Effects of Mirrors in Mobile Robot Navigation Based on Omnidirectional Vision

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Abstract. In this paper, we present a omnidirectional vision-based navigation system that includes three approaches: obstacle avoidance based on sonar vision, direction estimation based on sonar vision and confection method of obstacle avoidance and direction estimation. This paper peruses effects of the mirror in omnidirectional vision applied to mobile robot navigation, as well. We design and establish four mirrors: small non-uniform pixel-density hyperbolic mirror, small uniform pixel density hyperbolic mirror, large non-uniform pixel density hyperbolic mirror and spherical mirror. This paper provides autonomous navigation for a mobile robot in an unknown environments. We use omnidirectional images without any prior calibration and detects static and dynamic obstacles. Our experiments operates in indoor environment with our particular sonar vision. The result show that small uniform pixel density hyperbolic mirror have best performance and big non-uniform pixel density hyperbolic mirror have weak performance in vision base mobile robot navigation. Also, the experimental results show acceptable performance considering computation costs in our sonar vision algorithm.

Keywords: Omnidirectional vision · Mobile robot · Vision navigation · Sonar vision

1 Introduction

The purpose of mobile robot navigation is moving in a structured or unstructured environment, and transferring to the target.Vision based mobile robot navigation, in a structured environment, without having any prior knowledge of the environment, is a very powerful capability for robots. A major advantage of image based navigation systems, no need to have other sensors, and thus reduce the cost.

Omnidirectional vision sensors for mobile robots are valuable because they are provide full visibility of the surrounding environment of the robot, just in a frame [4]. This is important because knowing the positions of objects in the

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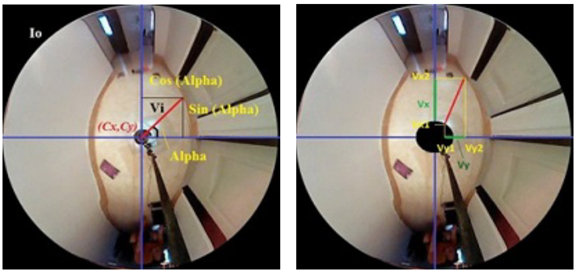
surroundings of the robot, will help robots to perform tasks such as matching or intuitive navigation map. 360 degrees field of view reduce visual perceptual bad view. In addition, use of omnidirectional vision system in a very dynamic environment and a burst of consecutive images of the environment around the robot, provides easy to use tracing techniques to follow the desired objects. Since access to the systems of all popular way for us not possible, therefore, in this work, we design and build our own special omnidirectional system.

In this work, we combine two main behaviors, which allow the robot to navigate in different environments. First, estimate the path and the second, identify barriers and lack of dealing with them which takes place during the pursuit. Both actions are performed using sonar vision algorithms [1] directly on omnidirectional images [2]. Both techniques are implemented simultaneously. The important point is that, omnidirectional image does not require any calibration and we do not change the appearance of the image all the way, as well. Also, all the steps can be performed directly on the original omnidirectional images.

The rest of the paper is as follows. In the section 2, we've talked about special omnidirectional system which created. In the section 3, we have explained the sonar vision algorithms. Also in this section, we describe the algorithm for estimating the path, avoiding collisions with obstacles and also remove the light reflection from the surface. In the section 4, we present how the robot navigation. Then in the section 5, presents the experimental results and discuss them. Finally, Section 6 presents the conclusion and future plans we have.



(a) (b)

Fig. 1. Examples of the image captured by our catadioptric system

2 Omnidirectional Vision

The sense of sight is one of the ways to collect information from the environment. Usually, normal camera used for machine vision as the visual system. In contrast, we believe that as many visual nature is designed for different tasks, we also need to design different visual sensors for robots and use them for different tasks. Due to problems such as cost and technical limitations, it is not always possible. But omnidirectional vision and especially catadioptric vision are more flexible than the photography systems. Omnidirectional vision sensor for mobile robots are valuable because they are provide full visibility of the environment of the robot, just in a frame [1]. In this work, we used catadioptric vision[1]. We used Spherical mirror, small uniform pixel density hyperbolic mirror, small non-uniform pixel density hyperbolic mirror and big non-uniform pixel density hyperbolic mirror. We use [4,5,10] to build our mirrors. For this reason, we have implemented our design, build and optimize omnidirectional vision system with financial support, the Science and Technology Park of Gilan[2].

3 Sonar Vision

In this work, we developed a method based on sonar vision algorithm for omnidirectional images that known as the OmniVisual sonars (OV-sonars) introduced in [2]. The omnidirectional sonar including virtual beams [1,2] which is a circle from the center and all the way up to the point where a gradient of the image would continue. The important thing is that, we have not done any calibration on the camera image and the images are processed directly in the mirror and get to navigation. In this method, we directly use the images, all the way, to the navigation and images does not become to the panoramic image or the birds eye image. Therefore, processing speed has gone up as a result of the reaction of the robot path goes up against obstacles.

According to [2] k-th sonar $\boldsymbol{V_k} = \{v_1, ..., v_r\}$ shows apeak of r pixel of the omnidirectional image. any pixel v_i tally with:

$$v_i = I_o\{i \sin\alpha + C_x, i \cos\alpha + C_y\} \tag{1}$$

$$\alpha = k.2\pi/N_s$$

where Io is the main 2D omnidirectional image with semidiameter r and center in (Cx, Cy) and N_s is the number of sonars proceed for each image. Figure 1a determine method of producing a visual omnidirectional sonar.

To do this, first we detect of the image edge with Sobel edge detection algorithm. Then the gray image with an appropriate threshold are converted to black and white image. Then with the help of equation 1, sonar vision production and then we estimated path and the obstacles identified. Since our image is black and white, each pixel has a value of 255 was the first visual sonar, as it will prevent detection. To calculate the final motion vector that represents the path is correct and unstructed path we took advantage of the unit vectors. As such, we've created a vector of motion using visual sonar vectors. Unit vectors added together and all the sonar target point representing the path is open and unstructed to obtain. Then we point the ultimate goal and direction from the point of origin to

[1] A kind of omnidirectional vision system which uses of mirrors.

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the point of final motion vector drawing that represents us. Calculating a path through the following equations:

$$V_{xi} = V_{x2} - V_{x1} \tag{2}$$

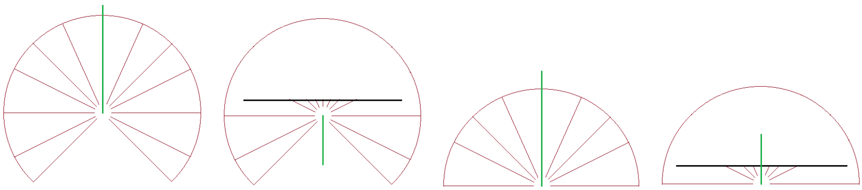
$$V_{yj} = V_{y2} - V_{y1} \tag{3}$$

$$\boldsymbol{f_k}(x, y) = V_{xi} + V_{yj} \tag{4}$$

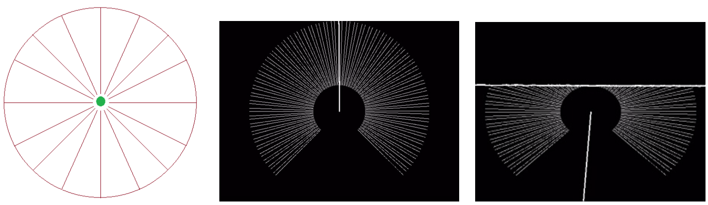
In this work, we predict the path for navigation, and along the way we will use the method of obstacle avoidance. An important point is that, in all phases of navigation, just the way, we use visual sonar. For obstacle avoidance we use the mothod in which Boyan et al [2] have proposed to have developed and innovative approach to predict the path will produce the visual sonar. Figure 1b define that how we obtain the unit vectors of a visual sonars.

3.1 Obstacle Avoidance Based Sonar Vision

To identify obstacles and deal with them in accordance with [2] we use 17 visual sonar. But changes in the scattering sonar created (Figure 2a).



(a) Without obstacle (b) With obstacle (c) Without obstacle (d) With obstacle



(e) Circle visual sonar vectors (f) Without obstacle (g) With obstacle

Fig. 2. Visual sonar vectors

We have to create a semi-spherical sonar, were inspired by [7]. But in the experiments, we found that there are problems in navigation. So we created our own special sonar (figure 2). We have formed the sonar because: 1-Generally, no obstacles behind valuable for navigation, thus the behind barriers would not affect to navigation. 2-The vector that represents the outcome of the move when there is no obstacle nowhere the final vector selects straight forward if there is no obstacle in the way when Boyan scattering sonar not choosing the right track. 3-When forward path is completely blocked the resultant vector indicates the reverse direction, in case if sonar in semicircular form, do not choose a path. 4-In this case, do not need our robots have a circular shape. Figure 2a and 2b display our sonars. Figure 2c and 2d display semicircle sonars. As you see despite the length of the final vector is small but just right direction is detected. In the section 3.2 you will see how we will solve this problem.

According figure 2e, you can see that in the case of Sonar are fully when there is no obstacle in the final vector is zero. In the figure 2c and 2d, you can see that when the Sonar semicircle despite a correct diagnosis in the absence of an obstacle course but when there is an obstacle in the path can not be detected correctly. In the figure 2, you can see that when the sonar are as follows: in both cases, unobstructed and obstructed, the resultant vector, correctly detects the correct path.

3.2 Direction Estimation Based Sonar Vision

We used an innovative method for estimating path. To do this, we use a lot of visual sonar to estimate the path. Unlike [2] that a large number of visual sonar to detect small obstacles sees fit, we hypothesized that the large number of sonar due to the resultant vector recognizes the right track and will determine the path, and we will show the right path to take. The reason for this claim is that due to the large number of sonars, despite dealing with small obstacles, but the end result Sonar on the right track and will be open. So, we created a visual sonar for every 2.5 degree. To complete the picture 360 degrees, we took the 144 sonar use. The tests found that the estimated path of the robot do not need back sonars, as well. Therefore, to estimate the direction of 108 sonar, we use the form in figure 3a and 3b. As you see in 3a the best direction estimated when there is no obstacle and correct path estimated when obstacle is in the robot forward.

3.3 Remove the Light Reflected from the Surface

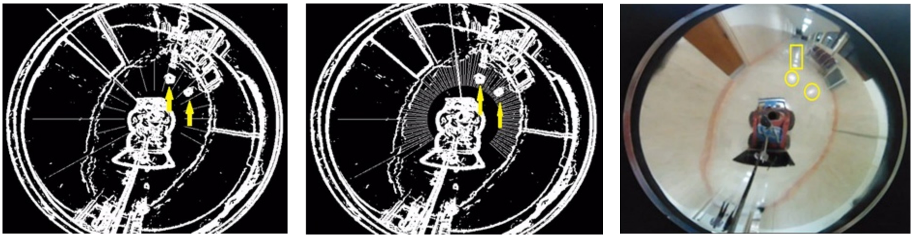
Usually this happens on the surface gloss with light sources and the issue of domestic environments are very common. Landscape reflected light is like an obstacle. To solve this problem, we decided to detect reflected light and forget them. In [2] boyan said that a pixel belongs to a reflected light when the HSV color space has a low saturation value (S), and a high value (V) is. Gradient of pixels with large difference $V - S$ do not need be considered as an obstacle. So unlike [2] only the value $w(i)$ with a certain amount of more than 100 tests were compared. If the number is above 100, it is not a barrier and if the difference is below 100, the obstacle is detected.

$$w(i) = V - S \tag{5}$$

$$\begin{cases} \text{Not Obstacle, if } w(i) \geq 100 \\ \text{Obstacle , if } w(i) < 100 \end{cases} \tag{6}$$

Where $v(i)$ and $s(i)$, are value, and saturation of pixel i in the HSV color space.

In all experiments and implementations in both the path and the minimal estimate of the barrier, the algorithm used to remove the light reflected from the surface. The following figure shows an example of the implementation of this algorithm. As you can see, all three pictures show the moment of testing. In figure 3a picture is related to the obstacle avoidance, and image 3b, the estimated path is. In both cases, the reflected light is detected correctly. In figure 3c, you can see a complete form of the reflection light on the floor.



(a) Obstacle Avoidance (b) Path Estimate (c) Main Image

Fig. 3. Remove the light reflected from the surface

4 Navigation

We use a very simple method for robot navigation. To obtain the direction of the robot, we average the final angles of estimate an obstacle avoidance vectors to obtain the angle of the robot motion. Equation 7, use to obtain the final vector of estimation vector and obstacle vector, as well. Algorithm 1, also, show how robot navigation in our project.

$$\boldsymbol{f}^* = \sum_{k=1}^{N_s} \boldsymbol{f_k}(x, y) \tag{7}$$

In this algorithm, when the final vector angle is between -2 to 2, robot is moving forward. Otherwise, the robot rotates to the right or to the left. As you can see, our motion algorithm is very simple. However, despite this simplicity very accurate and in almost all cases the robot has detected the correct path. Also nowhere with not hit any obstacle. Neither fixed nor prevent movable barrier.

Algorithm 1. Navigation

INPUT: $\alpha \leftarrow$ Angle where path estimate is achieve
INPUT: $\beta \leftarrow$ Angle where obstacle avoidance is achieve
OUTPUT: $SA \leftarrow$ Turn speed
OUTPUT: $SF \leftarrow$ Forward speed

$\gamma = (\alpha + \beta)/2$
Begin
  if $(2 \geq \gamma$ and $\gamma \geq -2)$ **then**
    SA= $\gamma/10$, SF = 0.2
  end if
  if $((\gamma > 2$ and $\gamma \leq 10)$ or $(\gamma < -2$ and $\gamma \geq -10))$ **then**
    SA= $\gamma/100$, SF = 0.15
  end if
  if $((\gamma > 10$ and $\gamma \leq 25)$ or $(\gamma < -10$ and $\gamma \geq -25))$ **then**
    SA= $\gamma/100$, SF = 0.1
  end if
  if $((\gamma > 25$ and $\gamma \leq 40)$ or $(\gamma < -25$ and $\gamma \geq -40))$ **then**
    SA= $\gamma/100$, SF = 0.06
  end if
  if $\gamma > 40$ or $\gamma < -40$ **then**
    SA= $\gamma/100$, SF = 0
  end if
End

5 Experiments and Results

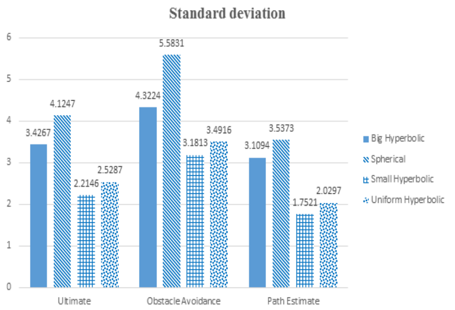
In this work, we put the robot in an empty and straight corridor without any obstacles with the help of three sonar vision algorithms [3], we testd each mirrors, separately.

The purpose of these tests, in general, are to evaluate the performance of the navigation algorithms rather than the mirror. No barrier of this stage of the experiments was to study the algorithms and mirror, in terms of the path. In these experiments, we examined the end vector results of all mirrors of the three algorithms and compared them together. Compared parameters are: 1. distortion and vibration data to the main line, 2. The distribution of the data to the path and 3. The number of frames to reach the goal.

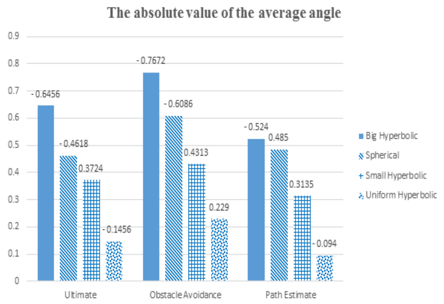
We examine the number of frames, because this agent is representing the whole time of the robot moves. Whatever the number of frames is more, the robot has spent more time to reach the destination.

Figure 5 shows the performance of the mirror, for the three algorithms. These figures show that big non- uniform pixel density hyperbolic mirror and spherical mirror, got through with a lot of distortion and vibration in the route, Whereas, small non-uniform pixel density hyperbolic mirror and small uniform

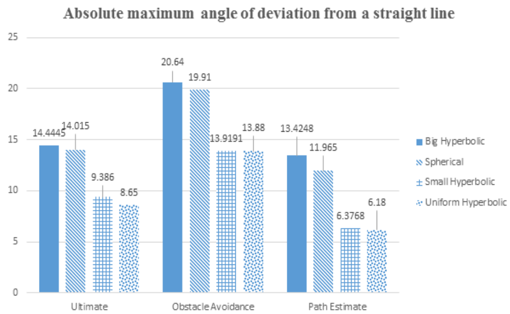
[3] Obstacle avoidance, path estimate and ultimate algorithm (Average of the obstacle avoidance and path estimate together.)



(a) Standard Deviation



(b) The Absolute Value of Average of Angle



(c) The Absolute Angle of Deviation from a Sright Line

Fig. 4. Statistical analysis

pixel density hyperbolic mirror, completed the route, smoother and with much less volatility.

From the perspective of the number of frames, as it is known, the small non-uniform pixel density hyperbolic mirror, have minimum number of frames which is indicative of the fact that the robot has arrived faster than other states. This is due to short variations in the path of the robot. Hereafter, we call mirrors such this: SNU[4], SU [5], SM [6], LNU [7].

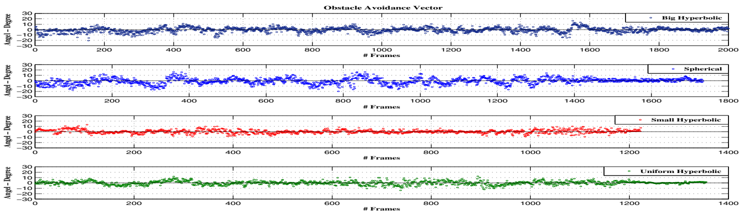
Table 1. Compare the distribution of the data in the algorithm

1	Path estimate algorithm
2	Ultimate algorithm
3	Obstacle avoidance algorithm

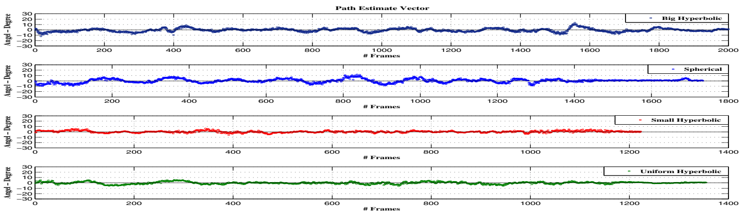
[4] Small non-uniform pixel-density hyperbolic mirror.
[5] Small uniform pixel density hyperbolic mirror.
[6] Spherical mirror.
[7] Large non-uniform pixel density hyperbolic mirror.

Table 2. Compare the performance of the mirror in various surveys.

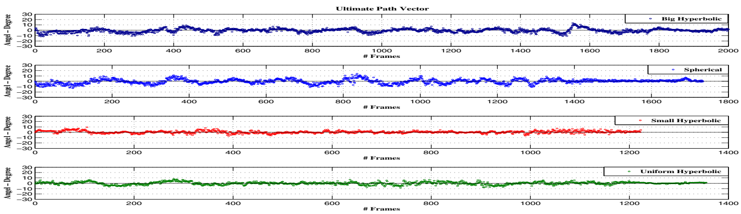
P	Frames	Vibration	Standard deviation	Average angle	Absolute angle of deviation
1	SNU	SNU	SNU	SU	SU
2	SU	SU	SU	SNU	SNU
3	SM	SM	LNU	SM	SM
4	LNU	LNU	SM	LNU	LNU



(a) Obstacle Avoidance Algorithm Vectors



(b) Path Estimate Algorithm Vectors



(c) Ultimate Algorithm Vectors

Fig. 5. Performance of the mirrors for three algorithms

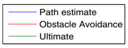
If we compare three algorithms, we find that, in all the mirrors, the data has not uniform dispersion. As can be seen, the path estimation algorithm is having the lowest dispersion of data, whereas, the obstacle avoidance algorithm is having the greatest dispersion of data.

Compare the number of the mirror in various surveys is in table 2 and compare the distribution of the data in the algorithm is in table 1. As you can see, the best performance is for the first one and the worst performance is for the last one.

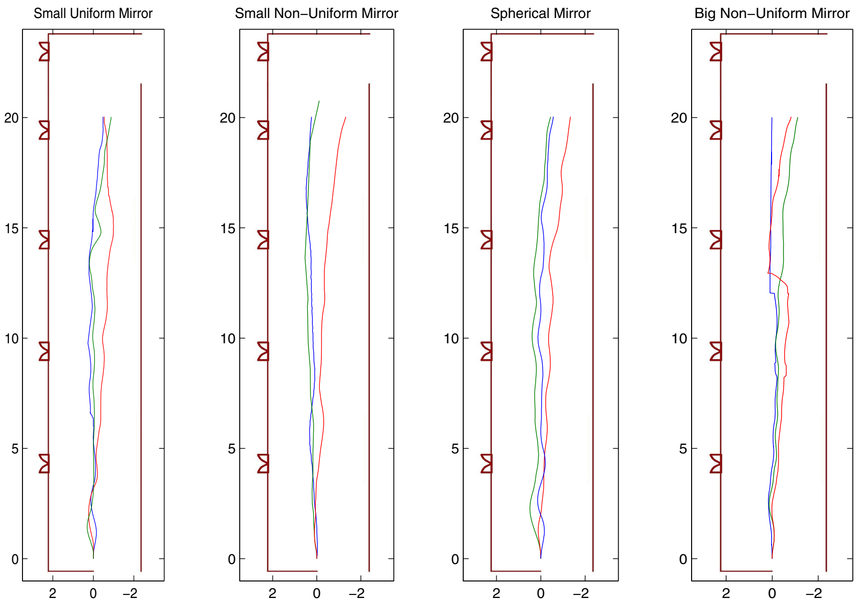
Figure 4a shows the standard deviation of each mirror for each algorithm, separately. Here, we evaluated the performance of the mirrors for each algorithm. As you can see, in this case, the spherical mirror has the highest standard deviation, and small non-uniform pixel density hyperbolic mirror has the lowest standard deviation in all algorithms.

Figure 4b shows the average angle of each mirror for each algorithm, separately. As you can see, the highest angle of the final resultant vector Related to large non-uniform pixel density hyperbolic mirror and the lowest angle of the final resultant vector is for small uniform pixel density hyperbolic mirror.

Figure 4c shows the absolute angle of deviation from a sright line each mirror for each algorithm, separately. In this case, the highest angle of deviation from



(a)



(b) (c) (d) (e)

Fig. 6. Trajectory Plots

a sright line Related to large non-uniform pixel density hyperbolic mirror and the lowest angle of deviation from a sright line is for small uniform pixel density hyperbolic mirror.

Figure 6 shows how the robot moves in the corridor. In this section we've tested the performance of the robot for each mirror and each algorithm, separately. As is known, the robot is able to correctly discern the correct path, and continue to move along the corridor in all cases. In all the mirrors the best performance in terms of movement is for path estimate algorithm (blue lines) and the worst performance in terms of movement is for obstacle avoidance algorithm (red lines). In all cases, the best performance in terms of movement is for small non-uniform pixel density hyperbolic mirror and the worst performance in terms of movement is for spherical mirror.

Compare the best performance in terms of movement for mirrors, as follow: 1. SNU (figure 6c), 2. SU (figure 6b), 3. LNU (figure 6e) and 4.SM (figure 6d).

6 Conclusions and Future Work

In this work, we have developed a method, which is capable of robot navigation in different environments. To do this, we used the omnidirectional vision system. The type of omnidirectional vision system was catadioptric. For experiments we used four mirrors: Spherical mirror, small uniform pixel density hyperbolic mirror, small non-uniform pixel density hyperbolic mirror and big non-uniform pixel density hyperbolic mirror. We also use the sonar vision algorithm for navigation. Sonar vision algorithm consists of three parts: 1. path estimate, 2. obstacle avoidance and 3. ultimate.

This method can be used in different environments, with no previous knowledge of the environment. This can be done by any of the omnidirectional vision system and without any calibration and changing in the picture mode. Also, this method has low computational cost. By combining this method and omnidirectional vision system, and due to the low computational cost, almost robots in all cases, be able to identify the correct way and the route, fixed and moving obstacles easily detected and avoid dealing with them.

Path estimate algorithm would greatly improve previous forms of this method [2], the uncertainty as it was. Especially in indoor, light reflected from the surface is detected by a particular method, and it was not chosen as a barrier and to ease the path continues. It is still uncertain, and this method can not be trusted 100%.

In general, compare the best performance of mirrors, as follow: 1. small non-uniform pixel-density hyperbolic mirror, 2. small uniform pixel density hyperbolic mirror, 3. large non-uniform pixel density hyperbolic mirror and 4. spherical mirror, and compare the best performance for algorithms, as follow: 1. path estimate algorithm, 2. ultimate algorithm and 3. obstacle avoidance algorithm.

Drawback of this method is dependent on the ambient lighting. A major disadvantage of this method is dependent on edge detection. In environments that can not be properly edge detection, this method will be in trouble. In continuation of our research, we are looking at ways that can reduce dependence on edge detection and improve the problem [8]. Also working on other control methods for this kind of robot motion, becomes softer [9].

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