An Application of Panoramic Camera to the Positioning and the Path Planning of An Automated Navigated Vehicle

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Abstract

The paper presents the Position and Orientation Measurement using Panoramic Camera (*POMPC*) for the automated navigated vehicle, the Adaptive Configuration Vehicle (ACV). *POMPC* is used as a position feedback system in the path planning of ACV, which can be applied to monitor unmanned and hazardous environments. Terrain vehicles are liable to contact slip that leads to positioning errors in locomotion. A position and orientation feedback system is required to calibrate the navigation path. *POMPC* consists of a panoramic camera fixed on the vehicle and the proposed measurement algorithm on the server. A remote monitoring control system is set up in the server that combines wireless motion control and video transmission. Some reference points are deployed on the ceiling of a known structured environment. From the relative position of the reference points in the acquired panoramic image, *POMPC* derives the position and orientation of the moving vehicle. The path-planning scheme will be applied recursively from the current position for a new route if the error of each movement command is over the tolerance. A prototype of the vehicle and the *POMPC* system are presented. The experimental analysis demonstrates the feasibility of the proposed structure.

Keywords: Path planning, Panoramic Camera, Unmanned vehicle, Coordinate measurement

1. Introduction

Unmanned vehicles are often applied to the exploration of dangerous and unknown environments, such as outer space [3] and hazardous laboratories. The environments might be uneven and full of obstacles. The Terrain Adaptive Vehicle (TAV) [2] can adjust its configuration to uneven terrains, and has high locomotion and obstacle-surmounting abilities [1]. The TAV included tracked vehicles, legged and wheeled vehicles. The wheeled vehicles have the high maneuverability and the simple configuration, and then they adjusted their configuration to go through obstacles. In order to arrive to reduce motors, stride over steps and go though obstacles, this study chose the wheeled vehicles, which possessed these functions to adapt various terrains.

Path Planning is an important issue for the navigation of an autonomous robot. It can be classified into global and local path planning. Path planning is applied to the exploration of unknown environments such as sea floor, jungle, outer celestial planets, etc.. The Tangent Bug Algorithm (TBA)[4] is a local path planning scheme. TBA applied on the vision system on the vehicle to find the nearest path planning to a given goal. If the vehicle encounters an obstacle, it adopts a detour strategy to go around the obstacle, and move toward the goal again. Global path planning is applied to a known environment such as factories, laboratories, etc. Typical rules of the path planning often convert the environment into grids and polygons[5], and search the centre lines of feasible network lattice point to obtain the best path. Yu etc. [6]modified TBA to search for a shortest path to avoid blocking obstacles and stride over passable obstacles in a known environment. The generated path is then decomposed into a sequence of motion commands to the navigation of a terrain vehicle, the Adaptive Configuration Vehicle (ACV).

Because robot movements are liable to slip, automated navigated vehicles must have some positioning system to feedback the current coordinates. Some literatures utilize the shape change of a known-radius cylindrical object[7] and the color picture division [10] to calculate the present location of the robot. Talluri etc.[8] estimated the robot’s position and pose by establishing the correspondence between the straight line features extracted from the images acquired by the robot and reference features. Wang etc.[9] used the angle between detected lines of reference features derived from an omni-directional image, and applied the trigonometric location method to calculate the robot’s position and orientation.

Because cameras are often used in a moving robot for surveillance, this study would like to develop a position system based on the image acquired from a panoramic camera (Enrise MapCam 360) mounted on the moving robot. Some reference points are first deployed on the ceiling of a structured known environment. The proposed method will use image processing to identify the reference points, and apply the least squared method from the relative distribution of the identified reference points in the panoramic image to calculate the position and orientation of the

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moving robot. The visual position system will then be applied to the path planning of an automated navigated vehicle.

2. The Orientation and Position Measurement System

Originated from the concept of astronavigation, this paper develops a simple indoor coordinate measurement system. Astronavigation is often used for vessel navigation. From the observation of the relative distribution of the asterism in the sky, the current longitude and latitude can be determined using trigonometric location method. Since a surveillance camera is required for automated guided vehicles, this study proposes the *POMPC* (Position and Orientation Measurement using Panoramic Camera) to locate the moving vehicle. The study first sets up some reference points on the ceiling of a structured predetermined environment. An *ICS* measurement method using the panoramic camera is proposed. *POMPC* then applies a least squared error method between the measured *ICS* and *GCS* for the reference points to track the current coordinate of the moving robot.

2.1. The Transformation of Coordinate Systems

For a simplified planar case as shown in Figure 1 where $d_z = \theta = \psi = 0$, there are only three variables to determine the relative position and orientation between the Image Coordinate System (*ICS*) and the Global Coordinate System (*GCS*). Point *O* is the origin of *GCS*, and Point *P* is the center of the panoramic camera, which is also the origin of the *ICS*. The relationship of a given reference point *R* between the coordinates of *ICS* and *GCS* is as follows:

$$\begin{bmatrix} R_x \\ R_y \\ 0 \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi & 0 & d_x \\ \sin\phi & \cos\phi & 0 & d_y \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} R_u \\ R_v \\ 0 \\ 1 \end{bmatrix} \quad (1)$$

where d_x, d_y, and ϕ are the position and the orientation of *ICS* relative to *GCS*.

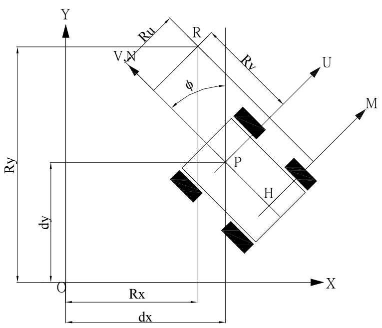


Figure 1 The relationship between *GCS* and *ICS*

2.2. The Polar Coordinate Measurement Using the Panoramic Camera

Because the panoramic camera is using a hyperbolic mirror to reflect the surrounding into a CCD, the panoramic image is like ring centered at the camera (Figure 3). The relationship between the number of pixels and the distance of a given point from the center of the image will be nonlinear. This session establishes the polar coordinate system (*ICS*) with the origin at the center of the image derived from the panoramic camera. We arrange some grid points of fixed spacing on the ceiling as shown in Figure 2, and derive the polynomial function (Figure 4) between the distance and the pixel numbers from the origin using a least squared error method.

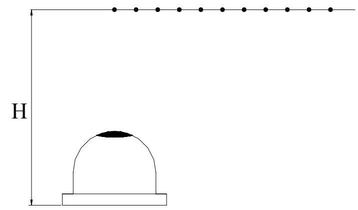


Figure 2 The arrangement of the correlation grid points on the ceiling

Figure 3 The panoramic image

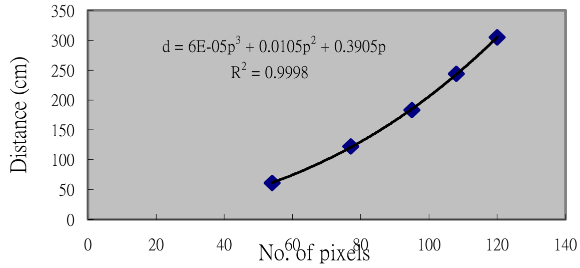


Figure 4 The fitted function for the pixel distance of *ICS* (H=280 cm)

2.3. The Error Analysis of the *ICS* Measurement System

The *ICS* measurement using the panoramic camera is subject to several error sources: the approximation error of the pixel-distance equation, the resolution restriction, and the assembly error of the camera system. The assembly error of the camera system will affect the symmetric of the panoramic image. This study estimates the distance error at various angles and concludes that the asymmetric error is negligible. The correlation error of the pixel-distance function is shown in the *L2* of Figure 5. The resolution of the panoramic image system determines the measurement resolution. The closer the feature to the center of the panoramic image, the higher the resolution. Thus, the location of the panoramic camera can cause estimation errors due to its resolution. The estimate error due to the image resolution is shown in the *L1* of Figure 5.

The total error of the prototype *ICS* measurement system, *L3* is the summation of *L1* and *L2*, which will be used to determine the spacing of the reference points in *POMPC*. Here we assume the spacing of the reference points is 1.5(m) in the following analysis, which provides the initial measuring error of 6(cm) from Figure 5.

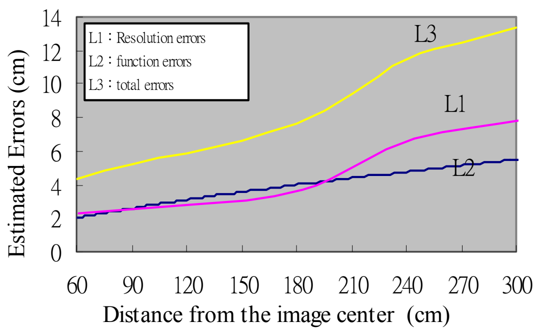


Figure 5 The estimated errors of the *ICS* measurement.

2.4. The Position and the Orientation Measurement of the Moving Robot

We mount a panoramic camera on the moving robot. Because some reference points are pre-arranged on the ceiling, their coordinates in *GCS* are known. The coordinates of the reference in *ICS* can be obtained using the proposed panoramic measurement system. If at least two reference points are identified, the three variables, d_x, d_y, and ϕ, can be solved for using equation (1) to locate the position and the orientation of the robot.

However, due to the measurement errors of the reference points in *ICS* using the panoramic measurement system, the exact solution of the unknowns in equation (1) is not available. Because the farther the reference from the center of the panoramic image, the larger the measurement error, *POMPC* identifies all the reference points in the preselected radius range as shown in Figure 6, and estimate their coordinates in *ICS* using the panoramic measurement system. The Least Squared Errors Method is then applied to improve the estimation accuracy. The objective function is defined as follows:

$$SE=\sum_{i=1}^{n}\left[\begin{array}{l}(R_{ui}\cos\phi-R_{vi}\sin\phi+dx-R_{xi})^2+\\(R_{ui}\sin\phi+R_{vi}\cos\phi+dy-R_{yi})^2\end{array}\right] \quad (2)$$

where *SE* is the sum of squared errors and *n* is numbers of the recognized reference points.

Figure 6 Search for the reference points

This study also investigates the influence of the number and the distribution of the recognized reference points on the estimation accuracy. The results are shown in Table 1, Table 2, and Table 3. As expected, the more number of reference points used, the higher estimation accuracy. Also, for the same number of reference points, higher accuracy can be obtained if the reference points are distributed evenly surround the camera. For instance, higher accuracy can be obtained if points 5 and 7 are used rather than points 7 and 8 (Figure 7) in the estimation.

Table 1 The estimating error using two evenly distributed reference points

	Δd_x (cm)	Δd_y (cm)	Δr (cm)	$\Delta\phi$ (°)
Avg. Errors	0.13	1.92	1.93	0.69

Table 2 The estimating error using two reference points located on one-sided of the camera

	Δd_x (cm)	Δd_y (cm)	Δr (cm)	$\Delta\phi$ (°)
Avg. Errors	0.04	4.28	4.28	4.68

Table 3 The estimating error using four evenly distributed reference points

	Δd_x (cm)	Δd_y (cm)	Δr (cm)	$\Delta\phi$ (°)
Avg. errors	0.01	1.31	1.31	1.03

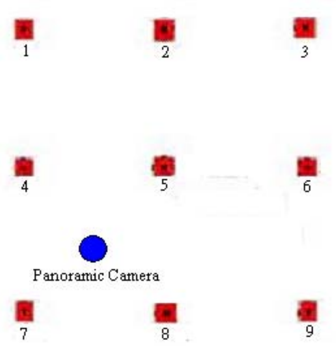


Figure 7 Distribution of the reference points

3. Design and Motion Control of the Adaptive Configuration Vehicle

3.1. The design of the Adaptive Configuration Vehicle (ACV)

ACV is a terrain vehicle with high locomotion capabilities[6]. It can be applied to the exploration of unmanned environment where the abilities to cross stages and trenches are required. Figure 8 shows the assembly view of the prototype ACV. In addition to four independently driving wheels, Front Left Wheels (FL), Front Right Wheels (FR), Back Left Wheels (BL), and Back Right Wheels (BR), two actuators, Arm Left (AL) and Arm Right (AR), control the rear wheel-arms to stride over obstacles. Another two actuators, Turning Left (TL) and Turning Right (TR), control the swinging angle of the front wheel arms. The front wheel arm enables ACV to spin around the middle of the rear wheel pair.

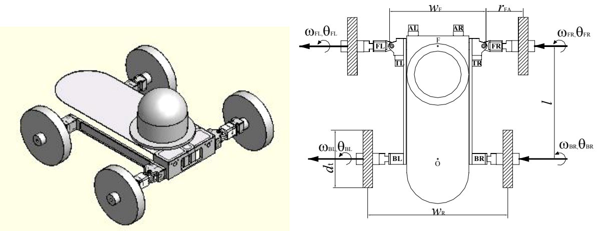


Figure 8 The overview of ACV

3.2. The Locomotion Capability of ACV

To simplify the control of the vehicle, the motion control of ACV is predefined into eight motion commands. The control parameters associated with each motion command are listed in, and the illustrations of the motion commands are shown in Table 4. To facilitate the execution of the motion macros, we design a customized GUI interface. This GUI interface serves as the integrated control panel of ACV for the path planning and motion control.

3.3. The Path Planning Strategy

This study applies a previously proposed path-planning scheme, the Modified Target Bug (MTB)[6], based on Kamon's Target Bug algorithm[4], for the navigation of ACV. The features of MTB include simplifying the moving patterns and including ACV's capacity of passing through steps and trenches. The Modified Tangent Bug is mainly used in a known environment. It allows ACV to select a shortest path to reach the target by avoiding obstacles and crossing specific terrain.

Figure 10 presents the procedure of path planning using the MTB. Departing from the starting point, ACV follows the To-Goal Mode and moves forward to the goal in a straight line. While encountering obstacles in the path, ACV then changes to the Obstacle Mode and goes around or climbs over the encountering obstacles. If ACV meets no obstacles in the path, it remains the To-Go Mode and goes straightly to the goal.

As to impassable obstacles, ACV avoids the obstacles by going around them. Depending on the shape of the obstacles, MTB will suggest a polyline or an arc to go around the obstacle. The MTB will switch to the To-Goal mode, if the obstacle no longer blocks the goal. The process reiterates until the goal is reached.

Table 4 Motion commands of ACV

Motion commands	Motion Description	Motion Parameters
LINM	Linear moving	v: Speed, d: Distance
CSTP	Climb the step	h: Height
STGP	Stride over the gap	w: Width
GARA	Going around by arc	θ_a: Angular displacement, C: Center of arc
SPIN	Spin around the middle of the rear wheel pair	θ_s: Spinning angle

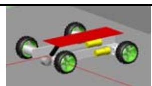
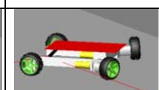
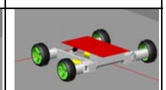
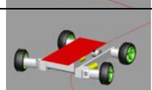
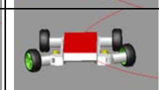
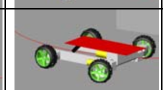
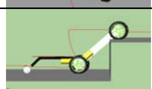
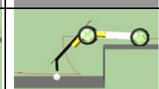
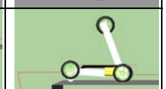
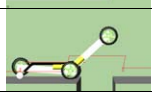
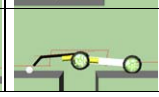
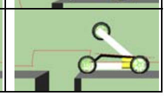
Motion commands	1st snapshot	2nd snapshot	3rd snapshot
SPIN			
GARA			
CSTP			
STGP			

Figure 9 The illustrations of the motion commands of ACV

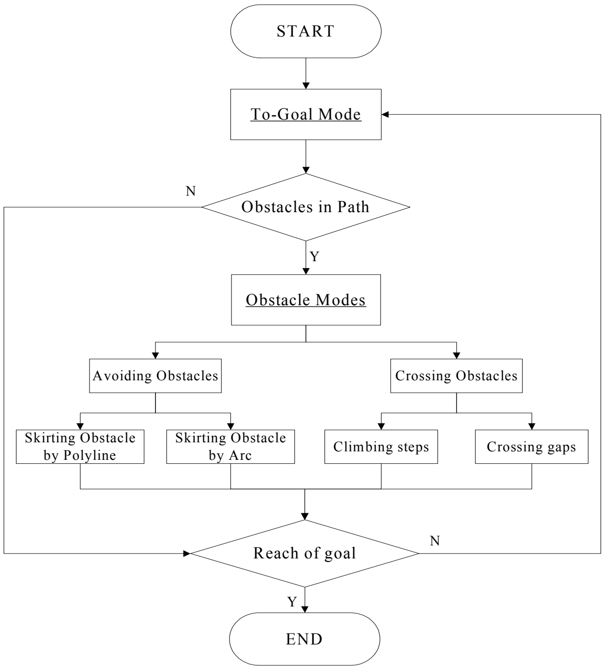


Figure 10 The Modified Tangent Bug algorithm

4. The Automated Navigation of ACV using POMPC

The server PC conducts the path planning for ACV and decomposes the designed path into a series of motion commands. The server communicates with ACV using the wireless modem through RS232. The microprocessor in ACV system uses PIC16F877 to generate PWM signal to control the motor speed. The angular encoder provides position information to the microprocessor for position control. At each controlling node, the panoramic images are sent to the server PC to estimate the orientation of ACV that becomes the position feedback system. If the error is beyond the positioning tolerance, the server will redesign a new route from the current position and command ACV for the next move until the reach of goal.

4.1. The *POMPC* System

The panoramic camera is mounted on ACV as shown in Figure 8. At the execution of each motion command, the acquired surround image is transmitted wirelessly to the remote server. This study adopts the BCB program for the image processing.

The reference points are highlighted using LEDs such that they can be identified by the brightness in the image. Figure 6 shows that we use the binary operation to look for the reference points. Next, the *GCS* coordinates of the reference points are identified from the color of the surrounding pads. Once the *ICS* coordinates of the reference points are obtained, *POMPC* applies equation (2) and the *fminsearch* function of MATLB to calculate the position and the orientation of ACV.

4.2. The Integration of *POMPC* and the Path Planning Algorithm

The path planning module is written using Matlab. The environment and the obstacles are given and built in the program. *POMPC* will locate the current position of ACV. For a designated goal position, a shortest path will be generated automatically as shown in Figure 11. The path is then decomposed into a sequence of motion commands as shown in Table 5. After the execution of each motion command, *POMPC* will feedback the current position and orientation of ACV. If the location error is beyond the tolerance, the Modified Tangent Bug algorithm will be applied recursively from the current position to search for a new route.

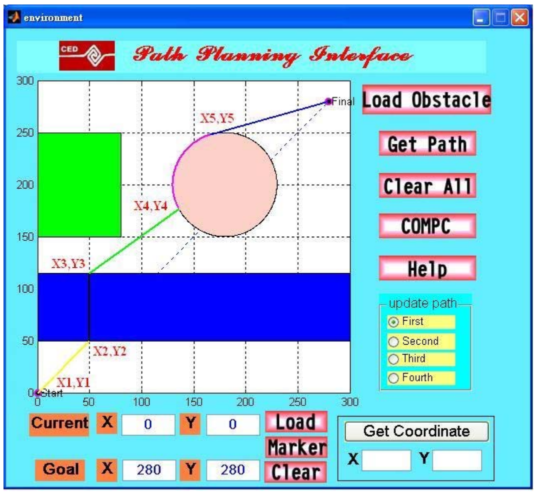


Figure 11 The Path Planning Interface for ACV

Table 5 The example motion sequence of ACV

Position	Present Orientation	Motion commands
X1, Y1 (0,0)	0°	*SPIN* (45) *LINM* (71)
X2, Y2 (50,50)	45°	*SPIN* (45) *STGP* (15)
X3, Y3 (50,115)	90°	*SPIN* (-55) *LINM* (42)
X4, Y4 (135,176)	35°	*SPIN* (20) *GARA* (103, 180, 200)
X5, Y5 (166,248)	15°	*LINM (45)*

5. Conclusions

This paper has presented an automated navigated vehicle using an image positioning system as a feedback system in a known environment. The proposed measurement system, *POMPC* is simple and low cost. *POMPC* uses a panoramic image and pre-deployed reference points to locate the position and the orientation of the vehicle within the accuracy of ±5cm and ±5°. Our study has successfully combined *POMPC* and the path planner, MTB, to automatically navigate ACV to any designated position in a planner environment. The prototype system has successfully demonstrated the feasibility of the concept, and can be applied to the surveillance of structured unmanned environments.

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應用環場影像器於自主式越障車之定位與路徑規劃系統

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摘要

本文探討以環場影像器作為座標與角度量測，藉以結合路徑規劃，作為越障車（Adaptive Configuration Vehicle，簡稱ACV）自動行進與導航之控制，以應用於已知環境如無人化工廠及危險環境之監控。在機器人與無人自走車的行進的控制中，車輛行進時與地面之間不免會發生滑動的現象，為了配合路徑規劃，因此需要一個車輛的定位裝置，藉以校正滑動誤差，並修正行進路線，以行進至指定地點。本研究所提出的量測系統*POMPC*，係藉由固定在行進車輛上的一組環場攝影機，與在遠端的伺服器上的量測運算法則所組成。人機介面以Matlab與Borland C++ Builder寫成，並運用遠端模組及無線影像傳輸之網路傳輸技巧進行遠端監控，以單晶片控制ACV的動作指令。藉由固定於天花板之已知參考點，應用環場影像器所擷取之全域影像，由影像座標系統與全域座標系統的比對，推算車輛之座標與方位，當誤差超過容許值時，將由影像器定位所得之方位，重新規劃到達指定目的地之新路徑。最後，本文藉由越障車的實作與機電整合，驗證所提出方法與系統之可行性。

關鍵字: 路徑規畫、環場影像器、無人探測車、座標量測