PAL-based Environment Mapping for Mobile Robot Navigation

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Abstract: The paper describes a mobile robot that is capable of autonomous navigation in a homogeneous, weakly-textured environment by appearance-based technique. The components of the system are an RC model car, a remote controller extended with some custom electronics, a wireless camera with panoramic annular lens, and a developed software running on a standard PC for controlling the robot. The main feature of the system is the mapper module, where the images of the original sequence are transformed into virtual top-view ones and melted into the global dynamic map.

Keywords: PAL (Panoramic Annular Lens), omnidirectional vision, appearance-based navigation

1 Introduction and Aims

1.1 Mobile Robotics at Budapest Tech

In the last decade several wheeled and legged mobile robots were developed at the Budapest Tech [1, 2, 3]. The researches included the study of development options of movement possibilities for mobile constructions [1], and also the automatic application of such robots in known and unknown environment [4]. The built wheeled robots can work with high speed, however only at good lie of terrain. The developed walking robots are slower but can move at worse terrain conditions. In the experiments different sensors and cameras are used for detecting the environment. Using this information the robots capable to avoid obstacles and to follow their path in the direction of the previously determined target position [4, 5].

The aim of the research is to investigate problems connected with the working environment of mobile robots, for which information gained through image processing offers some help. The goals are proper navigation, path planning and obstacle avoidance. Research comprises several elements based on each other. The digitalized picture of a camera serves as base information, which is filtered with different image processing algorithms. One of the elements of the investigation is the analysis of these basic algorithms and their collective effect. Another utilization of the camera image is to scan the position of objects in the robot's environment [1], and the mechanism of the map-building.

PAL optic was used for the first time in the case of stepping robots for the simultaneous investigation of the environment of the legs [1]. With this method it is possible to avoid obstacles nearby, and the legs can be moved more efficiently. In familiar outdoor environment the position and orientation of the robot can easily be calculated of the physical characteristics of the objects by using omnidirectional images [6].

1.2 Project Goals

The goal of this project is to create a wheeled robot equipped with a panoramic annual lens (PAL)-optics, which is capable of autonomous navigation and collision avoidance within a weakly textured environment. The long-term goal of this project is the ability of autonomous mapping of the environment; finding, and navigating through user-specified path; and searching for a predefined object within an unknown environment. In the following, the article summarizes the theoretical background, the main components, the applied techniques and the results of the system.

2 Theoretical Background

2.1 Theoretical Basis of PAL

The main characteristics of any *centric minded imaging* (CMI) system [7] is that it is in the center of the coordinate system that describes the three-dimensional scene, and not on its periphery, as in the case of conventional *see-through-window* (STW) imaging strategy. In STW strategy, one 'sees' the 3D world only through discrete chunks as if looking through a window by moving the head up and down or turning around. That is why, images taken by traditional optics show only a narrow sub region of the environment. As a result one cannot get full 3D information in real time. CMI based systems, however, because of their being in the center of the 3D space, totally eliminate this drawback of STW imaging. One such method is the omnidirectional vision sensor, where a cone mirror is put in front of the CCD camera. The other, and the most up-to-date CMI block is the Panoramic Annular Lens (PAL) [8, 6].

PAL considers the visual field to be cylindrical, rather than spherical. The image of object points will then be projected first onto an imaginary cylinder wall that is located at a distance equal to the prevailing vision distance, and then this panoramic image projection will be transformed onto a plane perpendicular to the axis of the cylinder.

As a result, the whole 360° visual field will appear on the plane surface as an annular image, and the image points retain the same 1:1 relation of the original object points. The width of the ring will correspond to the vertical viewing angle of the PAL, while points on concentric rings will represent different horizontal spatial angles within a given vertical viewing angle. Thus, the two-dimensional skeleton of the three-dimensional world will be encoded in this annular image.

This leads also to the coding of the appearance of depth on a two-dimensional surface as a convergence into one point, resulting in just one single vanishing point. For this 3D optical coding method, the term *flat cylinder perspective* (FCP) imaging was introduced. Here the entire 360° panoramic space becomes visible at once, however, both the usual and the inverted perspective will appear simultaneously. This is why at the first glance one has difficulties to orient himself in this type of picture. However, using appropriate software, the ring shaped image can be 'straightened out', i.e., the 360° panoramic image displayed in polar coordinates can be converted into Cartesian coordinates, and the mentioned discomfort immediately disappears.

One consequence of this type of CMI is that not a real but a virtual image is formed inside the PAL. Better to say a virtual image volume, which can be regarded as a miniaturized image volume of the 3D space encircling the imaging block, and one can assume that it contains all the imaging point data from the real 3D space. Using a PAL mounted on a mobile robot and collecting this information about the environment of the robot, it is easier to build a map and using the gathered information for navigation.

2.2 Navigation Using Appearance-based Matching

2.2.1 Techniques for Mapless Navigation [9]

One way of achieving autonomous navigation in a mapless environment is by 'memorizing' this environment. The idea is to store images or templates of the environment and associate those images with commands or controls that will lead the robot to its final destination.

Gaussier et al. [10] developed an appearance-based approach using neural networks to map perception into action. The robot camera captures a 270-degree image of the environment by combining a series of images each with 70 degrees of field of view. This panoramic image is processed and a vector of maximum intensity averages along x (the horizontal axis) is obtained. For each maximum value in this vector, a ‘local view’ is defined. This local view is a 32x32 sub-window extracted from the panoramic window. The set of all local views for a given panoramic image defines a ‘place’ in the environment. Each place is associated with a direction (azimuth) to the goal. Finally, a neural network is used to learn this association and, during actual navigation, it provides the controls that take the robot to its final destination.

Using appearance-based navigation, Matsumoto et al. [11] extended the place recognition idea for a mobile robot by using a sequence of images and a template matching procedure to guide robot navigation. Sub-windows extracted from down-sampled versions of camera images are used to form a sequence of images that works as a ‘memory’ of all the images observed during navigation. Each image in this sequence is associated with the motions required to move from the current position to the final destination this is referred to as VSRR (View-Sequenced Route Representation). After a sequence of images is stored and the robot is required to repeat the same trajectory, the system compares the currently observed image with the images in the sequence database using correlation processing running on a dedicated processor. Once an image is selected as being the image representing that ‘place’, the system computes the displacement in pixels between the view image and the template image. This displacement is then used in a table to provide real-world displacements and angles to be used in the steering commands.

Another system built around Matsumoto's VSRR concept is reported by Jones et al [12]. There the robot is given a sequence of images and associated actions (motion commands). Using zero-energy normalized cross-correlation, the robot retrieves the image from the database that best matches the view image. If the match is above a certain threshold, the robot performs the commands associated with that image, otherwise it halts.

2.2.2 Localization Using Omnidirectional Imaging [13]

Paletta et. al [13] developed a system deals with the localization of robots in an indoor office environment using an omnidirectional camera. After learning the office environment from training images, taken at certain known positions, a current image is compared to the training set by appearance-based matching. Appropriate classification strategies yield an estimate of the robot's current position.

For this work, the original catadioptric images were rectified and clipped. Splitting the rectified images into single, separately matched sectors led to an increased robustness with respect to two phenomena:

1) partial occlusions of the scene and
2) rotational differences between the robot's pose at the current position compared to the robot's pose at the next reference position of the training phase.

3 The Hardware Parts of the Mobile Robot System

3.1 The Robot Car and the Control

A remote controlled Model RC is used as the base of the robot. The Model RC is capable of precision controlling: both the direction and the speed can be set. The range of the remote control is about 30-40 meters; maximal speed is about 20 km/hours.

The PC is connected to the remote controller with an extra electronics, and then controls both controller transistors with three impulses. The impulses are generated by an 18F1320 PIC micro controller. An interrupt is generated in the PIC program with a timer every 15ms. On every interrupt, the PC is sending three signals: the first signal sets the beginning of the periodical time, the second impulse controls the direction of the car; the third control-data sets the speed of the car.

3.2 The Applied PAL

PAL optic [7, 8] is a device that transforms the surrounding environment to an annulus. Huge advantage is that from the image provided by this optic the direction and angle of the object can be directly computed. The PAL-optic with its reflecting and refracting surfaces consists of one single glass block. An auxiliary optic, however, is needed to project the virtual panoramic annular image that is formed inside the optical block to the detector surface, preferably, a CCD chip. Using this lens as sensor may reduce the necessary number of sensors and thus energy use as well.

Other advantage of using PAL optics, instead of a perspective one, is that there is no need of moving components; and there is no need to focus to gather information from differing distances. Therefore, one optical sensor gathers sufficient amount of information for the navigation.

The PAL-optic projects the 360 degrees of the environment to two dimensions, thus creating an annular image. The cylindrical projection of the image can be described using a polar coordinate-system. Due to the structure of the PAL-optic, there is a blind spot in the middle of the image, which must be taken in account while processing it. The main properties of the optics are: center of the PAL, inner radius, outer radius, and the angle of the field of view. The PAL-center is usually shifted from the middle of the image; therefore, software correction is needed.

The wireless camera is mounted on the top of the mobile car, looking at the floor; therefore, it is capable of observing the immediate environment only. The result of the camera is relayed using a TV tuner to the main program, which controls the robot automatically using the images gained from the camera as its only input.

4 The Developed Software

4.1 Image Preprocessing

The image flow arrives from the Input module, which is responsible for either capturing images from a camera, or play back a test video file. It forwards the images to both the decision maker, and the mapper module. The decision maker analyses the image, and sends a direction/speed signal to the navigation module, which, in turn, forwards it to the controller PIC.

In order to make a valid control decision, the image is preprocessed by three filters:

1 Using a HSL filter, the program segments the image to Hue, Saturation, and Luminance components. The Hue component is between 0, and 360, the Saturation, and the Luminance will fall between 0, and 100. The HSL filter is used in two cases: in line following mode, when the predefined track is homogeneous, or in object-following mode when the object to be followed is significantly differing in color from the rest of the environment.

2 The RGB filter is almost as efficient as the HSL, but the algorithm is significantly faster. Using this filter, the three color channels is analyzed, using a minimum, and a maximum values; if the color of the pixel is within these values, then it remains intact on the resulting image; otherwise the filter will make it black.

3 Using the threshold filter, image binarization can achieved; the result image will contain only the pixels needed for navigation [14].

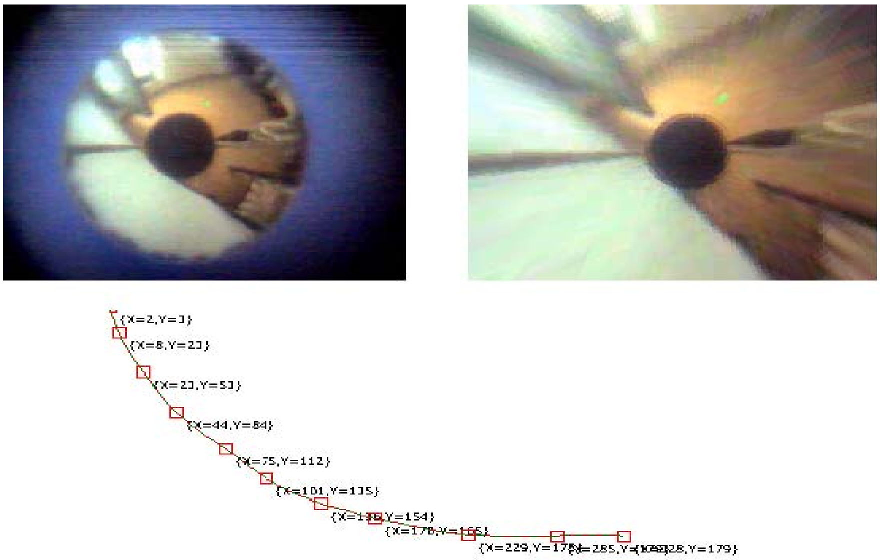

Figure 1

The original image (left), the transformed image (right) and the applied interpolator function

4.2 Mapper Module

The mapper module is used to implement a user-defined navigation: after the robot builds up the map of the environment, the user sets some checkpoints, and the robot tries to find the shortest path, and navigate through them, while avoiding any obstacles. The specific purposes of this module are localization of the robot, and storing and maintaining a virtual top-view image of the environment.

To achieve this goal, the image sequences received from the PAL-optics is mapped to a virtual top-view. To apply this transformation the algorithm assumes that the PAL-image is a regular annulus. Thus, transforming the distance of the pixels from the PAL-center will result in a top-view, map-like image. To determine the parameter of the transformation function, the relation is measured between the real distance, and the PAL-distance on several points from the center of the image; and a cubic spline interpolation is applied on the measured data (Figure 1). To increase the performance of the algorithm a transformation matrix is generated, which determines the source for every pixel on the resulting image. Once this matrix is generated, it can be used for every image, with real-time speed.

After the top-view transformation, the module uses a static mask to cut out segments from the image, which has no information-content [for example, the central blind-spot]. The localization process similar described in 2.2.2, but instead of rectification of the image the combination of the techniques is used: the program searches, and tracks characteristic features on the resulting image [6], and parallel it calculates a summed histogram value in radial directions in every 3 degrees. The feature points and the summed histogram values are used to determine the location, and angle of the robot. After localizing the robot, the module will rotate the image to reflect the initial direction of the robot; the resulting image is melted into the global map also.

In order to dynamically extend the map as the robot gathers more and more information, a static bitmap would not be sufficient; instead, the map is divided it into several, small images, and the module stores the two dimensional ordering between these segments. The 'melting' of one image into the global map is used in the navigation process, where the wave propagation based path planning is used (Figure 2).

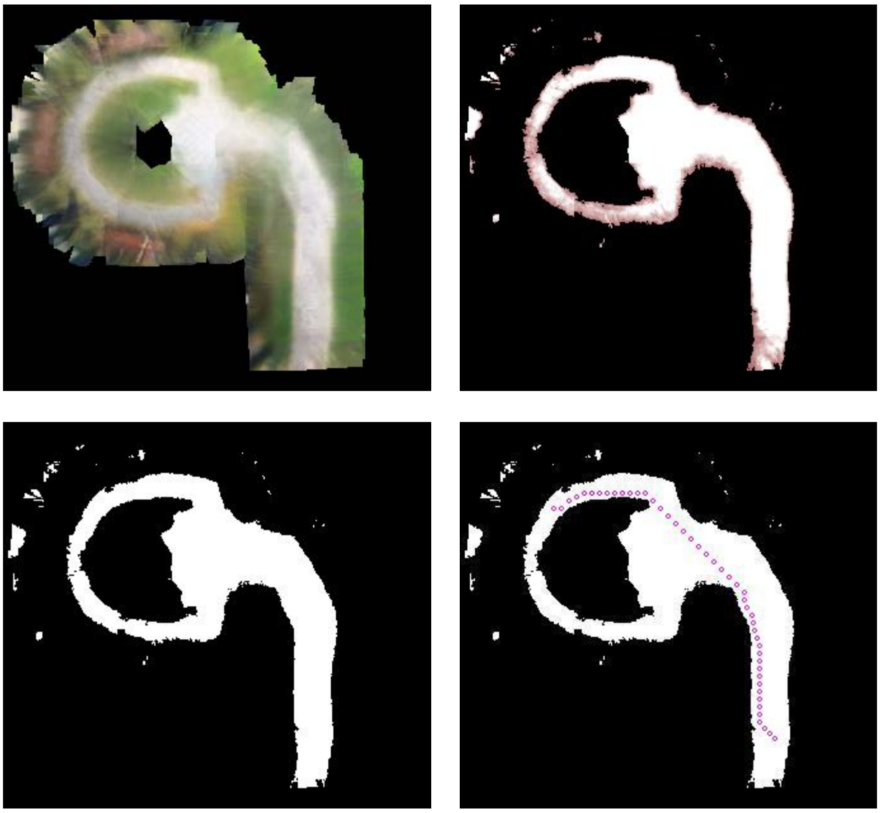

Figure 2
Melted image sequence (upper left), binarization with different thresholds (upper right and lower left), path generated with wave propagation techniques (lower right)

Conclusions

Although the tests started recently, some early results are already available. The developed system was tested indoor and outdoor environment also. Both cases the free work space were weakly-textured and significantly lighter then the obstacles. The built map in the outdoor environment can be seen on Figure 2.

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