Development of Ball Detection System with YOLOv3 in a Humanoid Soccer Robot

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Abstract. One of the practical researches of humanoid robots is research on the use of humanoid robots to play soccer. Research in this field is also encouraged by the existence of various humanoid robot soccer competitions. In humanoid robots for soccer, one of the important aspects is the robot's ability to detect the ball, goal, field boundaries and other players, both friend players and opposing players. This study focuses on the ball detection system which is a basic ability that humanoid robots need to have. The ball detection system developed in this study uses the YOLOv3 method. The test results show that the system built and trained with 3000 image samples can detect balls at a distance of 50 to 900 cm. The time it takes to detect the ball is about 0.033 seconds.

1. Introduction

Humanoid robot is a robot that has a body structure like a human so that it can walk like a human [1]. Humanoid robots also have senses like humans, so they are increasingly popular as research media. Many researchers around the world conduct research on various aspects of humanoid robots such as the ability to move on two legs, manipulate with hands, audio-visual sensing, interaction between robots and humans, and adaptive robot control systems [2].

One of the applications of humanoid robots is the use of humanoid robots to play soccer. In Indonesia, research in this field is also encouraged by the Indonesian Humanoid Soccer Robot Contest which is held annually by the National Achievement Center under the Ministry of Education, Culture, Research and Technology. The ability that a soccer humanoid robot needs to have is the ability to detect the ball, goal, field boundaries and other players, both friend players and opposing players. The robot's detection capability is supported by the development of a technology called computer vision. Computer vision is a field of knowledge that focuses on artificial intelligence systems and image acquisition and processing [3].

Computer vision that is applied to robots is usually called robot vision. Robot vision is the ability of a robot to extract, characterize and interpret information from a three-dimensional object [4]. In principle, the robot eye (camera) can distinguish the color of an image (object) it sees. Data from the image captured by the camera sensor will provide information about the color of the object, so that the robot can know the object it sees. After the object is seen by the robot, the robot will chase the object. In soccer robots, the detection of these objects is carried out, among others, by color segmentation, morphology, and "blob detection" [5]. With the development of machine learning, object detection methods are developed using artificial neural networks, one of them is a method developed by Joseph Redmon et al called You Only See Once (YOLO). The YOLO system has three stages, the first stage is to change the image size to 448 x 448, the second stage is to give the image to a single convolutional network, and the last stage will process the
results of the network based on a certain threshold to determine what objects are in the image. The image [6]. The YOLO method was later developed into several versions, including YOLOv3 developed by Joseph Redmon and Ali Farhadi [7] and YOLOv4 by Alexey Bochkovskiy et al [8].

The focus of this study is to build and test the ability of a ball detection system, considering that ball detection ability is the most important ability that a soccer humanoid robot must possess. The method that will be used in this study is YOLOv3. It is hoped that this method will allow the humanoid soccer robot camera device to better recognize objects. This study aims to test that the YOLOv3 method can be applied to humanoid soccer robots, so that humanoid soccer robots can detect ball objects quickly and accurately.

2. Method

The design of the humanoid soccer robot was developed from the mechanical design of ROBOTIS-OP3. The humanoid robot uses NVIDIA Jetson Nano as the main controller and OpenCR as a sub-controller that controls the servo motors. A soccer humanoid robot made using a Logitech C525 camera device to obtain object images. Data from the camera is then forwarded to the Jetson Nano, to be processed using the YOLO method. Furthermore, the main controller will control the servo motors through the sub-controller so that the robot can perform the desired action based on the results of ball detection, for example walking towards the ball or kicking the ball. The algorithm for the decision-making process of the robot can be seen in Figure 1.

Figure 1. Robot Control System Flowchart

The scheme of the humanoid robot detection system in this study consisted of the stages of sampling, labeling, training, optimization, and running (Figure 2). Sampling is taking an image of the object to be detected using a digital camera [9]. Objects are positioned under several possible conditions. In this study, 3000 image samples were used. The training process requires a training dataset. The dataset is in the form of images and image labels. The label in the image refers to a bounding box that has the properties of position (x,y), height and width, and the appropriate label. These labels are determined manually by us at the labeling stage with the help of labeling software. Furthermore, the training process is carried out so that YOLO can recognize objects that have been previously determined in the labeling process. This process generates a detection model.

The training model generated from the training stage is too complex to run smoothly on Jetson Nano. So that the model can be run on Jetson Nano more smoothly, the output model of the training results needs to be optimized using Tensor RT. After being optimized, the training result model can be used in the humanoid robot control program (inference stage). This inference process requires image input from the camera and produces an output in the form of a bounding box. This property of the bounding box will later be used to determine decisions in the robot control system, in this case detecting whether there is a ball or not. The program code for YOLOv3 used in this study is based on the code published by Alexey Bochkovskiy at https://github.com/AlexeyAB/darknet.

Figure 2. Stages of Object Detection System

The data to be taken in this study is the minimum and maximum distance of the robot in detecting the presence of the ball. A similar study has been conducted by Hakim et al, namely detecting the presence of a QR Code using a quadcopter [10]. Other data that is also observed is data on whether the robot can detect the presence of a ball that is still moving.
The data collection process was carried out three times and then the values were averaged. The purpose of data collection is to determine the maximum distance that can be detected by the humanoid robot detection system. In addition, this study also aims to determine the time required for the robot to detect the presence of the ball.

3. Results and Discussion

The procedure for data collection of the ball detection process against the ball can be seen in Figure 3. To simplify the data collection process, the distance taken in this study is the distance measured from the center position of the humanoid robot's foot to the ball.

![Figure 3. Procedure to test ball detection ability](image)

### 3.1. Ball Detection Ability

The ball detection method uses YOLO which is specifically made to detect the presence of the ball. In this experiment, the humanoid robot will focus on detecting objects (balls) by labeling samples of ball images. With this training, the robot is expected to be able to recognize objects in various situations that may occur. Figure 4 and Figure 5 show the robot in detecting the presence of the ball when the ball is fully visible and when the ball is partially visible. The two images show that the robot can detect the presence of a stationary ball in various circumstances, so it can be concluded that the ball detection system has worked optimally.

![Figure 4. Robot detects a fully visible ball](image) ![Figure 5. Robot detects partially visible ball](image)

However, Figure 6 and Figure 7 shows the system has not been able to detect the ball accurately when the ball is moving. The ability to detect a moving ball is needed in actual match conditions, the robot needs to move closer to the ball early so it doesn't lag behind the opposing players. Further research related to the detection of moving balls still needs to be done.
Figure 6. The robot does not clearly detect a slow moving ball.

Figure 7. The robot does not clearly detect a ball that is moving slightly fast.

3.2. Ball Detection Distance and Time
The ball detection distance test is carried out starting from a distance of 50 cm, then 100 cm, and then increasing by 100 cm. Tests show the ball can be detected up to a maximum distance of 900 cm, and at a distance of 950 cm the ball cannot be detected. Figure 8 and Figure 9 show the two conditions at a distance of 50 cm and 900 cm.

Figure 8. The robot detects a ball with 50 cm distance

Figure 9. The robot detects a ball with 900 cm distance

Figure 10 shows the relationship between the robot's detection time and the distance of the ball from the robot. In general, the detection time required for the robot to detect the presence of the ball is relatively constant. From the picture, it can be seen that the robot can detect the presence of the ball at a distance of 50-900 cm. The average time required for the robot to detect the presence of the ball is 0.033 s.
4. Conclusion
The ball detection system on the humanoid robot has been successfully built using NVIDIA Jetson Nano as the main computational unit. The test results show that the system built and trained with 3000 image samples can detect balls at a distance of 50 to 900 cm. The average time needed to detect the ball is 0.033 seconds. However, further research related to the detection of moving balls still needs to be done. Furthermore, this system needs to be developed to detect goals, field boundaries and other players.

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