Controlling the Motion of the Mobile Robot

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Abstract

Background/Objectives: The article contains some initial considerations with regard to the non-quantitative motion control. Methods: The approach implying the processing of the entire television frame discussed herein is more stable than existing approaches within the framework of which some specific points are selected and the tracking and recognition of these landmarks on the picture and at each control cycle. Let us consider the difference of rectilinear motion as compared with the motion along the arc for the two landmarks. Next, let us consider a simple way to distinguish landmarks on the television frame. Then we will discuss the original idea setting the motion path by means of the spectral analysis of the television frame. Finally, we will provide an example of this approach from the wildlife. Findings: Discussed concepts are new, aren’t encountered in the literature on robot’s navigation and motion control. In the author’s view such approach has great prospects. The main thing is that these methods are simple, and their application is possible for simple robots with low computational capability. Applications/Improvements: Given approach was preinspected on simple models. It showed method’s reasonably good stability against perturbations.

Keywords: Navigation, Picture, Robot, Spectrum, Television Camera

1. Introduction

To control any mobile object, it is important to solve the task related to the travel on a given route or path. In the meantime, to solve the task related to the travel along the path, it is important to be able to discern the rectilinear motion from the motion along the arc. Here comes the question: How to discern the rectilinear motion from the curvilinear motion without any calculations, i.e. without any quantitative estimation?

The question now arises of why it needed? The answer is simple: the overwhelming majority of robots (from simple robots to the automated automobiles) carry out too much excessive (but necessary on the current stage of robotics development) work such as building of map and trajectory on it. To put it in other words they compute these! As it is shown in this paper, there is no need to compute anything, only qualitative (viz. not quantitative) image analysis is necessary. More than that the analysis is very simple and does not require high computing power.

Such algorithms can be applied for simple robotic means, for example what is known as smartdust.

2. Conceptual Method Framework

So, let us suppose that the robot has only one sensor that can distinguish landmarks in the area surrounding the robot and monitor them. Let us try to figure out how corners directed to these landmarks behave in case of rectilinear and non-rectilinear motion.

First, we must understand that the first thing that comes to our mind when the landmark is unique and is located directly on the travel line is a very bad solution. Figure 1 shows that the robot moves in a certain way, but it is still focused on the given landmark. Consequently, it is impossible to distinguish the motion based on the given unique landmark.

Hence, there must be more landmarks than one, and none of them must be strictly in front – as we noticed, it does not give us any useful information.
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Figure 1. Demonstration of the robot direction toward the landmark. The symbol $\alpha$ denotes the area of the landmark identification.

The second thing that comes to our mind is two landmarks: on the right and on the left. Let us determine whether we will be able to discern rectilinear motion from curvilinear motion. Let us consider Figure 2, which, in addition to the robot and landmarks (A and B), shows the coordinate system (X and Y) coinciding with the robot at the start point thereof.

This figure shows the coordinates of landmarks and two possible motion paths of the robot: the vector denoted by $r$ shows the direction of rectilinear motion, while the arc of radius $R$ shows curvilinear circular motion.

Let us discuss how the angles directed to landmarks change depending on the trajectory. The formula for rectilinear motion is trivial

$$\alpha_{\text{landmark}} = \arctan \left( \frac{x_{\text{landmark}} - \Delta x}{y_{\text{landmark}} - \Delta y} \right)$$

where, $\Delta x$ and $\Delta y$ - robot displacement on the abscissa and ordinate.

If we assume that the Y-axis coincides with the direction of the rectilinear motion, the formula becomes even simpler:

$$\alpha_{\text{landmark}} = \arctan \left( \frac{x_{\text{landmark}}}{y_{\text{landmark}} - \Delta y} \right)$$

Consequently, if the robot travels rectilinearly (in the direction of the Y-axis in Figure 2), the angles directed to any landmarks in absolute magnitude are increased (i.e. the angles between the positive direction of the Y-axis and directions to landmarks increase). In other words, it is a prerequisite for rectilinear motion.

Is it enough?

Let us write the formula for the corners directed to landmarks in case of circular motion with the radius $R$ – as shown in Figure 2:

$$\alpha_{\text{landmark}} = \arctan \left( \frac{x_{\text{landmark}}}{y_{\text{landmark}} - R \sin (\alpha_{\text{robot}})} \right)$$

(1)

where, $\alpha_{\text{robot}}$ is the angle of robot orientation in case of motion based on the radius $R$.

For instance, let us consider the charts for the two positions of the center of rotation (point C in Figure 2) – see Figures 3a and 3b.

Figure 3a shows a situation where the landmark is located between the robot and the center of rotation, while Figure 3b shows a situation where, on the contrary, the center of rotation is located between the robot and the landmark. It is not difficult to guess that the "watershed" between the two cases is the condition where the landmark and the center of rotation are the same – then the angle directed to the landmark is always 90 degrees (the landmark is always on the beam line).

Let us analyze these two charts.

The first chart shows that the angle comes close to the ordinate. This occurs until the rotation angle of the robot is 55-60 degrees. The second chart shows that the land-
mark located farther on the center of rotation behaves differently – it is first removed from the axis of motion of the robot.

![Figure 3. Two versions of the landmark position.](image)

These two charts are a continuation of one another. Moreover, if the initial position of the landmark in situ is not aligned with the robot and the center of rotation, the initial position of the total chart is shifted to the angle that was initially directed to the landmark.

Consequently, the increase of angles is not sufficient to uniquely identify rectilinear motion. It is necessary to investigate the behavior of the angle directed to the landmark located at the same side with the center of rotation as seen from the robot.

Let us consider the derivative of the formula (1) based on the variable \( \alpha_{\text{robot}} \) responsible for the orientation angle of the robot:

\[
\frac{(R(-R + \cos(\alpha_p)(R - x_p) + \sin(\alpha_p)y_p))}{(2R^2\cos(\alpha_p) - 1) - x_p(2R(\cos(\alpha_p)) + x_p - 1) + 2R\sin(\alpha_p)y_p - y_p^2 - 1}.
\]

replace the sine by the square root of the squared cosine and solve it by equating it to zero.

We get the dependence of the extreme value on the parameters of the robot and landmark:

\[
\min(\epsilon_{\text{landmark}}) = \frac{-R^4 - Rx_p(3R^2 - 3Rx_p + x_p^2) + R(R - x_p)y_p^2 + \sqrt{R^2y_p^2(2Rx_p - x_p^2 - y_p^2)((R - x_p)^2 + y_p^2)}}{R^2((R - x_p)^2 + y_p^2)}
\]

The chart of the expression for the minimum at \( R = 1, \) \( \gamma_0 = 0 \) is shown in Figure 4.

![Figure 4. Curve of the angles of the robot orientation with which minimum values are observed with respect to the directions to the landmark.](image)

This figure gives some good advice: to uniquely identify the rotation, the landmark must be the entire object located closer to the positive direction of the Y-axis. However, the said landmark, in case of continued rotation, can quickly move to the other side of the robot, but at that rate it is possible to select another landmark.

### 3. Method Intended for the Selection of the Landmark

Now we have to explain how we suggest selecting landmarks and what a landmark is. As a rule, the landmarks mean (based on the daily representations) a visually eye-catching object. To allow for the automatic identification of objects by means of MVS and other sensors, we use algorithms of varying complexity intended for the processing of signals received from these sensors.

As used herein, the term “landmark” means some specifically reserved area identifiable by means of a simple processing of the video frame. It does not matter whether
these landmarks will be recognizable by the human eye or not.

Let us consider how the frame looks in digitized form. Each point of the image corresponds to the number characterizing the color of the given dot (pixel). Pixels are arranged in a two-dimensional array equipped with rows and columns

In case of color shots, each pixel corresponds to the three colors of the color chart – red, green, and blue. Using these three colors, it is possible to set any color in a very wide range and with a very high level of accuracy.

Let us sum up the pixel values in each column of the given two-dimensional array and find the average value for each column. Let us plot the average chart. We will move the camera and repeat the procedure. Let us make sure that the insignificant motion of the television camera does not have a significant impact on the average chart by columns. Let us take two images of the working area taken from the slightly different positions of the television camera – see Figure 5, a and b.

![Figure 5. Two images of one working area.](image)

It is noticeable here that the images are different. Let us perform processing by columns. Figure 6 shows average charts by the columns of each color. Figure 7 shows the fragment of the landmark in an enlarged form.

![Figure 6. Two average charts of one working area (for three RGB colors).](image)

![Figure 7. Two fragments of the average charts for the red color.](image)

If you look at the enlarged fragment, you will notice that a drastic spike is identifiable well enough in case the spike environment is taken into account. It is necessary to keep studying the method intended for the selection of the fragment of interest and the method intended for the “recognition” of the given fragment.

The size of the landmark is of great importance. In Figure 7, a clear spike from the shining right leg of the chair is a very good landmark. However, some additional
extremes are located on the right and on the left of it. Is it necessary to include them in the concept of a “landmark”? It can drastically increase accuracy when determining the landmark center. In this case, accuracy can fall drastically if the items constituting the secondary extreme values are at a different distance from the television camera than the object providing the main extreme values. At the same time, when it comes to non-quantitative navigation, such small value fluctuations are apparently of no importance3.

We should also mention the following. If we look at Figure 5, we will notice that the streaks on the floor resulting from the perspective projection converge. Let us consider a typical picture of the road – see Figure 8.

Figure 8. Photo of a typical road.

It is clearly noticeable that the edges of the road form lines converging in the perspective projection, while the objects surrounding the road complement the given picture from the top to the X-shaped “hour glass”. Moreover, the center of the “hour glass” is close to the center of the frame. Therefore, if you perform averaging by radii from the center of the picture described above, you will be able to securely, easily, and quickly “catch” even the plane of the road, road borders, track gage (if any), the sky, and so on.

Such a simple search algorithm designed to search for straight lines, in contrast to, for example, the Hough algorithm, requires low computing resources and does not require the preprocessing of such contouring.

4. Results

Now we have to explain how to control motion based on the information given above.

To control motion, it necessary to determine the operating principle for the feedback sensor detecting the position of the object in the environment (on the map). The position of the robot on the map (i.e. localization) is a mandatory task both for quantitative and non-quantitative navigation.

And, therefore, we must not avoid the following questions:

1. How to determine that the robot has reached the goal?
2. How to determine that the robot travels in path?
3. How to measure the distance from the robot to the goal?
4. How to measure the distance from the robot to the desired trajectory?

Consider Figure 9. It depicts the set of points M and two positions of the measuring device 1 and 2.

Figure 9. Diagram of distance measurement.

Let the measuring device scan the surrounding area clockwise – as shown in Figure 9. Let the measuring device also scan the space with the same angular frequency $\omega$. Let a clicking noise sound when identifying each point of the set of points M.

It is natural that the set of clicks creates some sound consisting of sets of frequencies the period of which depends on the angular frequency of scanning $\omega$ and the distance of the measuring device from the points of the set M. If there is a reference sound recorded at a certain distance from the points of the set of points M, by comparing it with the received current sound, we can definitely see where we have to move the measuring device – closer to or farther from the M:
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- If the frequency is higher than the reference frequency, therefore, the measuring device is far away from M; the measuring device must be moved closer to the points;
- If the opposite holds true – remove from M.

For Figure 9, you can move the measuring device back and forth and note the difference between the different parts of the reference and the current sound.

By roughening the reference sound, it is possible to set a large tolerated error for the less accurate determination of the position, if necessary.

Having a consistent set of reference sounds, you can create a moving robot with a measuring device, which will focus only on the path defined by means of reference sounds. You can create a controller that will monitor the difference between the sounds and the references and correct the path.

In other words, if you know the reference sound and compare it to the current sound, you can construct metric:

1. The distance from the point to the point itself is zero (the reference is equal to itself; there is no necessity to move anywhere);
2. The distance from point A to point B is equal to the distance from point B to point A (the reference and the current sound can be interchanged, and the required motion will not change);
3. The triangle inequality works (obviously).

Therefore, the given metric space is one-to-one (bijective) in relation to the Euclidean space.

Let us consider the charts shown in Figure 6. One can interpret these curves in a different manner to distinguish the frequency spectrum. The main thing is to clearly convert these curves into frequencies. It is not difficult to notice that Figure 6a will “sound” higher than Figure 6b, as the camera is a little further from the object.

5. Discussion. An Example from the Wildlife

Let us consider a bee. Bees have faceted eyes with a resolution not better than 1 angular degree. The flying speed of a bee is around 7 m/s. Eyes can distinguish flickering up to 250 Hz, i.e. when flying, a bee can react to objects of 30 mm, which are very close to the eye (in other words, during one recognizable period of flickering, a bee flies 28-30 mm at a cruising speed).

The path of the flight to the food trough and back to the hive (nest) can be written in the form of the spectrum, as mentioned above. The controller in the head of the bee understands the required speed based on some “carrier” frequency of the spectrum and the position based on the other harmonics.

By varying the speed, the bee can change the resolution of the eye, and, accordingly, the accuracy of path following.

This method provides the opportunity to transfer the information regarding the path to the other bees without much difficulty. It is said that the bees “dance” when transferring the information concerning the path. Perhaps, using this dance, they transfer the frequencies of the path spectrum to the feed through to their “colleagues”.

6. Conclusion

Discussed concepts are new, are not encountered in the literature on robot’s navigation and motion control. The examples from animated nature appear to be extremely simple and claim to be true. Indeed, as is known, decomposition of any signal by orthogonal (or near orthogonal) basis is an essence of the information recognition methods in wild-life.

The author believes, that the described above approach has great prospects. There is no need to compute various redundant values; to build map, trajectories, to carry out localization. Living organism while performing the motion toward the position goal is not interested in its own coordinates, only two characteristics are important to it:

1. Landmark recognition;
2. Obstacle avoidance.

The methods of achievement of the first characteristic – landmark recognition – are suggested herein.

The main thing is that these methods are simple, and their application is possible for simple robots with low computational capability.

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