SIMULATION OF TERRAIN REFERENCE NAVIGATION SYSTEM BASED ON IMAGE MATCHING FROM DIGITAL VIDEO CAMERA

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Abstract

In the paper general overview on terrain reference navigation is presented. The concept of affordable image-matching system was described. The system consist of positional and strapdown visual subsystems. Both subsystems use digital video camera and image matching process to compute the navigational information. In the system it is assumed, that the external data agreement with the data in the memory determine the camera position in a unique way. Two methods for correlating images are considered: the radial cumulative similarity algorithm and cross correlation – they were chosen to test the ability to perform the task. Results of numerical simulation are presented and quality of image matching and computational time compared. They prove applicability of at least one algorithm in visual navigation system.

1 Introduction

Terrain – referenced navigation systems determine navigational parameters of moving object by correlating external information from measurements with the data stored in the memory of the system. Several physical quantities such as electromagnetic, thermal and magnetic filed parameters or a distance may by used as information sources. In modern military and civil navigation terrain- matching systems the altitude is used most often.

Terrain – referenced navigation methods may be classified as:

- terrain characteristic matching,
- terrain contour matching,
- scene matching area correlation.

Matching is understood here as establishing the degree of correspondence (agreement) between various data sets, particularly images. Terrain characteristic matching is a technique of measuring a scalar quantity, which is compared with values stored in memory – it may be referred as 1D system. The idea of terrain contour matching is to measure values along specified lines, mostly parallel to the vehicle longitudinal axis – the 2D case. The measurement is performed in short time intervals. Scene matching or area correlation is a method based on image processing. An image captured by camera, called frame, is being searched in the area images database, called scene. This may be referred as 3D matching, as the “frame” of the object sensed depends on the position of the sensor relative to the object.

The advantages of the terrain-following methods are autonomous work and potential high accuracy. Therefore, they find military application, as the system may not transmit any signals but the hardware is rather expensive. System operation may be degraded by weather or electromagnetic radiation. Therefore, to avoid such situation, terrain – referenced navigation systems are being used as a part of navigation systems integrated with inertial navigation system (INS) or global positioning system (GPS).

The general objective of this research is to develop terrain – referenced navigation system based on using digital video camera as the source of the image. It will make the cost of the system lower, comparing to the advanced radiomagnetic field or thermal sensors.

In this paper the concept of system, the algorithms and their evaluation by numerical simulation are presented. In the next stages of the project the hardware will be developed and the system will be tested on a mobile platform.

2 Concept of navigation system

2.1 Methods of image matching navigation

There are two basic methods of image matching navigation: positional methods and strapdown methods. They are presented in this section and the concept of navigation system based on these methods is introduced.

The positional methods use the navigational information referred to parallel (to camera movement) scene, distance from scene or/and orientation of camera. First two cases are based on not sophisticated image matching or comparison algorithms, like those proposed in this paper. The procedure to find a position referred to the scene and the distance was presented in [6]. The geometric relations, which are essential for computing the distance using visual techniques also can be found in that paper. The orientation of the camera can be computed from the distortion of the edges of characteristic element. The algorithm to evaluate assignment can be found in [3]. Its application to image matching navigation will be subject of further investigation.

In strapdown, terrain-matching systems velocity is the navigational information. The movement of the camera can be established using optical flow methods as it is explained in the next section.

2.2 System schemes: position and strapdown

Image matching, positional navigation can be developed in two ways. In the first variant (simple) it is assumed, that vehicle (camera) moves along the prescribed track, and assignment of system is establishing a position of the vehicle on this track. Position referred to the scene is the navigational information utilized in this method. In the second variant (more complex) there are no constrains deployed on movement. In order to compute the position it is necessary to determine distance and reference point, and also (if necessary) – orientation of the measurement equipment.

In both manners system is not working continuously. Environment database contains characteristic elements of the frames. If vehicle appears in vicinity of such an element (control point) this element is being searched by the camera, and approximate position is corrected. The scheme of system is presented in Figure 1.

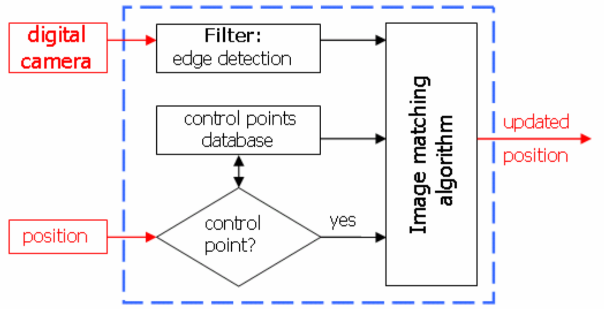

Fig. 1. Positional system.

Image matching, strapdown navigation system establishes velocity of the vehicle (camera). The idea is to find the relocation vector of specified object visible in both frames (taken in *i–1* and *i* time interval). The Kalman filter is used to find the most probable location of vehicle (camera) in present time interval. Scheme of system is presented in Figure 2.

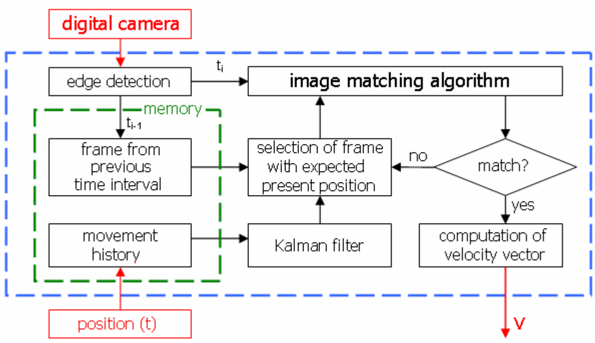

Fig. 2. Strapdown system.

2.3 The concept of integrated system

Integrated system consists of: GPS, digital video camera, computer unit. Its scheme is shown in Figure 3.

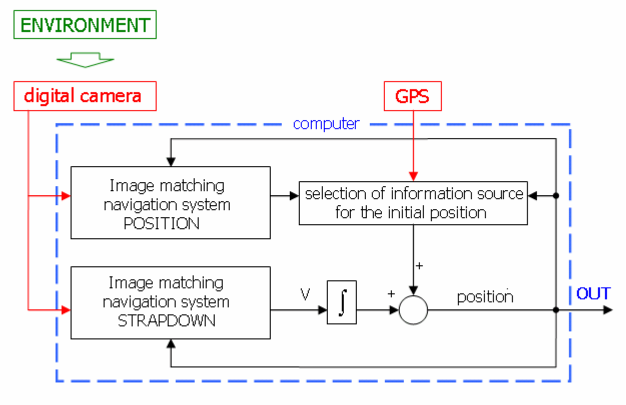

Fig. 3. Integrated system.

GPS is used to initialize work of the system. The position obtained from the GPS receiver can be also used to correct indications of visual image matching part of navigation system whenever it is needed and the satellite signal is accessible.

Navigation is carried on using continues strapdown method with the use of video camera. For every (or some chosen) time intervals visible object is being searched in database. When it has been found, the strapdown navigation is corrected by the positional, visual system and the vehicle position is updated.

3 Image matching and optical flow

According to [2] digital image matching automatically establishes the correspondence between primitives extracted from two or more images depicting at least partly on the same scene. This correspondence can be measured in several ways, but finally when it is normalized to TRUE or FALSE message it is precious source of navigational information.

Image matching algorithm is used in both manners: strapdown and positional navigation, as it is explained in the previous section. The idea of its application to establish the velocity vector was taken from optical flow methods [4].

The task of the optical flow computation is to extract a dense velocity field from an image sequence. It is necessary to assume, that the intensity of hues is constant during the displacement. There are several techniques of computation the optical flow. Generally they can be classified into four categories: differential, correlation based, energy based and phase based.

Not all of these techniques can be applied to navigational problem. Basically it is not a must to compute velocity field. The assumption is made that no point of the frame is moving relatively to any other what is the main assumption in terrain referenced navigation. As a result only one vector has to be computed, which, when inverted, is velocity vector of vehicle (camera).

Finally the optical flow problem becomes an image matching problem, the same as position estimation. It is essential to select appropriate algorithm: efficient, i.e. with low numerical cost. In this study two algorithms were taken under consideration. They are radial cumulative similarity (RCS) and cross correlation (CC).

Details on RCS can be found in [1, 5]. This is a method, which uses purely local image analysis without any preprocessing, such as smoothing or edge detection. A new image transformation is used, which characterizes the local structure of an image in a manner insensitive to points in an occluded region and which is sensitive to the shape of the occlusion boundary. This algorithm is able to track corresponding elements in multiple articulated surfaces. RCS is a kind of multiband algorithm, it processes color images.

CC is a simple monoband algorithm [2]. The correlation coefficient is calculated. This algorithm usually uses shades of grey as an input data. The coefficient is data dependent and has a value of 0 for no correspondence and the value of 1 for full correspondence. The pre-process of an images is necessary to provide the efficiency. In most cases edge detection is performed before the CC algorithm is used.

Image matching may be an ill-posed numerical problem, and additional assumptions and constraints have to be introduced to obtain correct solution. The algorithm must be evaluated by numerical simulation for various sample images. The results will show the ability to recognize the same object in images of various qualities, what is the key point in image matching navigation.

4 Simulation

Both of the above mentioned algorithms are subjects to the numerical simulation. The aim was to solve in this case two fundamental problems of image matching:

- ambiguous solutions: what values of result parameters denote images identity
- computational costs – is it possible to carry on the algorithm in real time ?

The result of RCS consists of two components [1]: central attribute and neighborhood function. The radius of the area to compute central attribute was chosen to be 2 pixels. The coefficient of trade-off between central attribute and neighborhood function was set to be 0.2 for the first quantity and 0.8 for the second one. As a data set representing images for numerical purposes, the RGB (red green blue) vector was taken. The vector was normalized to percentage scale. Result (denoted as D_λ) was multiply by 100 to change the scale.

Simulation of CC was preceded with the edge detection procedure. To do so the Sobel filter was applied. The filter computes two components of gradient:

$$S_X = (f_2 + 2f_5 + f_8) - (f_0 + 2f_3 + f_6) \quad (1)$$

$$S_Y = (f_6 + 2f_7 + f_8) - (f_0 + 2f_1 + f_2) \quad (2)$$

$$S(x,y) = \sqrt{S_X^2 + S_Y^2} \quad (3)$$

Pixels are denoted as it is shown in the figure 4.

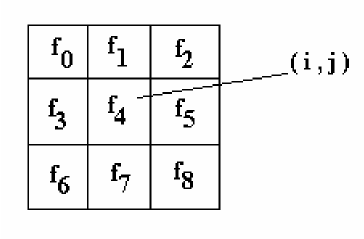

Fig. 4. Pixel notation for Sobel filter.

Then the luminosity function was used as a digital representation of image. Luminosity is computed directly from the RGB vector. The relation is as follows:

$$L = \frac{\max(R,G,B) + \min(R,G,B)}{2} \quad (4)$$

Three sets (no. 1, 2, 3) of images were used in the simulation. They are shown in the figures 5, 6, 7 respectively.

Fig. 5. Set of images no. 1.

Fig. 6. Set of images no. 2.

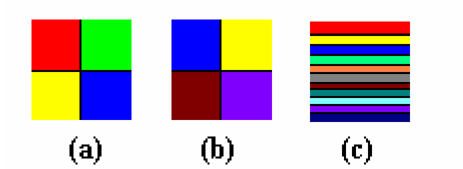

Fig. 7. Set of images no. 3.

Set no. 1 represent the same images with different background (a-b) and different images with the same (or almost the same) background (a-c). Set no. 2 represents the same object (face) in different light conditions (contrast). Set no. 3 consists of simple textures: the same texture with different colors (a-b) and different texture.

The results of both algorithms differ from each other. D_λ is minimized for similar images. In CC correlation coefficient (denoted as ρ) has a value in range <0,1> where 1 indicates full correspondence. Following tables (1, 2, 3) present obtained values of D_λ and ρ for set no. 1, 2, 3 respectively.

image \ image	a	b	c
a	$D_\lambda \rightarrow$	0,0324	8,9129
b	0,9999		8,8700
c	0,0988	0,0985	$\leftarrow \rho$

Table. 1. Results for set of images no. 1.

image \ image	a	b
a	$D_\lambda \rightarrow$	2,7452
b	0,6834	$\leftarrow \rho$

Table. 2. Results for set of images no. 2.

image \ image	a	b	c
a	$D_\lambda \rightarrow$	1,2225	4,7568
b	0,9328		2,97440
c	0,1980	0,1827	$\leftarrow \rho$

Table. 3. Results for set of images no. 3.

Output data obtained shows the range of values, which can be considered as an indication of similarity.

CC clearly shows the expected results. Despite the color difference, the coefficient value is about 1 (1a-1b in table 1, 3a-3b in table 3) because of the same or almost the same edges. Result of matching images 2a and 2b is not as high as the mentioned above. The reason is so big lightness in image 2b, that some edges were lost. Even in this case coefficient is higher than 0.5, what we can assume is a measure of frames conformability.

Simulation proved the ambiguity of RCS. Although in simple cases it works correctly, in more sophisticated tasks (matching 2a and 2b) D_λ value was almost equal to result of matching dissimilar images: 3b and 3c. It warns that the algorithm is not reliable in various light conditions.

The time of numerical operations was also measured. The average time of CC (including edge detection) is 0.05 [sec] on Pentium III 500 MHz machine. This is twice less then RCS time, which is about 0,11 [sec].

Simulation software was created in Microsoft Visual Studio as Win32 application. Programming language was C++.

5 Conclusions

The concept of terrain reference navigation system was presented in the paper. Both subsystems – positional and strapdown use image matching algorithms to establish the navigational information like position in control point and velocity. Two algorithms were chosen for numerical tests to check their usefulness in navigation.

The algorithm of cross correlation was evaluated as well-working and functional for navigational purposes. The radial cumulative similarity algorithm works well. Exception is a situation, when frames are taken in significantly dissimilar light conditions. This defect connected with doubled time of processing (comparing to CC) makes RCS not good enough method to apply in image matching navigation.

Acknowledgments

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