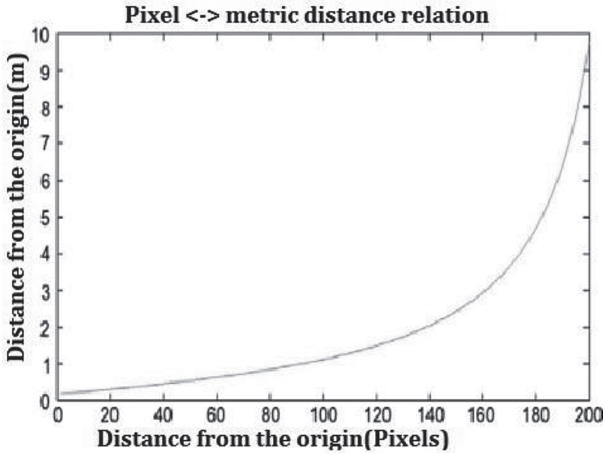
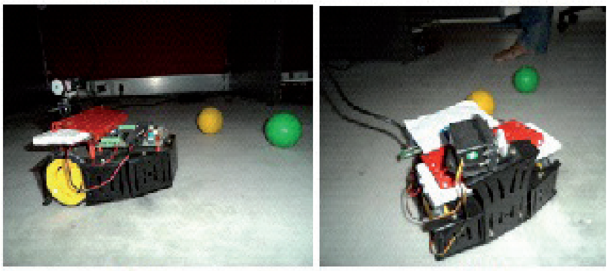


Fig. 19. Relation between pixels and metric distance



(a) (b)

Fig. 20. The experimental scenario

Where D_p indicates the real distances of planner distances (in c.m. units) and the D_i indicates the pixel distances of the omni-directional images. When the robot reaches "*Pos B*", it rotates itself until to direction "*Dir C*". The robot then moves along "*Dir C*" to touch the ball, and further to push the ball toward to the goal target.

Figure 14 shows the position of subgoal, ball and goal target become collinear.

Table 4.1. Recognition succes rate comparison

Methods	Figure 16(a) in %	Figure 16(b) in %
Traditional Method	85	79
Proposed Method	92	92

Table 4.2. Execusion time comparison

Methods	Figure 16(a)	Figure 16(b)
Traditional Method	16.02	20.91
Proposed Method	15.67	15.98
Improvement Rate	0.21	0.23

Improvement Rate =(T.M – P.M)/T.M

The accuracy was determined as the difference between the estimated values and the ones measured on the field, using pre-depend spots whose location is well known (e.g. the corner of the goal area). The precision (i.e. the difference between the measured value and the measurements average value for the same location) results are similar, and visual inspection made the average values seem trustable.

The experimental result also shows the graphics of the vision fusion of ball and the robot soccer distance measure respectively are shown in Figure 15.

In-addition color-based object detection, tracking and target following using our proposed method were also verified and tested in our laboratory.

7. Conclusion and Future Work

This paper addressed a real-time soccer robot for dynamically changing enviroments. Which is tested on images taken from local vision based on the soccer robot. The proposed algorithm was designed in a well structured manner and implemented succesfully for an omnidirectional soccer robot. In the soccer robot environments, promising results were obtained concerning posture accuracy and method robustness to image noise and distortion. The proposed method robustness meets the problem specification. We proposed both efficient color based object detection and tracking using Kalman filter to meet our goal.

In order to evaluate this robotic system, we investigated how fast image processing can be realized on this system and how control system can be performed. Now, we use this vision-based autonomous mobile robot as a standard platform for soccer robot research. To this end, it might be possible to use clustering technique recognition method for computing optimal and robust result. Moreover, applications of the suggested approach for multi-agent planning will be investigated.

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