Hibikino-Musashi Team Description Paper

Amir A.F. Nassiraei [1], Shuichi Ishida[1], Noriyuki Shinpuku[1],
Miyuki Hayashi[1], Naoya Hirao[1], Kazunori Fujimoto[1], Kazutaka Fukuda[1],
Kazutomo Takanaka[2],
Ivan Godler[2], Kazuo Ishii[1] and Hiroyuki Miyamoto[1]

[1]Kyushu Institute of Technology, Japan
[2]The University of Kitakyushu, Japan
ishida-shuichi@edu.brain.kyutech.ac.jp

Abstract. This paper presents some of the technical elements of the "Musashi robot" developed for the RoboCup Middle-Size League. Since there are some solutions that are common to many teams, only the most recent developments and interesting research studies that distinguish our multi-robot system from others and show our contribution to improving Middle-Size League performance are presented. One of our research objectives is to investigate the proper solutions towards realizing the idea of the human-robot interaction in soccer. Three considerable topics that they can play significant role in this content are Robot-Reliability, Robot-Maneuverability and Robot-Human Safety. In the following sections, our approaches to realize this idea, in different and interesting ways, are presented.

1 Introduction

"Hibikino-Musashi" is a joint middle-size league RoboCup [1] soccer team funded in 2004 by three different research and educational organizations, all located in the Kitakyushu Science and Research Park, Kitakyushu, Japan. The team's main objective is to develop a competitive team of soccer-playing robots oriented to inspire the interaction of human-robot in soccer. In this direction three topics, Robot-Reliability, -Maneuverability and -Human Safety, are selected as the main criteria for the most research orientation and the robot development plans.

In section 2, after a short overview to the "Musashi" robot design principles and its modular hardware architecture *(Robot-Reliability)*, the design concept and features of the developed solenoid-kicking device is described *(Robot-Maneuverability)*. Our recent studies on Robot-Human safety based on evaluation of the risk in MSL and the protective measure of Soccer-Robot are presented in section 3 *(Robot-Human Safety)*. On the software side, our scientific innovation content on development of auto color calibration algorithm using SVM (Support Vector Machine) is presented *(Robot-Reliability)*.

The "Musashi" robot self localization method using MCL & Dead reckoning, and the features of the fusion of Omni-camera & Monocular camera for the goalie in order to detect the height of Flying ball are presented in section 4 and 5, respectively.

2 Hardware system

2.1 Musashi Robot Architecture and Specification

The current hardware configuration of the "Musashi" robot and its fully modular mechatronics architecture including an omni- directional moving mechanism and an omni-vision system is shown in Fig.1 [2-4]. The modular robot architecture provides an effective way to improve reliability, robustness, ease of maintenance and transportation by decomposing hardware complexity into the smaller and compact modules. The robot is equipped with three 70 watts DC motor from Maxon, arranged in the shape of triangle. The maximum nominal motor speed of 7000 rpm is reduced through a planetary gearbox GP42 with the ratio of 12:1. The amplified mechanical torque on the output shaft of the gearbox is transferred to the wheel's shaft through the direct coupling and supported by a pair of the radial ball bearings with housing- T shaped type. The velocity feedback is done by using 500 pulses digital incremental encoders. The velocity of the wheels is controlled by three Faulhaber motor drivers (MCBL 2805), each equipped with a RS232 communication port. The controllers read the pulse trains from the motor encoders and produce PWM output voltages for the motors based on a PID algorithm. The result is a mobile robot with maximum linear speed of 2.4m/s and acceleration of 2.5m/s2.

The only sensors using in the "Musashi Robot" are an omni-directional camera, a compass and three DC motor encoders. The electrical power is supplied by a set of Li-Polymer batteries (nominal voltage 25.9V/2Ah). The necessary required voltage for the camera, compass module and the micro computer power supply are produced by converting 25.9V to 12.0V and 5.0V. The power consumption of the robot is in average about 40W, and the operation duration of the robot is estimated to be 0.5h. In order to realize the shooting capability, an electromagnetic kicker, designed and constructed specifically for "Musashi" robot. The kicker is based on an Induction-Coil-Gun Approach and consists of two interacting parts, the coil and the rod.

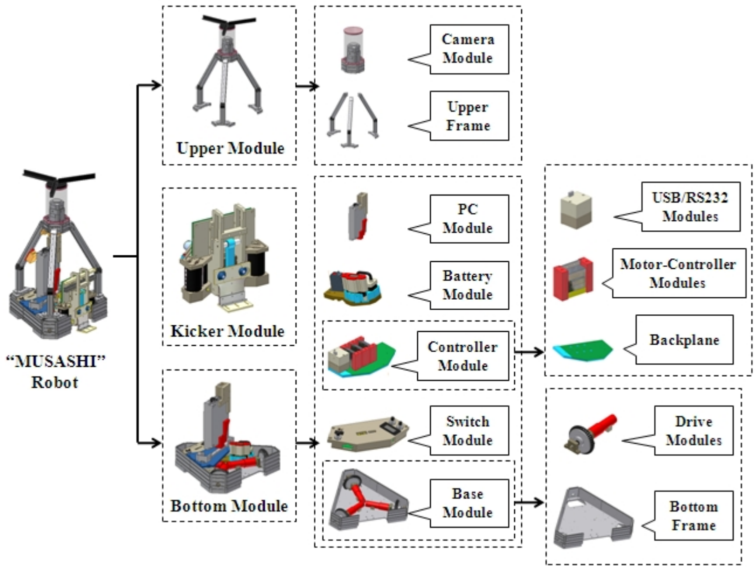


Fig.1 "Musashi" robot hardware configuration and modular architecture

2.2 Development of the electromagnetic kicking Device

The previous kicking device was spring based type. The key idea was to charge a series of strong torsion spring by using a special design of a cam in shape to shoot and lift the ball. The disadvantage of our spring type kicking device was to not able to change the shooting power, then we could not use the kicker for passing function specially in set-player. In this direction, an electromagnetic kicking device was developed in order to increase the team strategy variation using pass function.

The developed kicking device was designed and constructed specifically for "Musashi" robot (Fig.2). The kicker is based on an Induction-Coil-Gun Approach and consists of two interacting parts, the coil and the plunger. The coil is wound over a nonconducting tube with a central longitudinal whole. The tube is constructed from PVC and has 2 [mm] thickness. Inside the tube lies the movable rode which is made out of a ferromagnetic material. By sending a current through the coil, a magnetic field emerges which magnetizes the rod in the same sense as the coil. So the side of the rod, facing the rod, sees an opposing pole and the rod shoots out of the tube. This effect (of the two separate magnets) is the attraction of the rod inside the coil as a shooting mechanism. The rod is constructed out of two parts: First, the front part, which is constructed out of MC Nylon and which is in the deactivated state inside the coil and second the rear part, which is constructed from a ferromagnetic material like steel. As the metal part moves inside the tube, the front part pushes against a lever arm. To control the kicker functionality a Peripheral Interface Controller (PIC) based module is developed.

The DC/DC converter is a typical element which can convert 24V DC to 90V DC to provide power for the 90V solenoid. The kicking device is equipped by four 22000 [μF] capacitors. Total 88000[μF] is used as a buffer that can be charged from the sub battery. The capacitors will be charged automatically when the kicker switch turns on. According to the team strategy, PC installed on the robot can send the different signal, "kick signal" or "pass signal" to PIC (PIC18F1320) installed on kicker controller board. The kicking device control depends on the amount of current through the coil. The kicking device power is controlled based on the amount of current which can through the coil. The coil current is controlled by five MOS-FETs which are functioned as a switch between the capacitors and the solenoid. In instance, If the kick signal send to the PIC, the current is thrown to the coil for 10 [msec], and the robot will kick the ball with speed of 7 [m/s]. And in case of the short pass signal, the current is thrown to the coil for 5 [msec] resulting in passing the ball for set-player. After kicking or passing, capacitor is charged for 4 seconds automatically. The kicking device will become on standby for next time.

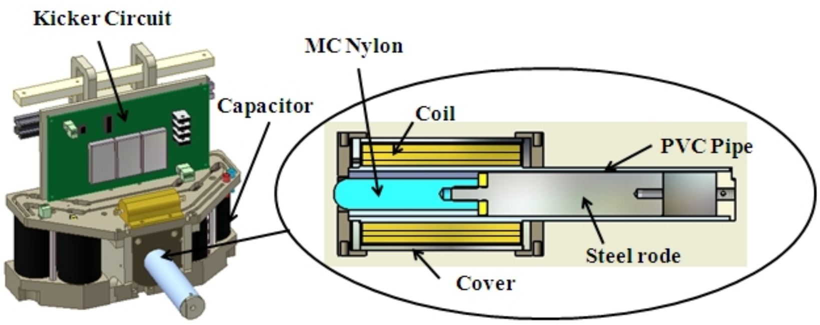


Fig.2 Overview of the developed Electromagnetic Kicking Device

3 Human-Robot Safety Concept

It is necessary that MSL obligates to give the security precaution to the robot of all team in consideration of the safety of all people who have the possibility of coming in contact with the robot. Based on our previous studies on reducing the risk through the risk-assessment, and surveying of the critical hazard in other team's robots that could guide us to understand the present situation regulation regarding to the safety concept, in last year, we conducted the collision experiment using an oil-clay and a chicken-leg-bone, and proposed the "Severity"[5].

However, the structure and strength of the chicken-leg-bone is different to the human one. Therefore, we considered that the reliability of the previous severity was not enough. In this year we selected the pig-leg-bone, because of it has the closer Young's modulus to the human-leg-bone, and we reevaluated the severity. In our evaluation in comparing the pig-bone with the chicken-bone, the acceptable "pain level" can increase from 13.6 [mm^3] to 30 [mm^3]. Moreover, we conducted the collision experiment which used a robot and oil-clay, and got the relation between the robot collision speed and a dent-amount of clay (Fig.3). Based on the obtained relation data, we derived the equation 1. The equation 1 shows that the dent-amount of the clay exceeds 30.0 [mm3] when the collision speed of the robot was more than 1.6 [m/s].

$$\text{Dent-amount [mm3]} = 18.3 \times \text{Velocity of the robot [m/s]} \qquad (1)$$

As a result, we can figure out that the robot-speed of 1.6 [m/s] has the possibility of breaking the human-bone and it is recommended to avoid using the robot with more than 1.6 [m/s] speed. On the other hand using 1.6 [m/s] as a maximum robot speed cannot make dynamic and attractive game as we expect for future of MSL. Then we have to add a new definition of a risk based on ISO14120 to our Human-Robot safety concept. In this direction, the risk is defined by following equation:

$$\text{Risk} = \text{Frequency} \times \text{Severity (Velocity [m/s])} \qquad (2)$$

Fig.3 The pig-leg-born for experiment

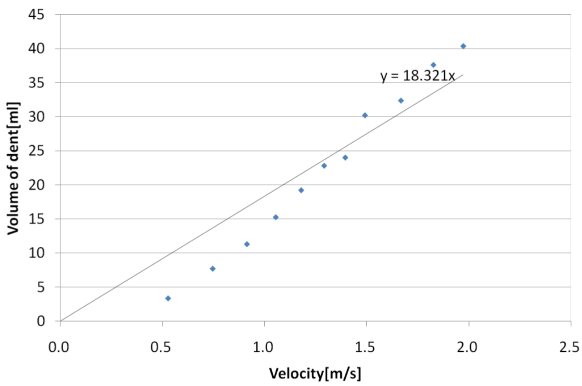


Fig.4 The relation between robot speed and dent-amount

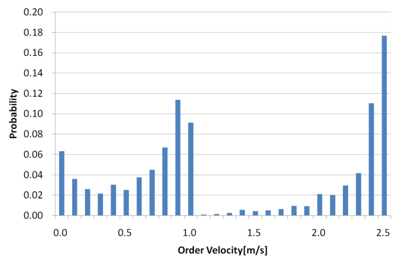


Fig.5 The generating frequency of robot speed

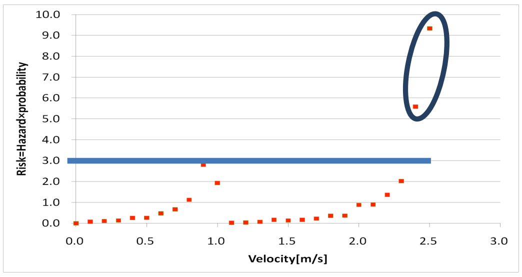


Fig.6 The generating frequency of robot speed

Based on the above equation, the risk consists of the severity and the generating-frequency. Fig.4 shows the generating-frequency corresponding to the robot speed. The data illustrated in Fig.4 was recorded from a game, done in our experiment field, for 15 minutes. To decrease the risk factor, and keeping the game dynamic and attractive, we set the 10 percent as a border value of the generating-frequency. Then, the border value can be calculated 3 based on equation 2. From the Fig.5 and equation 2, we can obtain the risk distribution corresponding to each robot speed, shown in Fig.6. In instance, the “Musashi” robot is "unsafe" if it drives more than 2.4 [m/s]. In conclusion, to introducing the safety concept based on the global standard to the RoboCup MSL, we suggest following rules:

- Introducing the risk-assessment by collision experiment for all participant robots
- Introducing the concept of “stamina” (limitation to the capacity of the battery, limitation to the execution time of maximum speed by software)

4 Software System

4.1 Auto Calibration Algorithm using Support Vector Machine (SVM)

In this section, we present a color recognition algorithm using the support vector machine (SVM). In the rules of RoboCup MSL, robots must detect a yellow ball, green field, white lines and black obstacles. Currently, the parameters of our robot color recognition are set manually, however RoboCup organization has vision that the game environment should be changed to outdoor from indoor in near future. Therefore the development of automatic color recognition algorithms, which can have reliable performance in the outdoor environment under dynamic changing light condition, will be a critical point. In this direction, we developed a color calibration algorithm using SVM [1, 2]. SVM is one of the classification algorithms which it has high generality since it can calculate a super plane that maximizes the margin of classes, Fig.7.

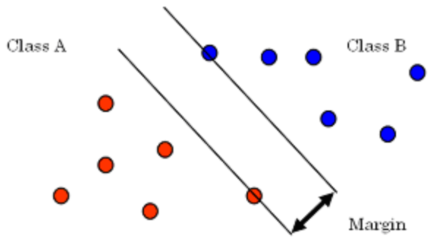


Fig.7 The principle of SVM

Fig.8 Camera image

Our current vision system uses YUV color space. The obtained image is binarized by different thresholds to detect target colors.

In our algorithm, the SVM is trained by the YUV values of the classes and the mean of the obtained image YUV values. After training, the obtained image is binarized by setting the maximum and minimum value in the distribution of each class as a threshold. In instance, the image in Fig.8 was binarized manually (however, the person in charge of color adjustment is professional) and by using SVM resulting in Fig.9 and Fig.10, respectively. In these figures (a), (b), (c), and (d) illustrate the yellow, green, white, and black color, respectively.

To evaluate the performance of the developed algorithm, we compare ten different images obtained from our experiment RoboCup field. We consider the similarity of manually and SVM binarized images as the recognition rate of SVM. The results are shown in Table 1. The mean of the recognition rates are over 90% in each class. The time, to convert result of SVM classification to the binarized image, is about 15 seconds.

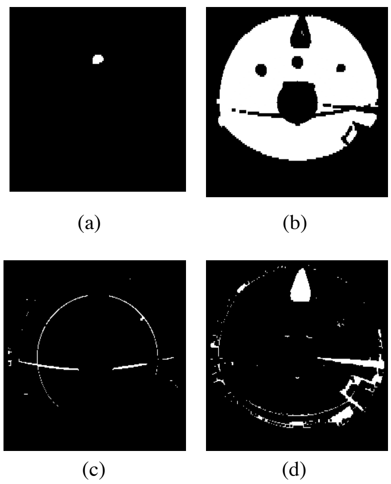


Fig.9 Images binarized by hand

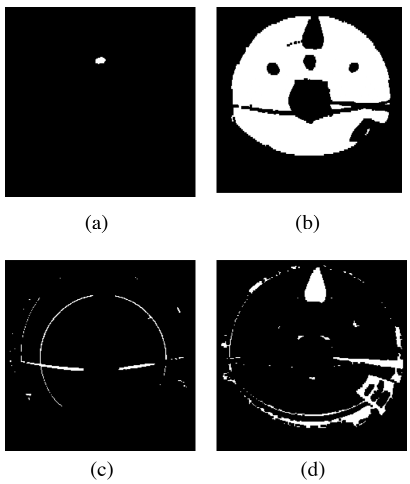


Fig.10 Images binarized by SVM

TABL.1 EXPERIMENT RESULT

Yellow Recognizing rate [%]	Green Recognizing rate[%]	White Recognizing rate [%]	Black Recognizing rate [%]
99.92	94.28	98.57	96.05

4.2 Self Localization using MCL and dead reckoning

Our vision system uses omni-directional images in the YUV and HSV color spaces. We extract white and green from these images to avoid detecting white objects existing out of the field. To detect field lines, we scan the image using multi-layered scan lines arranged in radial direction and search the crossing points between the field lines and the scan lines(Fig.11).

We use the MCL method which is one kind of particle filters for robot self localization. This method is used widely for mobile robot localization since it has good real-time performance and robustness. The field model is a Cartesian coordinate system with the origin at the center of the field in our algorithm. The robot state is represented by a vector $\mathbf{x}_t$ which consists of position (x, y) and direction θ . We calculate the posterior probability distribution $p(\mathbf{x}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_t)$ from the state of a robot $\mathbf{x}_t$ and the sensor data at $\mathbf{y}_t$ the current time t . In the particle filter, a probability distribution is represented by a set of N random samples. This method proceeds in two phases.

Prediction Phase: In the first phase we predict a current state of the robot. This is specified as a conditional distribution $p(\mathbf{x}_t \mid \mathbf{x}_{t-1}, \mathbf{u}_{t-1})$ from the previous state $\mathbf{x}_{t-1}$ and a control input $\mathbf{u}_{t-1}$. The predictive distribution is obtained by following equation.

$$p(\mathbf{x}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_{t-1}) = \int p(\mathbf{x}_t \mid \mathbf{x}_{t-1}, \mathbf{u}_{t-1}) p(\mathbf{x}_{t-1} \mid \mathbf{y}_1 \ldots \mathbf{y}_{t-1}) d\mathbf{x}_{t-1} \tag{3}$$

Where $\mathbf{u}_{t-1}$ is the odometry data and it added to each particle.

Update Phase: In the second phase we update the distribution $p(\mathbf{x}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_t)$ according to the sensor data. The likelihood of $\mathbf{y}_t$ at state $\mathbf{x}_t$ is represented as $p(\mathbf{y}_t \mid \mathbf{x}_t)$. The posterior distribution is obtained using Bayes theorem.

$$p(\mathbf{x}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_t) = \frac{p(\mathbf{y}_t \mid \mathbf{x}_t) p(\mathbf{x}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_{t-1})}{p(\mathbf{y}_t \mid \mathbf{y}_1 \ldots \mathbf{y}_{t-1})} \tag{4}$$

Where $\mathbf{y}_t$ is distance to the field line. After updating the likelihood of all particles, they are normalized and re-sampled. Re-sampling proceed according to the weight of each particle: new particles are generated around the particles that have high likelihood. There is possibility of failing in detection of direction because of the symmetric shape of the field; a direction sensor is implemented on the top of the robot.

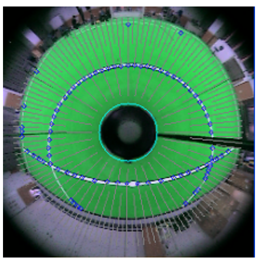
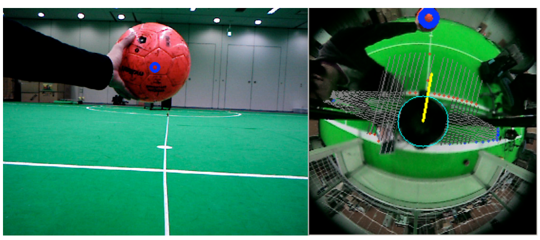


Fig.11 Detecting the field lines



(a) (b)

Fig.12 Monocular camera image (a), Omni-camera image (b)

5 Fusion of Omni & Monocular camera for the goalie

An omni-directional camera is prevalently used in Middle Size League to obtain a 360 degrees image of the pitch and information on the distance to the ball. But, to detect the height of a flying ball is a demanding task by using only an omni-directional camera. So we added a monocular camera to realize a stereoscopic view of the ball. Image obtained from camera is used in perspective projection. We developed the expression for omni-directional camera's and monocular camera's ray. The intersection of the two lines is the ball's position. Fig.12 indicates the captured images and the position of the ball (shown by blue color in each image) detected by developed algorithm.

Acknowledgements

This work is supported by Meisenkai Co.

References

[1] H.Matsubara, M.Asada, H.Kitano, "History of RoboCup and Prospects of RoboCup-2002", RSJ, Vol.20, No.1, pp.2~6, 2002, In Japanese

[2] A.A.F.Nassiraei, "Concept of Intelligent Mechanical Design for Autonomous Mobile Robots", Kyushu Institute of Tech., Ph.D thesis, 2007

[3] A.A.F. Nassiraei, Y.Takemura, et. al. "Concept of Mechatronics Modular Design for an Autonomous Mobile Soccer robot", CIRA 2007, Jacksonville, pp.178~183

[4] A.A.F. Nassiraei, K Ishii, "How Does "Intelligent Mechanical Design Concept" Help Us to Enhance Robot's Function?," Intelligent Unmanned Systems: Theory and Applications, Volume 192, pp. 155-178, Springer 2009.

[5] A. A. F. Nassiraei, Yuichi Kitazumi, "Hibikino-Musashi Team Description Paper", RoboCup 2010 in GRAZ, 2010

[6] C.J.C.Burges, "A Tutorial on Support Vector Machines for Pattern Recognition", Data Mining and Knowledge Discovery, vol.2, pp.121-168, 1998.

[7] K. Tsuda, "Overview of Support Vector Machine", J.IEICE, Vol.83, No.6, pp.460-466, 2000.