NuBot Team Description Paper 2013

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Abstract. This paper presents the developments of our middle-size league robot team "NuBot" for RoboCup 2013. The robot platform, active ball handing system, robot's distributed motion control system, the goalie's stereo vision system, arbitrary ball recognition based on omnidirectional vision, robot's global self-localization, and application of MPC for trajectory tracking are introduced.

1 Introduction

The middle-size league competition of RoboCup provides a standard test-bed where many technologies of robotics and artificial intelligence can be examined and integrated.

NuBot (Fig. 1) is the RoboCup Middle Size League team of National University of Defense Technology. This team was founded in 2004. Since 2006 we have continuously participated in five World RoboCup competitions and entered into the top 8 from 2007 to 2009, and the top 6 in RoboCup 2010 Singapore. We have also participated in RoboCup China Open and won the 1st-place from 2006 to 2008, the 3rd-place in 2009 and the 2nd-place in 2010. Now our research focuses are on multi-robot cooperation, robust robot vision, robot control, Multi-robot cooperative perception, etc.

This paper describes the recent developments of NuBot for RoboCup 2013.

Fig. 1. NuBot team

2 The Robot Platform and Active Ball Handling System

After RoboCup 2009 Graz, we have developed a totally new robot platform, as shown in Fig. 1 and Fig. 3. The motion ability especially the acceleration can be improved greatly comparing to our former robots. We also design a new omnidirectional wheel, as shown in Fig. 2. This wheel can provide more friction than our former wheels. More details can be found in our mechanical and electrical description materials.

The active ball handling system, which is designed for dribbling the ball, is made up of the active ball handling mechanism and its control system. The ball handling mechanism is shown in Fig. 3.

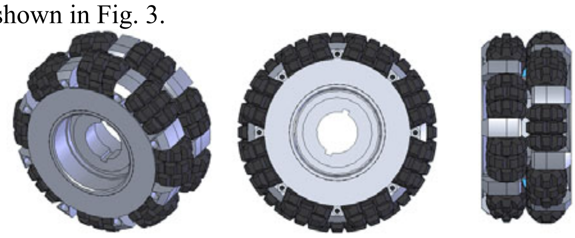


Fig. 2. Our new omnidirectional wheel

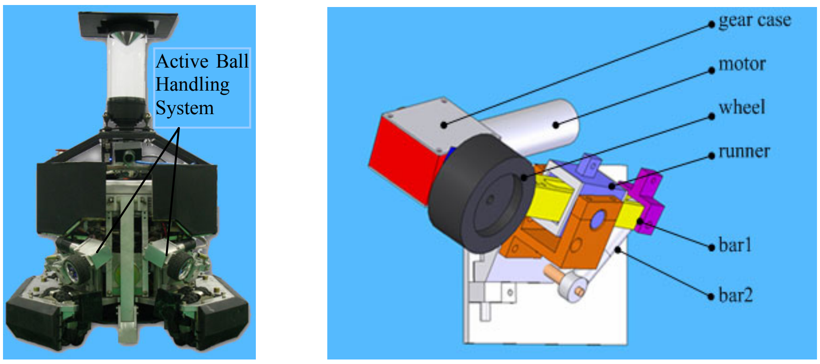


Fig. 3. Our active ball handling system

The main parts of our active ball handling mechanism are wheels (one at each side), DC motors, axis, spring and the parts using to limit the rotation angle of the axis. When the robot is dribbling, the spring keeps pressure between the wheels and the ball, and the wheels driven by the DC motors provide frictions to make the wheels keep in touch with the ball. The control architecture includes two levels. On the lower level, the velocity of the wheels is controlled by DSP. On the higher level, the PC decides when the active ball handling system works. In comparison with the passive ball handing mechanism used before, the active ball handling mechanism has three advantages: firstly, it introduces the opportunity to drive the ball not only forward, but also at any direction, which makes path planning easier. Secondly, the robot could stop the ball at any place, which is useful when the robot is dribbling near the corner and sideline. Thirdly, the robot is capable to grab the ball from the opponent robot with the mechanism. We will further our research on the following issues: ameliorating the mechanism, improving its reliability, enhancing the adaptability to the dynamic environment, and optimizing path planning based on the active ball handing system.

3 The Robot's Distributed Motion Control System

The electrical circuits system of our robots can be divided into three modules: the DC motor control module, the shooting module and the module of RS232 to CAN convertor, as shown in Fig.4. In comparison with our former system [1], the biggest change is that motion control turns to be distributed, which means that each motor has an independent controller. The module of RS232 to CAN convertor and the DC motor control module are mainly built upon TMS320F2808 DSP. TMS320F2808 DSP is the core IC of these two modules, which takes charge of the realization of motion control algorithms, data processing, PWM signal producing, AD input receiving, communication with each other and PC, and so on. The motor control module is designed in the form of H-bridge including four MOSFET and a special driver IC. Two close loops, namely the speed loop and the current loop, are used in the motor control module, so it can control a DC motor independently. The shooting module, also named as kicker driver, is mainly composed of a relay and an IGBT FGA25N120ANTD. The module of RS232 to CAN convertor is mainly composed of a TMS320F2808 DSP and some communication interface IC. It is responsible for communicating between the industry PC and the motor control module and the shooting module.

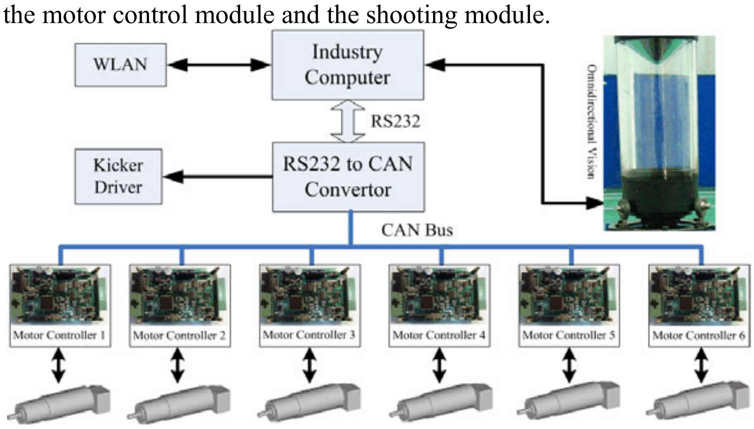


Fig. 4. The architecture of our distributed motion control system

4 The Goalie's Stereo Vision System

Since most of the shoots in the competition are kicking the ball up from the ground, it is very important for the goalie to locate the ball and estimate its motion trace in 3D space. We utilized a stereo vision system for the goalie to realize ball recognition and localization in 3D space, and proposed a technique for the fitting of the ball's moving trace and the prediction of the touchdown-point. Based on the prediction information, the goalie is more effective to make a strategic decision to intercept the shooting ball.

Fig. 5 shows the stereo camera. The stereo camera is produced by Point Gray Research Company. The left and the right cameras of the stereo camera system grab images respectively and transport them to the computer via IEEE-1394 port. Then the ball can be recognized in the left and right images respectively, as shown in Fig. 6. The 3D reconstruction is accomplished to calculate the 3D coordinates of the ball. Once the ball is kicked up from the ground, the coordinate-points of the ball are recorded, and a parabola fitting is performed by using the first several coordinate-points to obtain a moving trace of the flying ball. With the new coordinate-points recoded, the new parabola fitting is performed iteratively to update the trace, as shown in Fig. 7. Based on the trace of the ball, the prediction of the touchdown-point can be acquired easily to determine whether the ball will goal and when and where the ball will goal. Based on the perception information, finite state machine is applied to design the goalie's defense behavior to intercept the shooting ball. The experimental results show that soccer robots' ability can be enhanced greatly for object perception and defense in 3D space by the described work, as shown in our qualification video.

Fig. 5. The stereo camera **Fig. 6.** Ball recognition results in the left and right images

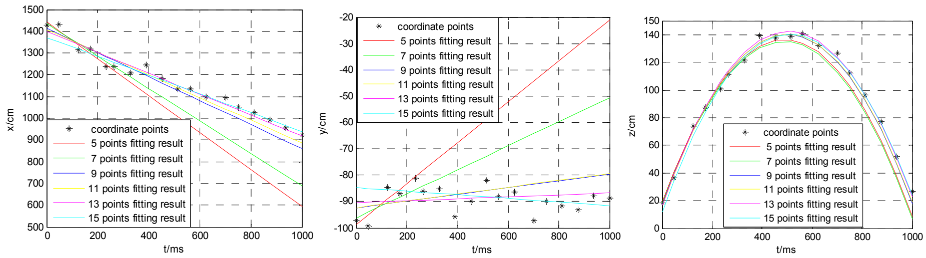
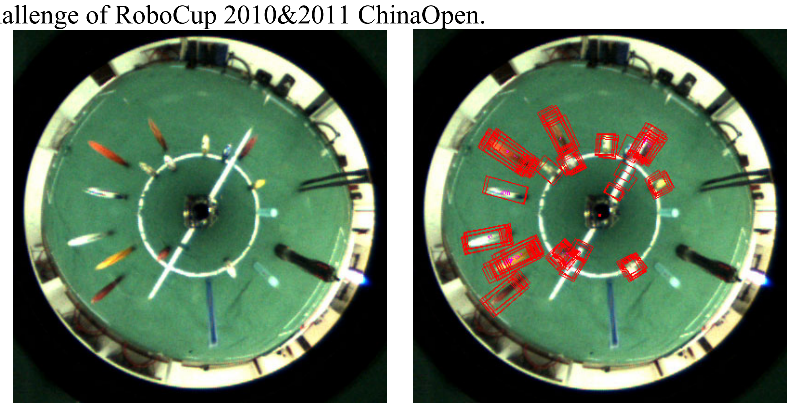


Fig. 7. Fitting results of the ball's trace

5 Arbitrary Ball Recognition Based on Omnidirectional Vision

Recognizing arbitrary standard FIFA ball is a significant ability for RoboCup Middle Size League soccer robots to play game without the constraint of current color-coded environment. An arbitrary FIFA ball recognition algorithm based on our omnidirectional vision [2][3] and AdaBoost algorithm [4] is developed. The recognition algorithm includes two phases: the off-line training phase and the on-line recognition phase. In the off-line training phase, dozens of panoramic images which contain different kinds of arbitrary balls are acquired by our omnidirectional vision system. Then sub-images including the ball or not are extracted from the panoramic images, and used as the positive samples or negative samples of the training set. Then the Haar-like feature vectors are calculated from each sub-image of the training set, and are combined as a feature matrix. Finally, a classifier is generated with the feature matrix as the input of the AdaBoost learning algorithm. In the on-line recognition phase, a series of rectangle windows are defined along the radial direction of the panoramic image. According to the imaging characteristic of our omnidirectional vision, the lengths of the rectangle windows vary along the radial direction of the panoramic image. Then the whole panoramic image is searched by these rectangle windows along both the rotary and radial direction. Finally, the learned classifier is applied to classify these rectangle windows, which means the classifier judges whether the window contains a ball or not. The experimental results show that arbitrary FIFA balls can be recognized effectively with our algorithm. A typical panoramic image and the ball recognizing result is shown in Fig. 8. With this algorithm, NuBot team won the 3rd place in the technical challenge of RoboCup 2010, and the champion in the technical challenge of RoboCup 2010&2011 ChinaOpen.



(a) (b)

Fig. 8. A typical panoramic image (a) and the ball recognizing result (b). The red rectangles are the recognized FIFA balls.

6 Robot's Global Self-localization

Self-localization is the basis of motion planning, control decision and cooperation. With Omnidirectional vision and Motion Trackers instrument (MTi), matching optimization localization algorithm [5] is employed to realize the global localization and localization tracking quickly and accurately for our soccer robots [6][7]. For global localization, robot should localize itself in the field without any priori knowledge about its position and orientation, so the kidnapped robot problem can be solved.

First, the robot obtains its orientation θ in the global coordinate system by MTi. Because the robot may be located anywhere in the field, so we define 315 samples as possible positions which are distributed uniformly on the field with the dimension of 18m*12m, and then calculate the error functions for these samples according to the detected mark-line points by robot's omnidirectional vision. The smaller value of error function means the higher probability of the related position close to the real robot's position. We select five samples with the smallest errors as the candidate positions of the robot, and then obtain five new positions and error values by optimizing these five samples using matching optimization localization algorithm [5]. At last, if the error value of the position with the smallest error among these five new positions is less than a threshold, the position is chosen as robot's real position, and robot's global localization is achieved successfully. Otherwise, the global localization process should be restarted until successful localization is realized. Recovery from robot's being kidnapped is shown in Fig. 9.

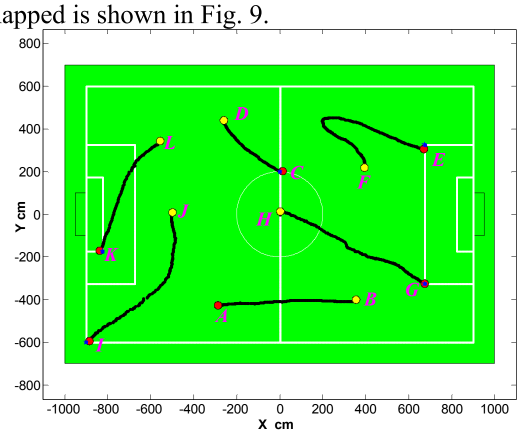
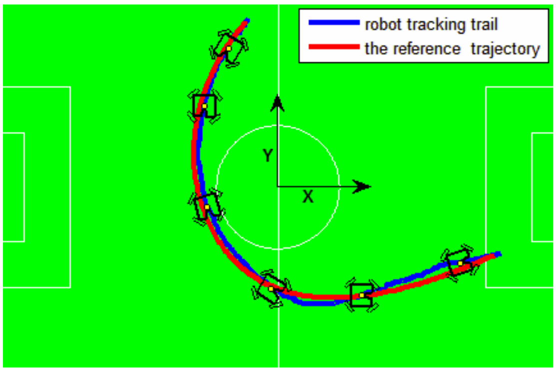


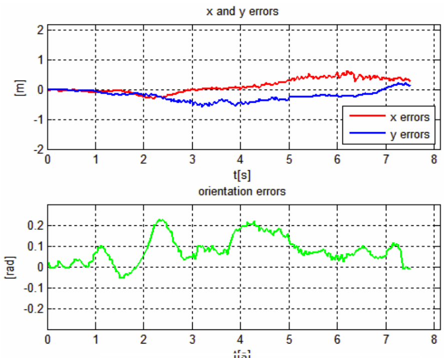
Fig.9. Recovery from robot's being kidnapped. Robot is kidnapped from the yellow points to the red points, like $B \rightarrow C$, $D \rightarrow E$, $F \rightarrow G$, $H \rightarrow I$, $J \rightarrow K$. The blue points are the global localization achieved with our algorithm.

7 Application of MPC for Trajectory Tracking

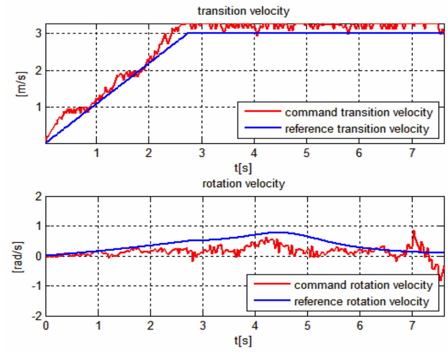
In order to perform accurate and stable tracking of high-speed trajectories for our robots, a strategy using Model Predictive Control (MPC) is proposed. An important advantage of this type of control lies in its ability to achieve optimal control signals, which refer to the future information from the whole trajectory and from predicting the state of mobile robot. This improvement allows action to be taken before the error occurs, thus the model predictive controller wins out over others in tracking high-speed trajectory. Besides, it can directly handle the hard constraints on controls and states in the optimizing process, so that a superb tracking performance can be achieved under both the velocity and acceleration constraints [8]. The first step of our strategy is to obtain the linear error dynamics model around the reference, which is based on the kinematics model of the robot, and then MPC is employed to design the control law to satisfy the kinematics constraints and dynamics constraints. Furthermore, the Laguerre Networks is used in designing, by substituting a long horizon with a small number of parameters, so that the computation cost can be cut down for practical applications [9]. The experimental results show the robot can track the trajectory wit higher speed, quick dynamic response and low tracking errors with our algorithm, as shown in Fig. 10, so the motion ability and the obstacle avoiding ability of our robot can be improved.



(a) The reference trajectory and the real trajectory



(b) Tracking errors



(c) Tracking speed

Fig. 10. The experimental results of trajectory tracking with the proposed MPC algorithm.

8 Current Research Focuses

Our current main research focuses are listed as follows:

-**Robust robot vision:** Soccer robots will have to be able to play games in outdoor environments and get rid of the color-coded environment sooner or later [10]. We will go on developing our robot vision system to make the robot work well in the environment with highly dynamic lighting conditions and even in totally new field without any off-line calibration. We are also doing further research on arbitrary FIFA ball recognition with our omnidirectional vision system. We are also interested in recognizing and distinguishing the robots belonging to different teams and other generic objects by using the advanced pattern recognition techniques.

-**Multi-robot cooperation:** Multi-robot cooperation holds an important place in distributed AI and robotics field. We have designed a good multi-robot cooperation mechanism and also realized several two-robot cooperative behaviors [11]. Now we have to do deeper research to develop our robot's cooperation ability by involving more robots and more complex cooperative behaviors in this mechanism.

-**Multi-robot cooperative perception:** As the MSL environment becoming more and more complex and the field larger and larger, for the field of view of every robot is limited, the occlusion of important objects such as the ball is very common in the highly dynamic game, and the inconsistent world model of every robot brought by perception noises will also affect team's strategy. So we are interested in building a global, accurate and consistent world model of multi-robot team by cooperative perception such as cooperative object localization and robot's cooperative localization.

9 Conclusion

This paper describes the current developments of the NuBot team as follows: the robot platform, active ball handing system, and robot's distributed motion control system in robot hardware; the goalie's stereo vision system, arbitrary ball recognition based on omnidirectional vision, robot's global self-localization, and application of MPC for trajectory tracking in robot software. Our current research focuses are also presented finally.

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