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Review of Vision-Based Robot Navigation Method

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ABSTRACT

Vision-based robot navigation is a research theme that continues to be developed up to now by the researchers in the field of robotics. There are innumerable methods or algorithms are developed, and this paper described the reviews of the methods. The methods are distinguished whether the robot is equipped with the navigation map (map-based), the map is built incrementally as robot observes the environment (map-building), or the robot navigates using no map (mapless). In this paper will described navigation methods of map-based, map-building, and mapless category.

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1. INTRODUCTION

Navigation can be defined as a process to determine a suitable and safe path between the starting point and the destination point where the robot moves them [1]. Next navigation on a mobile robot can also be defined as the ability to move in any particular environment, or science in guiding a mobile robot that can move on the environment [2]. As for the problems that accompany this process is the navigation can be defined in three questions, namely: "Where am I", "Where am I going", and "How do I get there". For the first and second questions can be answered by completing the appropriate robot with sensors, while the third question can be done with an effective planning system navigation. The navigation system itself is directly related to the presence of the sensors used in robots and the structure of the environment, and that means there will always match the purpose built robot and the environment in which the robot will be operated [3]. Vision-based navigation tremendous progress with the implementation of various autonomous vehicle, whether it is being run on land (Autonomous Ground Vehicles/AGV), at sea Autonomous Underwater Vehicles/AUV, and in the air (Unmanned Aerial Vehicles/UAV). Regardless of the type of vehicle or robot is built, then the system utilizes a vision sensor for navigation purposes, can roughly be divided into two general categories: systems that require prior knowledge of the environment in which it will be operated (in this case the system requires maps / folder) and systems who see environmental conditions to which he will navigate. Systems that require a map can be subdivided into folders-using systems and topological map-based systems [1]. As the name suggests, then the navigation system using a map (map-using navigation systems) should include a complete map of the environment before starting navigation. While the metric map-building systems all over the map itself built and used in the next phase of navigation. Furthermore, other systems that are in this category is a system that can perform self-localize on the environment simultaneously performed during map construction purposes [4]. And other types of map-building navigation systems are encountered eg al: visual sonar-based systems or local folder-based systems. Both of these systems collect environmental data when navigating, and build a local folder that is used to support in order to be appropriate navigational purpose. As for the local map includes mapping the barrier and the space, and this is usually a function of the angle of view of the camera [1]. The last system, namely: a topological map-based, which builds a topology map that consists of nodes (nodes) are connected by a line, where the vertices represent the place / specific positions on the environment, and links represent the distance or travel time between the two vertices [1] [5]. The next Navigation System is mapless navigation systems which mostly includes reactive technique that uses visual cues are built from image segmentation, optical flow, or the search process features between image frames obtained. There is no representation of the environment on these systems, and environments seen / perceived to navigate the system, recognize objects, or browse landmark [4]. In addition to the knowledge of the environment described above, then the robot vision-based navigation is distinguished also by the environment in which the robot is operated as follows: indoor and outdoor. Both types are also surrounding environment or navigation model that consists of map-using / map-based, folder-building, and mapless navigation system.

2. THE VISION-BASED NAVIGATION

Vision-based navigation method can be categorized as map-based navigation, map-building based navigation, and mapless navigation.

2.1. Map-Based Navigation

In the map-based navigation or map-using it seems clear that for the purposes of navigation, the robot is equipped with a map of the environment in which it will be operated [6]. There are several models of maps used, including: geometric models, topological, sequence of image [4]. One of map-based navigation implementation as in [7] which uses visual-based navigation system with stereo camera on a wheeled robot golf balls' collector. It's aided by the wide angle camera mounted on top of the golf course with specification: - Coverage area is of 20m x 20m - Vertical viewing angle is 80o and horizontal viewing angle is 55o - The height of the camera installation is 7m above the ground - The maximum resolution of this camera is equal to 1280x780 pixels. The way of the system works is started by the camera catches the image and then processed by a computer server which then builds navigation map grid-shaped, or it defined as occupancy grid map [8] [9]. This occupancy grid map can indicate where to position of the robot on the golf course, and wherein the position of the balls to be taken. According to the map determined by the server, the robot can move toward a certain position, based on the information sent wirelessly [10] [11] [12] [13]. In this category there is also a map-based navigation approaches using semantic-based map. This approach is called holography map is divided into three hierarchical items in the house, and is divided into 13 classes of objects [13].

2.2. Map Building Navigation

2.2.1. Metric Map

Robot navigation using metric-map approach in the category map-building commonly referred to also as grid-based map, in addition to other models, namely: topological map, hybrid map. In the study [14] the previous map was built by a local mapping to study the map grid and features the image of a place that crawled like a corner room and so on. Then in each of these places are created by using a grid map FastSLAM [8] [15] [16], which distinguish image features available in each place with image features that have been stored in the database [14]. Next at these locations, with a simpler form between places, then the map detail is not made, but the connections between the information only with intricate shapes are studied. Connection topology is basically a process which seen whether it is a new place or a place has been visited by the robot. The decision obtained by using image features matching process by using speeded Up Robust Features (SURF) [14].

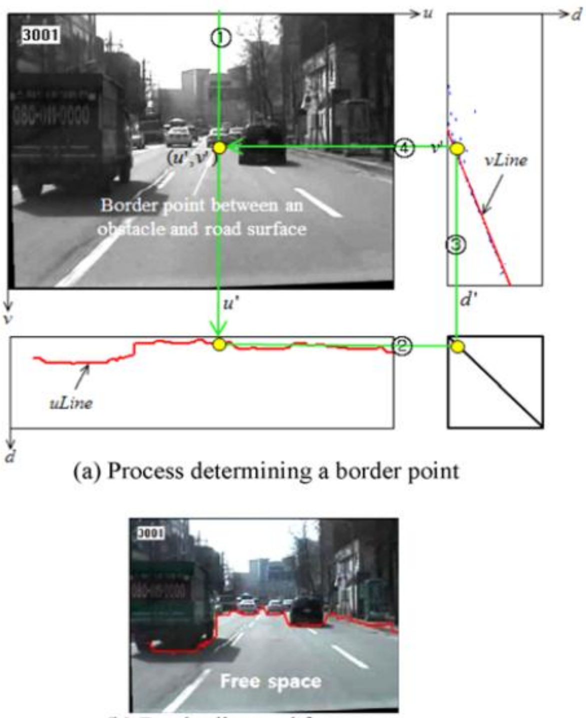
2.2.2. Score Map Building

In this section, one of the navigation methods developed by category map building that scores navigation map. It is a novel algorithm that was developed from information derived from the stereo camera [17]. The aim is to estimate the free space of the vehicle (car) which is in front of where the system is run, particularly for navigation on the highway. By utilizing the difference map (disparity map) [18], it will obtain information on whether the condition of the vehicle in front of him was 'solid' or 'rarely'. Further to the development of scores folder, because the sensor used is a stereo camera, which is carried out next is a stereo matching process based on image data that is passed longitudinal road surface. Detection of free space is done by extracting the road surface without any obstacle. The detection is done with the procedure, namely:

a) First use of high Vline and considering a used vehicle (vehicle research). Map of the difference (disparity map) is divided into two parts: the obstacle disparity map and the road surface disparity map.

For Vline itself represents the profile of the road surface along the direction of vision cameras that are estimated using methods Dijkstra's [19].

b) Second, in each column of the disparity map, a disparity histogram which is a frequency of a disparity in a range [0, dmax] is made. The maximum values of each column of the histogram possibility, formed by a single obstacle as an obstacle usually have the same disparity.
c) Third, to reduce the occurrence of errors, this paper introduces a new concept that scores the folder that represents the possibility of the existence of the obstacle. Then the score disparity map was constructed from histogram above obstacle disparity map and the road surface disparity map, then both are combined. Using dynamic programming, from the combination of the two folder is searched for a corresponding disparity separately to mark obstacles or barriers are closest to the stereo camera and the road surface.
d) The last step is to extract constraints (boundary) between the road surface and obstacles, which in this case is used Vline and Uline as ilustrated in Figure 1 and the lower part of the boundary line (border line) is a free space.



(a) Process determining a border point

(b) Border line and free space

Figure 1. Free space detection ilustration

3. POTENTIAL BAN METHOD

These Potential Ban methods mimic how humans in avoidance when it finds when walking, and in this case the man would try to move from the hitch to the place or position more secure. This method was originally developed from the traditional navigation method known as artificial potential field method and was first introduced in 1986 by Dr. Khatib [20]. This method was originally used as a method to avoid the obstacle, and path planning, the robot manipulator. The general idea is to create a virtual, potential force field on an object that is 'seen' by the camera, from which will return virtually determined the field around the object that can be passed safely in order to navigate the robot [21]. Later in the progression to potential ban method, at every iteration step process is carried out to detect the possibility of a collision. If there is a possibility of a collision, then the potential tire described on a grid map. Basically potential tire is the value of confidence by a robot where he had to maneuver against a moving obstacle. Virtual certainty distribution of values around the collision point is shown in Figure 1. The value of the virtual certainty this will tend to increase in the direction of movement of the barriers, that value is the prediction of the position of the hitch per 2m steps before and after the collision, and is calculated by the following equation: [20] [22]

$$VC(i,j) = k\frac{C_{max}}{2m} \qquad k = 1, 2, \ldots, 2m$$

Where:
VC = Virtual Certainty
Cmax = maximum value Certainty
k = constant
m = maximum value prediction step

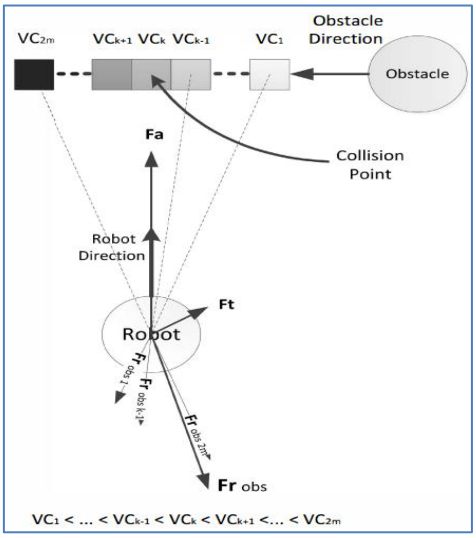


Figure 2. Potential Ban transmitted through the grid map [22]

4. STEREO-BASED VISUAL NAVIGATION

From the name obviously robot navigation method relies on the stereo camera is used. In the example implementation of this method, the navigation is done is outside the room automatically by wheeled robot on a previously unknown environment, using stereo cameras and robots are non holonomic models. The first step is carried out for the exploration of the unknown environment is construction on the surrounding environment in real-time [23]. Then from the disparity image obtained from a stereo camera, and the data is translated into a 3D-Space, then constructed point cloud models from the environment around them. The next step is projecting these points to the field XZ local folder and put together in accordance with the visual odometry obtained from stereo camera. Thus the global map of the environment can be constructed in real-time. In this study, the A * algorithm is used to investigate optimal path [3], and non-linear back-stepping controller guides the robot to be able to follow the path identified [23].

5. SUB-GOAL METHOD

In this method, the map is built based on the environmental image information obtained from a camera mounted on the robot. From the information that was then built the best information about the navigational paths that can be taken by the robot safely. The flowchart of this method is shown in Figure 4 [3]. Figure 3. Flowchart method of navigation with sub-goal [3] On implementation, this method uses two sensors, namely sensors and cameras infrared sensors. Therefore this method divides into two layers for the system built. At the beginning of the method, the navigation destination information obtained according to what is programmed to the first layer in this method. On this first layer image data process is continuously obtained from a single camera is used, and the video is then processed in a way such as: - Low pass filter to reduce noise in images acquired - Detect edges characterize the Canny edge detection method - The strengthening of the edge characteristics obtained previously, in order to reinforce the image obtained - Perform the operation region growing at the edge of the characteristic image of the object that has been previously bold - Conducting region growing operation in the image part of the floor - Next is to build a trapezoidal floor region so clearly the difference between the floor and the hitch. Next with the help of software, maps on the environment from a previously created image processing [24].

In Figure 3 below shows how the shortest path built for navigation purposes robot, built using the steepest descent method [25].

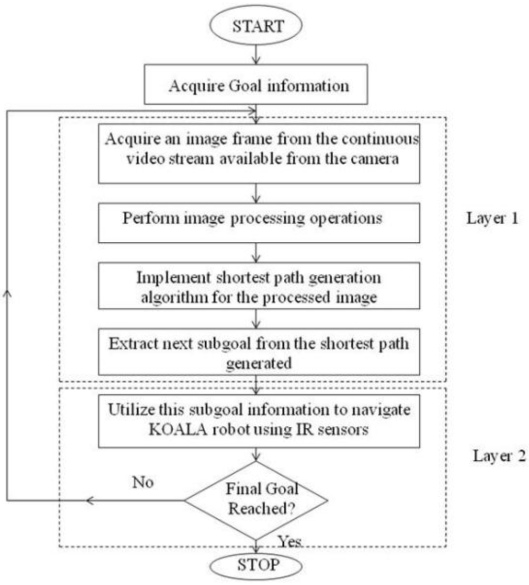


Figure 3. Flow chart of navigation method using sub-goal [3]

Once the navigation map obtained then the next robot to navigate based on the information and circumstances which used infrared sensors to the point goal by taking the first sub-goal predetermined by the system. If the purpose/goal is reached then the robot will stop moving [3].

6. MAPLESS NAVIGATION

6.1. Optical flow-based techniques

Opticalflow based methods mimics how the visual behavior of animals bees, in which the robot movement speed is determined by the basic difference between the image seen by the eye (camera) and the right of the image seen by the eye (camera) left, and the robot will move to the side of the speed image is smaller changes [4]. This method is widely used to detect an obstacle, and following this method developed further in many algorithms, including the Hom-Sehunek algorithm (HS algorithm) and Lueas-Kanade algorithm (LK algorithm). In the HS algorithm, proposed an equation of optical flow method that meets the constraints and smoothness constraints globally. While LK algorithm proposed quadratic equation of optical flow with the smallest weight [20] [27] [28]. Furthermore, the optical flow is the instantaneous velocity of each pixel in image at a certain point. Optical flow field (optical flow) is described as a field of gray (gray) of all pixels on the image of the observed field. This optical flow field reflects the relationship between the time domain and position adjacent frames of the same pixel position [29]. Inconsistencies between the directions of optical flow field and optical flow and major movements can be used to detect an obstacle. Uses optical flow field computed multi-image obtained from the same camera at different times, and the main movement of the camera in the estimation based on optical flow field (optical flow field). Optical flow can be generated from two camera movements that flower and flowrot, if the distance of the object in the field of view and the camera is d and the angle between the object and the direction of translational movement is θ, then the camera will move with translational velocity (translational velocity) v and angular velocity ω. Next optic flow (optical flow) generated by the object can be calculated by this equation: [27]. Where: F = The amount of optical flow (optical flow) v = velocity or displacement translation (translational velocity) d = object in the field of view of the camera + ω = angular velocity (angular velocity) θ = the direction of translational movement is.

6.2. Appearance-Based Techniques

In the appearance-based method, basically done keeping in mind the environment by saving a series of images, which are usually constructed from sub windows are extracted by performing down-sampling of images from the camera, then at a specified time, an image is taken and scanned on along the template that had been prepared, which will then be known where the image that matches the image that has been stored previously. If there are images match, the appropriate action will be determined for proper navigation [30]. The approach taken in this method is that the model-based and view-based. On this model-based approach (model-based approach), the system is equipped with a previously known object models, in order to recognize features in a complex environment and to localize itself in the environment [4]. In the view-based approach (View-based approach), which is not used at all extraction features that have been previously recorded image, self-localization is done with image matching algorithms (image matching) [28].

6.3. Row Based

This method was introduced in [31] that are implemented on the farm robotic applications in an orchard. In this method, the color image captured later clustered with mean-shift algorithm. The new on these methods is the classification technique based on the theory of graph partitioning, classifying, clustering form the image of a class that can be defined, including navigation terrain, trees, and sky [31]. Then by using the Hough transform, image extracted middle lane needed for robot navigation in the garden [27]. By using this technique furthermore then, the mobile robot can change and improve the ability to direct it in accordance with the desired path [31]. Flow char from the method shown in Figure 9. Figure 6. Flowchart Row Guidance Navigation [31] Based on the above, it can be summarized several navigation methods that have been developed since 2010 until now, and it is presented in Table 1.

7. RESULTS AND ANALYSIS

Table 1. Summary of vision-based robot navigation method

Indoor-Outdoor	Category	Method	Paper
Outdoor	Map based	Occupancy Grids	[7 – 12]
Indoor	Map based	holography	[13]
Indoor	Map building	Metric and grid	[14 -16]
Indoor	Map building	Score map	[17 -19]
Indoor	Map building	Potential ban method	[20 – 22]
Indoor	Map building	Stereo-Based	[3] [23]
Indoor	Map building	Sub-goal based	[3] [24-25]
Indoor	Mapless	Optical Flow	[20] [27-29]
Indoor	Mapless	Appearance-based technique	[4] [28] [30]
Indoor	Mapless	Row based	[27] [31]

Table 1 shows the summary of navigation method based on map-based, map-building, and mapless navigation. Many of navigation methods is map-building based. Besides mapless navigation is one of the popular category of in.

8. CONCLUSION

According to the summary of the navigation methods above, meanwhile the map-building based navigation is the method that many researcher concent on.

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