Effective Detection of Position and Orientation Using Infrared LED Arrays and Camera, for Humanoid Robots in an Arcade Game Machine

Woosung Yang, Ill Woo Park, Jun Sup Kim, Sun Woo Lee, Jin Oh Kim

1, First Author
School of Robotics Kwangwoon University, dreamrize@kw.ac.kr

2, Corresponding Author
School of Robotics Kwangwoon University, mrquick@kw.ac.kr

3, School of Robotics Kwangwoon University, time2space@outlook.com

4, School of Robotics Kwangwoon University, sayhacker@gmail.com

5, School of Robotics Kwangwoon University, jokim@kw.ac.kr

Abstract

In this paper, we propose and demonstrate the effectiveness of a practical method to detect the positions of toy-sized, humanoid fighting robots in an arcade game machine. The positions of the robots on the game stage are detected by camera, which is located under the stage. Infrared LED arrays, used as markers, are attached to the soles of the feet of the humanoid robots. The detection method is based on finding the LED position markers using camera vision. For reliable detection unaffected by ambient visible light or heat, we used infrared LEDs and band-pass filtered camera lenses. The positions and orientations of the robots are determined by detection of the marker patterns. These also make it possible to identify each of the robots.

Keywords: Position detection, IR LED marker, Vision System, Robotic Arcade Game

1. Introduction

In this paper, we propose a practical method to detect the positions of humanoid figures in an arcade game machine. The action figures in this game are two fighting robots. When one robot knocks the other robot down, the player-in-control gains points. After a two minute game, the player who has the most points wins the game. The machine contains two toy-sized humanoids, a CCD camera, a stage, a power supply for the robots, two joysticks, a user interface screen, and decorative lights. The game has two operation modes. The first is two-player-mode, in which each player operates one robot to knock down the other. In this mode, the proposed method is not applied during the game. At the finish of the game, however, the robots return to their home positions on the stage automatically, to be ready for the next game. The second mode is one-player-mode, in which a player operates one robot and fights against the other robot. In this mode, the second robot is computer operated. In this single player (automatic) mode, the position-detection-function is required at all times.

Methods for detection of position can be divided into two categories, contact and noncontact methods. The contact method can easily detect objects with reliable accuracy, but it can affect the object-dynamics due to unpredictable disturbances by the detection device. If the amount of disturbance is acceptable, such as a potentiometer located on the output of the reduction gear of a motor-gear actuation system for measurement of rotation angles, then contact detection might be used. For a biped robot; however, the contact method is generally an undesirable solution, because the robot itself has relatively poor stability (i.e., it can easily fall down).

A good example of a noncontact system to detect positions, is use of a camera, such as that used in a robot soccer system [1, 2]. The robots in the system have markers on their tops and the vision camera is located on ceiling of the system [3, 4]. The camera detects the markers and determines positions with respect to the stage, which supports the robots. In this situation, another problem arises, power supply cables. If the robot has an internal battery, and charging or replacing the battery is allowable, the power supply problem is negligible. In the case of an arcade game, maintenance time – including for changing batteries – must be minimized. The amount of gaming time directly affects circulation of users, and the...
number of games, which affect income. For these reasons, a constant external power supply is better than using internal power.

The vision system of the robot soccer game, introduced above, uses color images of the marker for detection of position and orientation. The recognition rate is easily affected by the brightness and color temperature of ambient light [5]. Thus external light conditions may cause misrecognition of position, and decrease reliability. In the soccer game, conditions are strictly regulated according to the rules of the game. In the case of the robot fighting game, light conditions around the machine cannot be realistically regulated, because the installation circumstances involve various light sources and the machine needs to be treated as the other arcade game machines are.

We solved these problems simultaneously by locating the power supply line on the ceiling of the machine, and by installing the markers on the soles of the feet of the robots. A dark, transparent glass plate was used as the stage floor, and the camera was located at the bottom of the game machine targeting the bottom of the glass stage. The marker patterns on the soles of the robot feet were made using an infrared (IR) LED array, and IR pass filters were installed on the lens of the camera. With this arrangement, visible light and heat were filtered out, and the camera could detect the robots reliably using black-and-white images.

This paper is organized into six sections. The overview of the system design is explained in Section 2 and the hardware realization of the vision system in Section 3. The algorithm for detection of positions is explained in Section 4, and we present the experimental results in Section 5. Last, we present conclusions in Section 6.

2. System overview

Figure 1 shows the overall system design schematic, and Figure 2 shows pictures of the game machine. The system is composed of cable connection mechanism, main controller for operation of the game, and the camera.

On the roof of the machine, the cable connection mechanism is installed. As shown in Figures 3 and 4, power lines for actuation of, and communication with, the robots and lines for IR LED marker control pass through a three-slip-ring mechanism. Two rings are for each robot, and one ring is for collecting the lines and connecting with the main controller and power of the game machine. This mechanism ensures the connection of lines for communication and power with respect to the random movement of the two robots, with small and allowable dynamic disturbances from the spring type flexible cable.
The main controller determines the location of the two robots with the camera, plays the game sounds, displays the game situation, operates the robots, and interfaces with two joysticks through USB (Universal Serial Bus) lines. The camera is installed under the stage floor, which is the dark, transparent glass plate supporting the robots.

As shown in Figure 5, the marker is controlled by the main controller communication signal. The signal goes to the local controllers, which have microprocessors, installed inside each robot. The LED arrays on the soles of their feet are controlled by the local controller.

![Figure 2. Humanoid arcade game machine](image1)

![Figure 3. Cable connection mechanism using 3 slip rings](image2)

![Figure 4. Schematic of the control signal connection](image3)
3. Vision system design for detecting the robot positions

The vision system is designed with IR LED arrays, a dark, transparent glass plate, wide range optical lens, IR low and high pass filter, and camera as shown in Figures 6, 7, and 8. The array pattern is an “L” shape on each sole to identify the position and orientation of each robot in 2-dimensional space. Surface-mounted LED-chips on printed circuit boards (PCB) were installed on the bottom of the soles, facing the glass plate. To apply an easy and simple algorithm for detecting positions, the array patterns were designed with shapes that would allow the system to distinguish the left and right soles of each robot (see bottom of Fig. 6). A centroid calculation algorithm was used to determine the position of the center of each body.

Figure 5. Local controller schematic of the humanoid

Figure 6. Vision system design
The wavelength of the IR LED used as a light emitting marker was 700 nm. Other ambient radiation was filtered with the IR high and low pass filters. The higher frequencies of light, such as visible light, were filtered out by the low pass IR filter. The lower frequencies of IR light (heat) were rejected by the high pass IR filter. This type of configuration is called an IR band-pass filter with a filter frequency of 700 nm. This design only allows the IR light of the markers (generally called middle wavelength IR) to pass through to the camera. The possibility that the CCD image sensor might be affected by unexpected light noise, such as fluorescent light (shown in Figure 9), was thus avoided. As a result, the detection of positions was achieved with high reliability, as shown in Figure 10.
We used a wide range optical lens with 110° angle of view. This lens type has a wide range of view and it shortens the distance between the object and the camera, resulting in a reduction of height. It can also introduce a barreling distortion effect of the image, which can introduce error near the edges as shown in Figure 9. These negative effects can be dealt with a compensation algorithm (which adds to the calculation burden) or by simply cropping the near edge image. We cropped the distorted part of image and used the acceptably distorted images in order to keep the image processing (position detection) speed within 25 fps (frames per second). This cropped image decreased the resolution of the image, but handling the distorted or blurred parts was also meaningless. In the end, we used the center part of each image with a resolution of 500×360 pixels, from the full resolution of 640×480 pixels. After the crop, we scaled the image size into 320×240 for fast image processing.

![image](a) Before light noise incident  
(b) After light noise incident  
(c) IR band-pass filtered image of (a)  
(d) IR band-pass filtered image of (b)

Figure 10. Improvement of image with IR band-pass filter

4. Position detection algorithm

We used a simple algorithm, the centroid method, to achieve a light calculation burden. The detailed algorithm is displayed in Figure 11. From the two centroids, left and right, we can get the robot’s position. Connecting the two centroids with single line, we can also get the orientation of the robot as shown in Figure 12, with respect to the coordinate frame of the stage. Identifying each robot requires repetition of this process for each robot. The total time for position and orientation scanning is four image frames for both robots. The speed is relatively slow (6.25 Hz = 0.16 s), but it is enough, because the step frequency of a robot is less than 5 Hz (i.e., 0.2 s).

This simple method was more powerful than any other high level image processing technique, for the goals of this system. Many high level image processing techniques can be categorized as having two objectives: improving robustness and identifying the performance of the robot. The first of these was achieved as stated in Section 3. The second one was solved by system design, which allowed the marker patterns of each robot to be turned on and off.

5. Experimental results

The accuracy of the position and orientation results is indicated in Table 1. In this experiment, we translated the robot alongside with vertical direction (Y) with its orientation 45°. The maximum position error was about 7mm, and the orientation error was 3°. If we adopt the diagonal distance as a representative measure for comparing the footprint of a robot (87mm × 55mm)
with the position error, the maximum error ratio was about 10% and the mean error ratio was less than 6.6%. The error ratio for orientation was less than 6.9%.

From another viewpoint, considering the stage size (700 mm × 600 mm), the maximum error was about 1%. This result is quite accurate, considering also the effective resolution of the camera (500 × 360 pixels). This means that one pixel on the X-axis covered 1.4 mm, and one pixel on the Y-axis, 1.67 mm. Converting the maximum error into pixels, we have a four-pixel error in the X and Y directions.

Figures 13 and 14 show the results from the control software and tracking experiment. The center of the circle represents the position and the lines in the circle indicate the orientation. The situation is that the start positions and orientations of the robot are random, and the robots are returning to their home positions automatically to prepare for the next game.

Figure 11. Position and orientation calculation process
Figure 12. Algorithm for calculating orientation

<table>
<thead>
<tr>
<th>Real Position</th>
<th>Real Orientation(°)</th>
<th>Position Result</th>
<th>Orientation Result(°)</th>
<th>Position error</th>
<th>Orientation Error(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X(mm)</td>
<td>Y(mm)</td>
<td>X(mm)</td>
<td>Y(mm)</td>
<td>X(mm)</td>
<td>Y(mm)</td>
</tr>
<tr>
<td>678</td>
<td>162</td>
<td>45</td>
<td>676</td>
<td>156</td>
<td>43</td>
</tr>
<tr>
<td>678</td>
<td>276</td>
<td>45</td>
<td>673</td>
<td>227</td>
<td>42</td>
</tr>
<tr>
<td>678</td>
<td>487</td>
<td>45</td>
<td>672</td>
<td>480</td>
<td>44</td>
</tr>
<tr>
<td>678</td>
<td>595</td>
<td>45</td>
<td>675</td>
<td>589</td>
<td>45</td>
</tr>
</tbody>
</table>

Figure 13. Control software
6. Conclusion

We designed an arcade game machine which features two humanoid fighting robots. For this machine, we created a simple and effective method for detecting the position and orientation of the action figures using a vision camera. We systematically designed the detection system to ensure its robustness, accuracy, and reliability regarding hardware and software. We achieved detection at 6.25 Hz for two robots, with a 1% error ratio.

7. Acknowledgement

This research was conducted with the support of a research grant from the Seoul R&BD Program (JP110042).

8. References