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Vision Based Tracking and Interception of Moving Target by Mobile Robot Using Fuzzy Control

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Abstract: This paper presents a simple Fuzzy Logic Controllers (FLC) based control strategy to solve the tracking and interception problem of a moving target by a mobile robot equipped with a pan-tilt camera. Before sending commands to the mobile robot, video acquisition and image processing techniques are employed to estimate the target's position in the image plane. The estimate coordinates are used by a fuzzy logic controller to control the pan-tilt camera angles. The objective is to ensure that the moving target is always at the middle of the camera image plane. A second FLC is used to control the robot orientation and to guarantee the tracking and interception of the target. The proposed pan-tilt camera and robot orientation controllers' efficiency has been validated by simulation under Matlab using Virtual Reality Toolbox.

1. Introduction

Tracking and interception of moving targets using wheeled mobile robots is an important task in many roboticapplications such as surveillance systems, assistive robotics, soccer robotics… (Wang et al. 2001, Freda and Oriolo 2007; Friudenberg and Koziol 2018). Vision is widely used in robotics, as it is a very powerful sensor mimicking human vision and allowing non-contact measurements of the robot environment by defining its visual properties as colour and shapes. Machine vision can increase the accuracy of the tasks carried out by a robot, provides it with the ability to operate in a dynamic environment, and allow it to interact with objects without predefining of their positions in the robot's environment.

Different methods have been proposed to solve the target tracking and interception problem. Visual based tracking method is one of the most important approaches and many researchers have used it in several robotic applications (Manchester et al. 2007, Zhang et al. 2016). For example, in (Freda and Oriolo 2007), a vision-based scheme for driving a non-holonomic mobile robot to intercept a moving target is proposed. The method relies on a two level structure. In the lower level, a pan-tilt platform carrying an on-board camera is controlled to keep the target at image plane centre, and in the higher level, the object relative position is retrieved from the pan-tilt angles through simple geometry, and used to compute a control law driving the robot to the target. Whereas, the authors in (Wang et al. 2001) proposed a visual feedback controller using a fixed camera to control the mobile robot to track a moving target. The target is supposed predetermined and its dimensions known. In (Tsaia et al. 2009), the authors introduced a novel dual-Jacobian visual interaction model to design a robust visual tracking control system with a visual tracking controller and a visual state estimator for tracking a dynamic moving target. The authors, in (Tsalatsanis et al. 2007), proposed a real-time object tracking and collision avoidance method for mobile robot navigation using a stereo vision and a laser sensor. Stereo vision is used to identify the target while laser finder is used to avoid collision with surrounding objects. A vision based moving target tracking for mobile robots based on robot motion and stereo vision information, using the data from multiplesensors, such as gyroscope, robot wheel encoders, pan-tilt actuator encoders and the stereo camera is considered in (Kim et al. 2011). In (Kao et al. 2017) an active stereo camera is used to predict the target movement and guides the mobile robot to a suitable interception point. Trajectory predictions are of utmost importance to give the robot enough time to move.

Geometry based methodsare another effective methods of target tracking; the strategy presented in (Belkhouche and Belkhouche 2004) is based on the combination of geometrical rules and kinematic equations of the robot and the moving target, by keeping the robot in the line joining the target and a reference point.Other approaches like potential field (Ge and Cui 2002; Huang 2009), PID controllers (Padhy et al. 2010), sliding mode control (Qiuling et al. 2007) and Lyapunov based nonlinear control (Carelli et al. 2005)are also developed to solve the target tracking problem and allow a mobile robot to track easily a moving target. A combination of potential fields, typically used for obstacle avoidance, and parallel navigation has proposed in (Friudenberg and Koziol 2018). The unified algorithm allows a mobile robot to guide to, and rendezvous with, a moving target

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Nomenclature

AMTC	Adaptive Moving Tracking Control	x_c	x coordinate of the object in the image plane,
CAMS	Continuously Adaptive Mean Shift	x_r	x coordinate of the robot position,
DPRFNN	Dynamic Petri Recurrent-Fuzzy-Neural-Network	y_c	y coordinate of the object in the image plane,
e	Error, the first input of the fuzzy controller	y_r	y coordinate of the robot position,
FLC	Fuzzy Logic Controller	α	The mobile robot steering angle,
HSV	Hue, Saturation and Value	φ	Camera pan angle
l	Mobile robot length	$\bar{\varphi}$	Normalized pan angle
RGB	Red, Green and Blue	ψ	Camera tilt angle
UAV	Unmanned Aerial Vehicle	θ_r	Orientation of the mobile robot
v_r	Mobile robot velocity	Δe	Error change, the second input of the fuzzy controller

while avoiding obstacles in its path. However, these approaches require a mathematical models of the mobile robot and its surrounding workspaceand their efficiency depends on the model precision (Benbouabdallah and Qi-Dan 2013).

Fuzzy logic based method is one of the most common approaches for target tracking and interception (Li et al. 2004, Cherroun and Boumehraz 2012, Benbouabdallah and Qi-Dan 2013; Handayaniet 2017). In Li et al. (2004), the authors designed a real-time fuzzy target tracking control scheme for autonomous mobile robots via infrared sensors and a fuzzy sliding mode control scheme is suggested to accomplish the control task. In (Olivarez-Mendez et al. 2009), the authors proposed a path following approach based on a fuzzy-logic set of rules, which emulates the human thinking behaviour. Whereas, the authors in (Antonelli et al. 2007) presented a UAV onboard pan-tilt video platform, the platform is controlled by two fuzzy-controllers using a Lucas-Kanade tracker in order to follow static objects. In (Wai and Lin 2013), an adaptive moving-target tracking control (AMTC) scheme using a dynamic Petri recurrent-fuzzy-neural-network (DPRFNN) is proposed. Continuously adaptive mean shift (CAMS) algorithm is used to detect the moving object in the image coordinate frame.The main advantage ofvision based fuzzy control approach is that it can incorporate a human experience about how to control a system and it does not require a mathematical model of the system and the target or an odometry system.

This paper presents a control strategy to track and intercept a moving target by a mobile robot equipped with a pan-tilt camera. The strategy is based on the use of two fuzzy logic controllers (FLCs). The first one controls the angle of the pan-tilt camera using the relative target position in the image plane in order to keep the target in the image plane centre. The second one is used to drive the robot toward the target by adjusting the steering angle using the pan-tilt camera angles in order to drive the pan-tilt camera angles to zero while keeping the target in the image plane centre. The rest of the paper is organized as follows. The description of the tracking system is presented in the second section. The approach used for the target detection is presented in section 3. The target tracking control strategy is presented in section 4. Then, simulation results are shown in the section 5. Finally, some conclusions are given in section 6.

2. System description

The aim of this work is the driving of a mobile robot to intercept a moving target using a vision-based control method in an environment without obstacles. The vision system comprises a 320×480 pixels pan-tilt camera mounted on the robot as shown in figure 1.

The mobile platform is a tricycle mobile robot with non-holonomic property that restricts its mobility in the sideways direction and with limitation of angle. It is oriented by its steering angle.

The mobile robot kinematic model is given by the following equations (Belkhouche and Belkhouche 2004):

$$\begin{aligned} \dot{x}_r &= v_r cos\theta_r \\ \dot{y}_r &= v_r sin\theta_r \\ \dot{\theta}_r &= \frac{v_r}{l} tg(\alpha) \end{aligned} \tag{1}$$

where(x_r, y_r) are the robot position coordinates, θ_r is the orientation of the robot and l is the robot length. To track a moving target two-steps are needed; target detection and target tracking. In the detection step, the target is detected using image processing techniques. Then, the relative coordinates of the target in the image plane are used to drive the camera and the mobile robot.

3. Object detection

The ability to detect and identify mobile and fixed objects plays an important role for achieving robots autonomy. Object detection is a very challenging problem in vision computer based applications that deals with detecting instance objects of certain class in digital images and videos. An efficient object detection system should be able to determine the presence or the absence of objects in arbitrary scenes and be invariant to object scaling and rotation, camera viewpoint and environment changes such as illumination, shading and highlights (Sundararajan 2017).

Object detection in real-time using low cost, compact and easy to use sensors remains a research goal.Despite the decades of intense research in object detection, there are no definitive and general solutions to choosing the optimal feature and obtaining an optimal detection algorithm. After image acquisition, image processing approaches are used to detect and localize the target in the image.

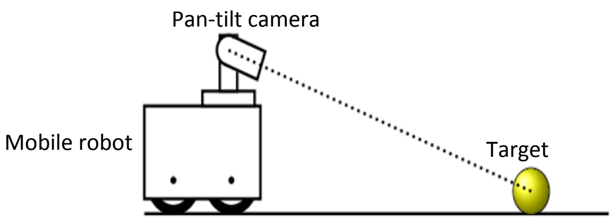

Fig. 1. Vision-based mobile robot system.

3.1 Image acquisition

In order to acquire the video stream, a single high resolution camera mounted in the mobile robot is used. The reason of using a single camera is its low cost and easy mounting on the platform due to its reduced weight and size.

3.1 Image processing

The main objective of camera tracking algorithm is to determine the location of the object and maintained it in the middle of the image plane. For this end, the first step in the tracking algorithm is to detect the object depending on its color and shape, and determine its position in the image plane.

Object detection is an important and fundamental topic in computer vision (Cyganek 2013). It is a critical part in many applications such as image search and scene understanding. The target chosen for detection and tracking in this work is a simple object (ball) with fixed color. To detect it quite easily a color based method is used and in order to successfully segment objects using color-based methods, the background and foreground (the object) should have a significant color difference (Karasulu and Korukoglu 2013). In color segmentation approach, the image is divided into distinct regions in order to extract objects of interests from a surrounding environment.

To implement the color based object recognition methods, the Hue, Saturation and Value(HSV) color space is used in the aim to obtain robust results, because it separates the color components Hue and Saturation from Value (lightness). For different lighting conditions, Hue and Saturation are often constant but lightness changes. For this end, many applications use HSV color model in which the value (V) component is ignored.RGB space is not suitable because a small variation in the light intensity can change significantly the object description and does notgive correct information about the color for different lighting conditions (Sundararajan 2017).Before its transformation from the RGB into HSV space, a 3X3 median filter is used to clean the image from acquisition noise.

The First step of color-based methods is color filtering in order to keep only objects with the predetermined color and remove all the rest. The color segmentation uses thresholding method in HSV color space to differentiate the ball color from objects in the image.

This process is executed based on a ball color histogram during a preliminary color calibration (Freda and Oriolo 2007). The second step is noise elimination by applying morphological operations on the obtained binary image by thresholding (Sundararajan 2017). Morphological operations are erosion and dilation. In the main object, the unnecessary small holes can be eliminated by applying morphological closing. Closing operation involves dilation, followed by the erosion with the same structuring element. The unnecessary small white patches outside the object can be eliminated by applying morphological opening. Opening operation can be achieved by erosion, followed by the dilation with the same structuring element. The result of the first two steps is shown in figure 2.

If the environment contains other objects with the same color, combined shape-colorbased recognition approaches may be also performed to detect the ball (Toshev et al. 2012).

4. Target tracking strategy

The proposed approach is based only on the use of visual information to solve the interception problem and does not need long-term predictions of the target motion; also we don't need a robot odometry system because the controllers are purely image -based.

The proposed control strategy is inspired from biological interception strategy and has a two-level structure (Freda and Oriolo 2007). In the lower level, the angle of the pan-tilt camera is controlled using the relative target position in the image plane in order to keep the target in the image plane center. In the higher level, the steering angle of mobile robot is controlled by the camera pan-tilt angles in order to drive the robot toward the target. A biological system seeks a target by rotating the head. Once the target is in the front, then the body follows the head while moving towards the target.

4.1 Camera control

In order to keep the object in the image plane center a fuzzy logic controller is used to control the pan angle of the camera. Let $\boldsymbol{x_c}$ and $\boldsymbol{y_c}$ be the ball center coordinates in the image plane, the image center is defined as the coordinate system origin as shown in figure 3. Since the cameraresolution is 320×480 pixels then $\boldsymbol{x_c} \in$ [−240, 240] and $\boldsymbol{y_c} \in$ [−160, 160].

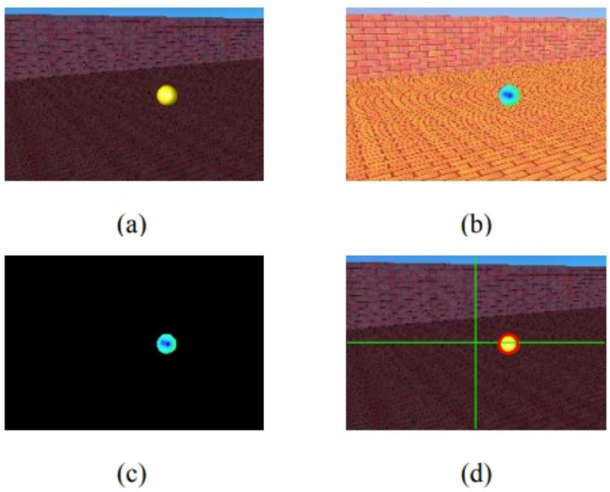

Fig. 2. (a)- Acquired image, (b)-HSV image, (c)- Filtred object, (d)- Image and detected object in the coordinate system.

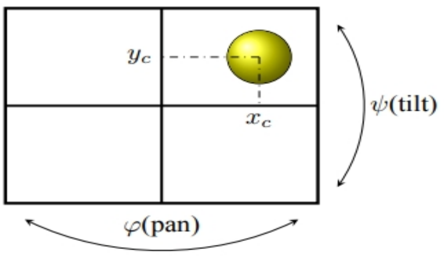

Fig. 3. States definition in an image coordinate frame.

The objective is to drive the camera so that the ball center coordinates will be superposed on the coordinate system origin ($\boldsymbol{x_c}$ = 0, $\boldsymbol{y_c}$ = 0). The fuzzy controller has two inputs and one output. The first input is the normalized error given by

$$e(t) = \boldsymbol{x_c}/240 \tag{2}$$

The second input is the normalized error change given by

$$\Delta e(t) = \frac{\boldsymbol{x_c(t)-x_c(t-1)}}{480} \tag{3}$$

The tow inputs are decomposed into the following seven fuzzy partitions: NB (Negative Large), NS (Negative Small), NM (Negative Medium), ZR(Zero), PS (Positive Small), PM (Positive Medium) and PL (Positive Large). The control output is also decomposed into seven fuzzy partitions with the same linguistic terms. The membership function of $e(t)$ and $\Delta e(t)$ of the fuzzy controller used in this paper are represented in figures 4 and 5 respectively.

The output of the fuzzy controller is the normalized pan angle $\bar{\varphi}$ with the membership functions given in figure 6. Since φ∈ [-π/2, π/2] then

$$\bar{\varphi} = \frac{\varphi}{\frac{\pi}{2}} \tag{4}$$

4.1 Mobile robot control

In order to track and intercept the target, the mobile robot must follow the camera direction while moving towards the object as closely as possible. A fuzzy logic controller is used to command the mobile robot to follow the camera orientation; it is based on the use of the information obtained from the vision system. The fuzzy controller has two inputs and a single output. The first input is the normalized orientation error given by:

$$e(t) = \bar{\varphi}(t) \tag{5}$$

$\bar{\varphi}$is the normalized pan angle. The second input is the normalized orientation error change, which is the variation between current and previous pan angle given by:

$$\Delta e(t) = \frac{\bar{\varphi}(t)-\bar{\varphi}(t-1)}{2} \tag{6}$$

The output of the fuzzy controller is the normalized steering angle of the robot.

The rule base is designed using heuristics and human experience about the problem under consideration and is shown in Table 1. The fuzzy controller surface is represented in figure 7.

To simplify the implementation, thefuzzy controller used to drive the camera share the same membership functions and the same rule base with the fuzzy controller used to control the mobile robot.

The procedure for intercepting and tracking the moving target is shown in the flowchart in figure 8.

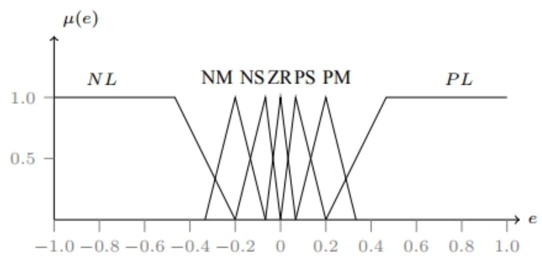

Fig. 4. Membership functions of input $e(t)$.

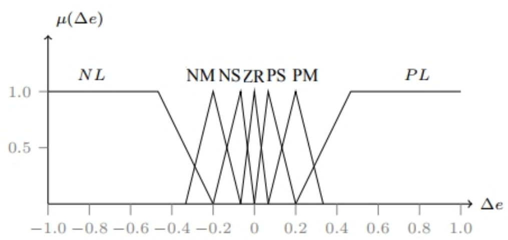

Fig. 5. Membership functions of input $\Delta e(t)$.

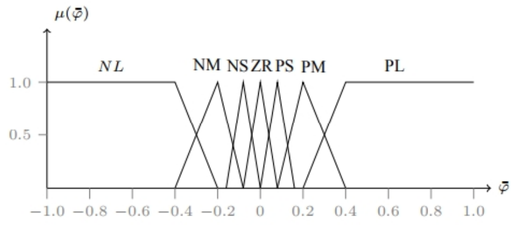

Fig. 6. Membership functions of output $\bar{\varphi}$.

Table 1. Fuzzy controller rule base.

$\Delta e(t)$	$e(t)$						
	NL	NM	NS	ZR	PS	PM	PL
NL	NL	NL	NL	NL	NS	NS	ZR
NM	NL	NL	NL	NM	ZR	PS	PS
NS	NL	NL	NL	NS	PS	PS	ZR
ZR	NL	NM	NS	ZR	PS	PM	PL
PS	NM	NS	NS	PS	PM	PL	PL
PM	NS	NS	ZR	PM	PL	PL	PL
PL	ZR	PS	PS	PL	PL	PL	PL

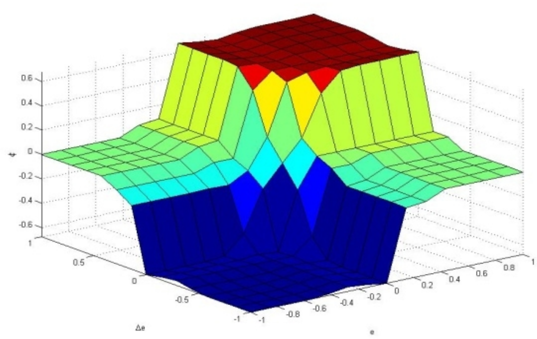

Fig. 7. Fuzzy controller surface.

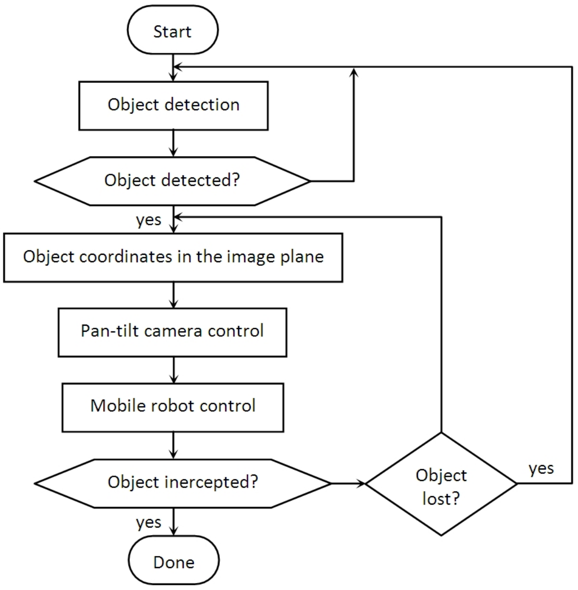

Fig. 8. Flowchart of the interception procedure.

As first step, the camera tracking subsystem was tested to verify the performance of the first fuzzy controller. The objective is to keep the ball as close as possible to the center of the image plane.To achieve this, the ball is stationary and invisible for the robot camera (out of the camera field of view). The simulation results are given in Fig 10, the results show that the ball, initially invisible by the camera, is finally very close to the center of the image plane and the controller assures good tracking.

In the second step, the complete robot-camera system was simulated to verify the effectiveness of our approach. Figure 11 represents results for different scenarios, ball moving in straight, circular and sinusoidal path with constant speed 1m/s respectively, it can be observed that the robot moves toward the ball and intercept it effectively. Figure 11.a shows the target trajectory in red and robot trajectory in blue while Figure 11.b shows the distance between the robot and the ball trajectories during interception. The distance converges to zero for all scenarios.

5. Simulation results

In order to demonstrate the efficiency of the approach presented in this paper, a simulation has been carried out using Virtual RealityToolbox in MATLAB to accomplish a mobile robot target tracking. The simulation environment is shown in figure 9.

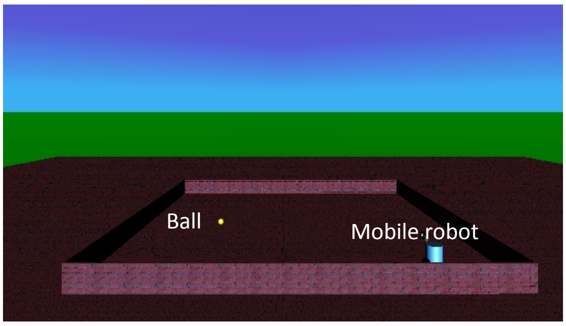

Fig. 9. Simulation environment.

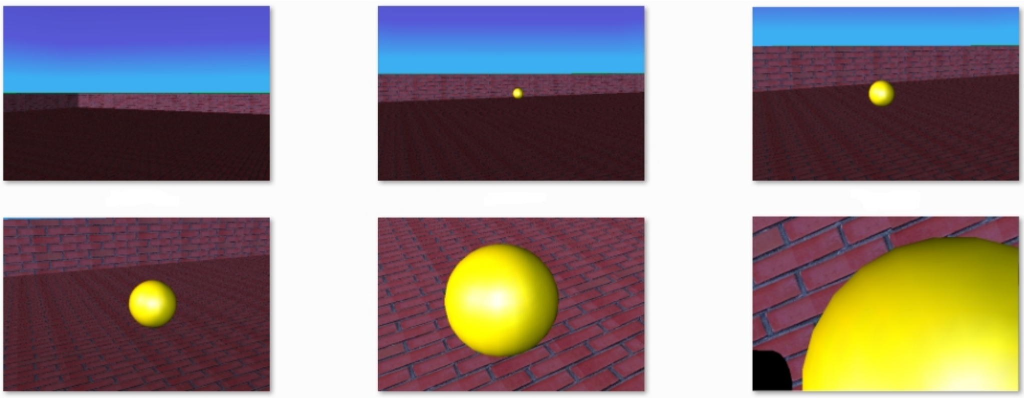

Fig 10 Ball localization by camera tracking.

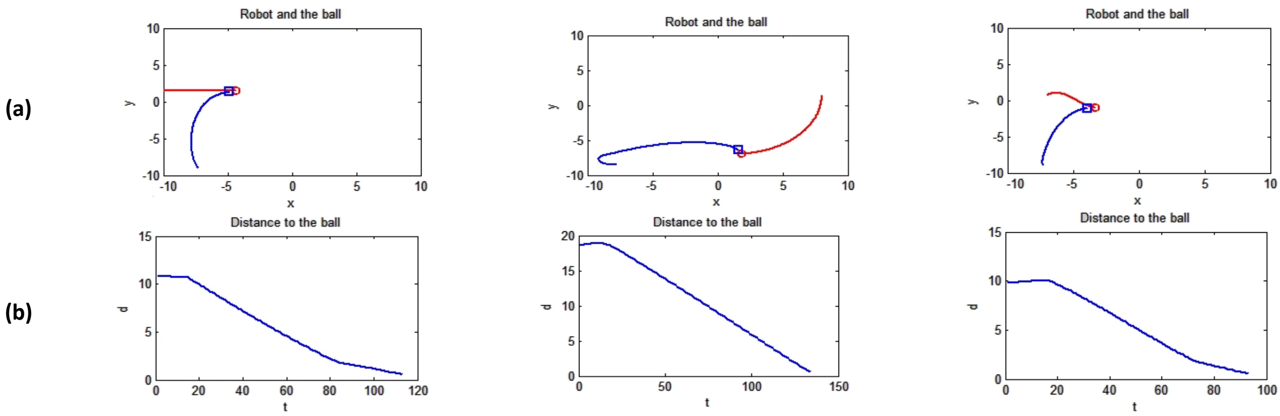

Fig. 11. Robot, ball trajectories and the distance to target for different scenarios. (a)-Robot trajectory (blue) and target trajectory (red), (b)- The distance to target.

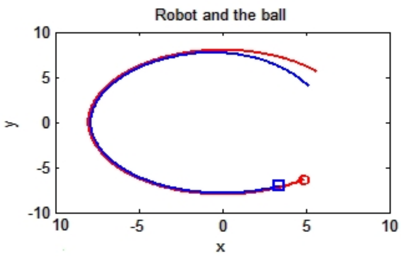

Fig. 12. Pursuing a faster target with circular path

In simulation result shown in figure 12, when the ball is moving in a circular path with the same speed as the mobile robot, we observe that the robot pursues the ball and can't catches it, which means that the interception problem becomes a pursuit problem. The interception of the moving target can be accomplished ifmoving target is slower than the mobile robot.

If the ball disappears from the camera view then the mobile robot stops and the pan-tilt camera starts an environment scan to search the ball.

Figure 13 represents the scenes in the start, the middle and the end of an experiment.
The principal advantage of this approach is that it is model independent; the mathematical models of the mobile robot, the moving target and the environment are not required. It is vision based and doesn't need an odometrysystem. However, this approach suffers from a luck of stability. The stability cannot be guaranteed because it is highly dependent on the object detection method, which cannot be mathematically modeled

6. Conclusion

In this paper, we have presented a simple fuzzy logic based control strategy for tracking and intercepting moving target by mobile robot equipped with a pan-tilt camera. The strategy is based on the use of two fuzzy logic controllers.The first one controls the angle of the pan-tilt camera using the relative target position in the image plane in order to keep the target in the image plane centre. The secondis used to drive the robot toward the target by adjusting the steering angle using the pan-tilt camera angles in order to drive the pan-tilt camera angles to zero while keeping the target in the image plane centre. The proposed approach has been implemented with MATLAB using Virtual Reality Toolbox and its efficiency has been demonstrated using many simulation experiments. The mobile robot can intercept the moving target fordifferent scenarios. When the mobile robot speed cannot allow target interception, the mobile robot continue to pursue the target.

The approach efficiency can be improved by the combination of the proposed strategy with vision-based object tracking algorithms such as mean shift algorithm to predict the future ball position and to anticipate the mobile robot motion. The advantage of the proposed control strategy are the efficiency, the simplicity and no need to telemetry sensors and it does not require models for the environment, the target movement and the mobile robot.

Future works will be focused on real-time implementation of the proposed approach using Dani mobile robot of national instrument and the study of the tracking and interception problem in an environment containing obstacles and the case of cooperative tasks by several mobile robots.

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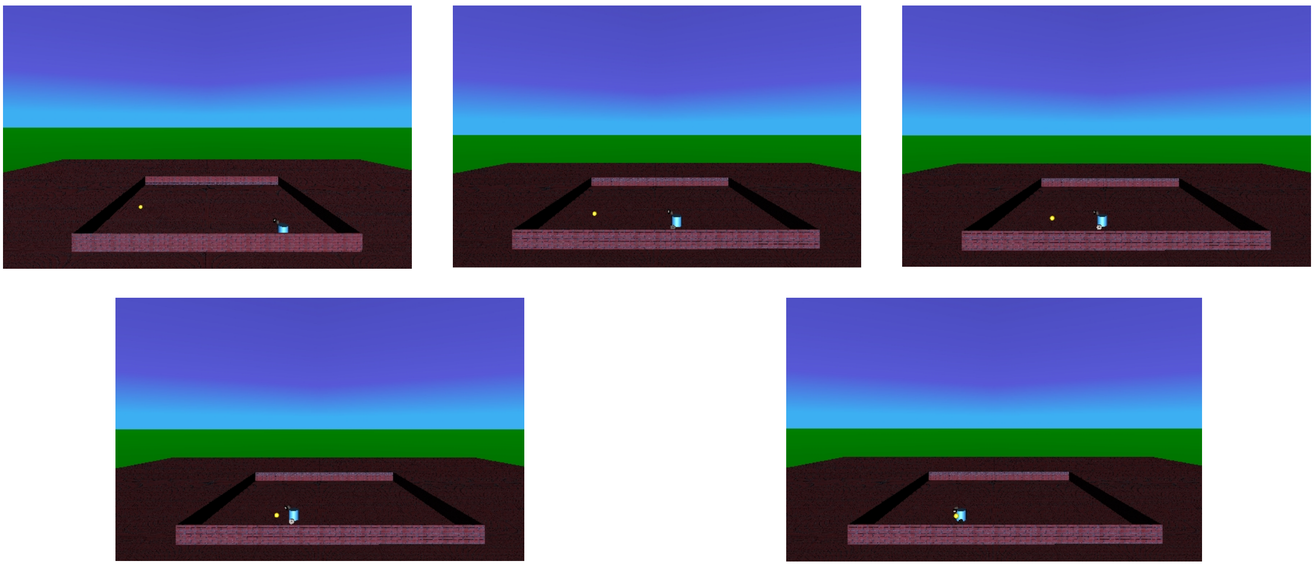

Fig. 13. Frames in the start, the middle and the end of an experiment

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