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Computer Vision for Mobile On-Ground Robotics

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Abstract

Autonomous mobile robotics needs reliable information on relief of underlying surface and location of obstacles. Planning the route of a mobile on-ground robot supposes mapping of a visible area with separating it into zones of good or conditional pass ability, impassability, and indefinite zones. It needs recognition of standard objects (marking, traffic signs) and types of surface (snow, sand, or water) as sources of evident or hidden obstacles.
3D calculation requires large computer resources and leads to delays, limiting the velocity. Contouring of boundaries simplifies image decomposition to objects and defines key tasks of mapping such as image vectorization and recognition of objects. They must be divided as in algorithms so at a hardware level. An idea of process multisequencing results in division of data processing on several processors. Along with vector analysis of obstacles it leads to radical cut of 3D update time, ensuring the data supply for high-speed motion of robots.

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Keywords: robot; vision; mobile; obstacle; decomposition

1. Problem declaration

Almost or partly autonomous operation of mobile robotic vehicle must be provided with computer vision equipment as well as algorithms and means of video information analysis. Motion in an undetermined medium requires solving of localization and navigation tasks on a base of 3D environment study. Coordinate measurement is the high-priority function of a computer vision system. In practice, it means that autonomous mobile robotic vehicle needs reliable information on relief of underlying surface and location of obstacles.

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Peculiarities of computer vision system operation result from dynamics of data gathering on board of a mobile robot that leads to continuous variation of camera viewpoints. This circumstance tightens requirements on update rate of 3D image data gathering and limits possibilities of scanning system application.

Planning the route of a mobile on-ground robot needs mapping of a visible area with separating it into zones of good or conditional pass ability and impassability. Conditional pass ability zones are such areas of underlying surface, where motion is possible only with limitations on velocity or direction.

Measurement of a 3D image from one point of view does not allow us to obtain comprehensive coordinate information. Objects under study are not transparent, so among their sides only those are seen, which are directed towards the observer. Areas behind the objects are shielded if object heights are comparable or exceed a level of sensor location. Along with the listed above zones on the visible-area map, it is necessary to introduce a denotation of indefinite zones. In a case of primary image reconstruction they can be recorded as zones of conditional impassability.

Peculiarities of one-viewpoint 3D image registration lead to the fact that even at use of a pulsed ToF (Time of Flight) technique, which is the most direct way of coordinate data gathering, the time interval required for data processing (mapping the visible area) becomes noticeable non-zero. For comparison of computer vision methods and systems, it is reasonable to introduce two parameters: upper and lower limits of the time required for reconstruction of the 3D visible-area image. The upper limit corresponds to a “cold start” mode, when a sensor memory contains no information on environment, and the lower limit corresponds to an update mode with no change in the image.

Despite the variation absence in the last case, any computer vision system has to execute a number of long-term operations: data gathering, calculation of the coordinate information, its referencing to an applied coordinate system and comparison with the previous measurement result for revealing dynamics. Let us call the upper limit of the range as the time of 3D analysis, and the lower limit as the 3D update time. The last parameter determines the limiting possibilities of a robotic vehicle in motion. In any case it is necessary to remember that higher dynamics in a 3D visible-area image causes lower robot velocity due to limitations of its control system possibilities.

If the medium of motion is completely undetermined, the proposed classification of pass ability zones may be insufficient. For example, presence of movable objects creates dynamical zones of impassability and zones of unsafe motion. Moreover, in such conditions it is necessary to combine equipment of coordinate data gathering with apparatus for visual information record and even recognition systems. Autonomous mobile robotics requires recognition of standard objects (marking, traffic signs, traffic lights) and cover types of underlying surface (snow, grass, sand, water), which can be sources of evident and hidden obstacles for motion.

2. Vision technique overview

The simplest method to obtain the 3D coordinate information is measurement of 2D angular distribution of the range to the transparency zone boundary with successive calculation of linear coordinates [1]. Passive methods based on triangulation [2] require a great amount of calculations and do not ensure reliable correspondence of the results. Optical location systems with two-coordinate scanning [3] are also hardly applicable for solving tasks of mobile robotics due to extended time of data gathering, for instance.

Maximum velocity of data gathering may be provided by the ToF technique [4] of range measurement with simultaneous calculation of propagation time delay by a special array detector [5]. Unfortunately, the last approach is unreasonably expensive due to technological complexity of array ToF sensor manufacture, so, it hardly may be widely used in mobile robotics. At present, one of the most promising directions to promote the ToF technique into mobile robotics is connected with combination of parallel and serial methods of data gathering that gives the opportunity to provide high-rate information update and radically reduce technological requirements to sensor manufacturing and its cost.

More simple approach is application of triangular methods on a base of structured laser illumination and ordinary TV array information sensors [6]. The main problem of the technique is a great amount of additional calculations needed for reconstruction of 2D range distribution from the illumination intensity distribution. Decrease in the illumination duty factor results in drop of certainty in determination of illumination angles and increase of error possibility. Rise in the duty factor leads to resolution diminution.

The last circumstance is often considered as a negative factor at comparison of devices but hardly when the key parameter is rapidity. Estimations show that even for an ideal flash lidar [7], the simplest algorithm of range measurement by determining the time of flight, the process of 3D image reconstruction from 2D range distribution requires rather long interval and leads to significant limitations of update rate.

3. Biological and technical vision comparison

The analysis of binocular vision typical for mammals shows that estimation of distances to objects is not the main function of biological stereoscopy. The key function of the binocular vision is formation of a volume image by insignificant variations in viewpoint angles, which result in parallax of a far-field image on the boundary of a closer object. Contouring of boundaries significantly simplifies decomposition of the image to objects as well as their subsequent identification and evaluation of distances by known overall dimensions and observed angular sizes.

Beginning from range in units of meters, the accuracy of distance determination by the angular size of the known object is almost the same as the accuracy of triangulation technique based on the parameters typical for human vision. When distances are lengthened, errors increase linearly for the angular technique and in square-law for triangulation. Thus, the bionic approach supposes contouring objects as the first step in analysis of the visual information and image decomposition as the second. Fig. 1 presents functional schematic of a binocular visual data processing.

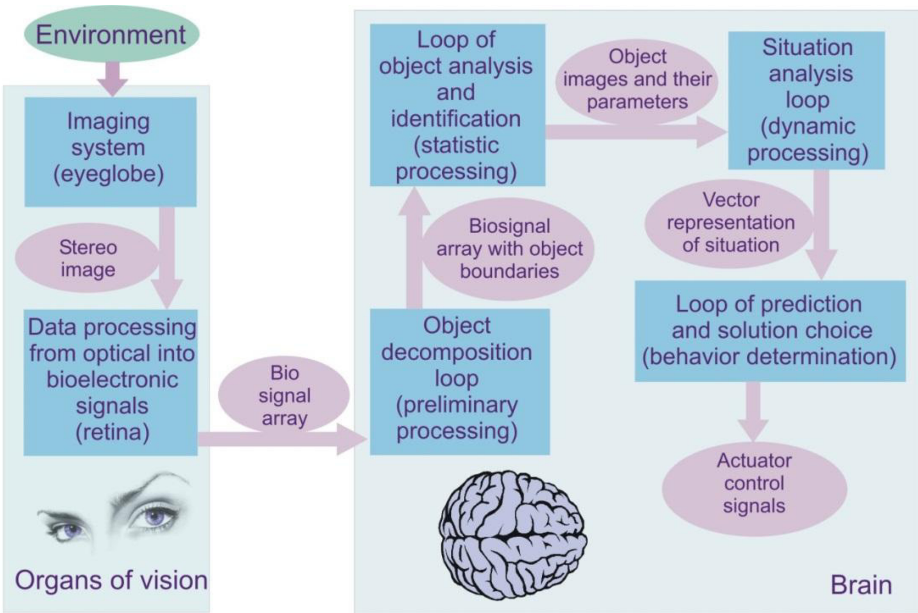

Fig. 1. Functional schematic of binocular vision data processing.

Unfortunately, application of the bionic approach for solving the problem of sensor equipment for local navigation subsystem is limited by differences in the modern technical computation and biological neural networks. However, the key tasks of robotic navigation are also vectorization of graphic information (decomposition to objects) and their identification (recognition). In biological systems, both tasks are decided practically in parallel by the same neural network that is extremely ineffective for technical systems due to consequent character of processor computing.

For enhancing rapidity of technical systems, it is necessary to provide an efficient parallel data processing. First of all, it means separation of vectorization and identification tasks not only in algorithms but also at a hardware level. Moreover, for releasing the central processor resources from excess processes for concentration on functional tasks, the preliminary processing in the both channels is expediently to perform by separate processors as shown in Fig. 2.

Developing the idea of parallel data processing, it is reasonable to transfer information from the object contouring processor in three directions. Closed contours of objects goes to the identification channel for allocation of object zones and to the vectorization channel processor, which is responsible for defining positions and angular sizes of obstacles. The coordinate information from zones of objects is also directed to this processor. The third direction is input of another processor of the vectorization channel, which receives the coordinate information from zones free of objects for calculation of underlying surface inclination and definition of good pass ability zones.

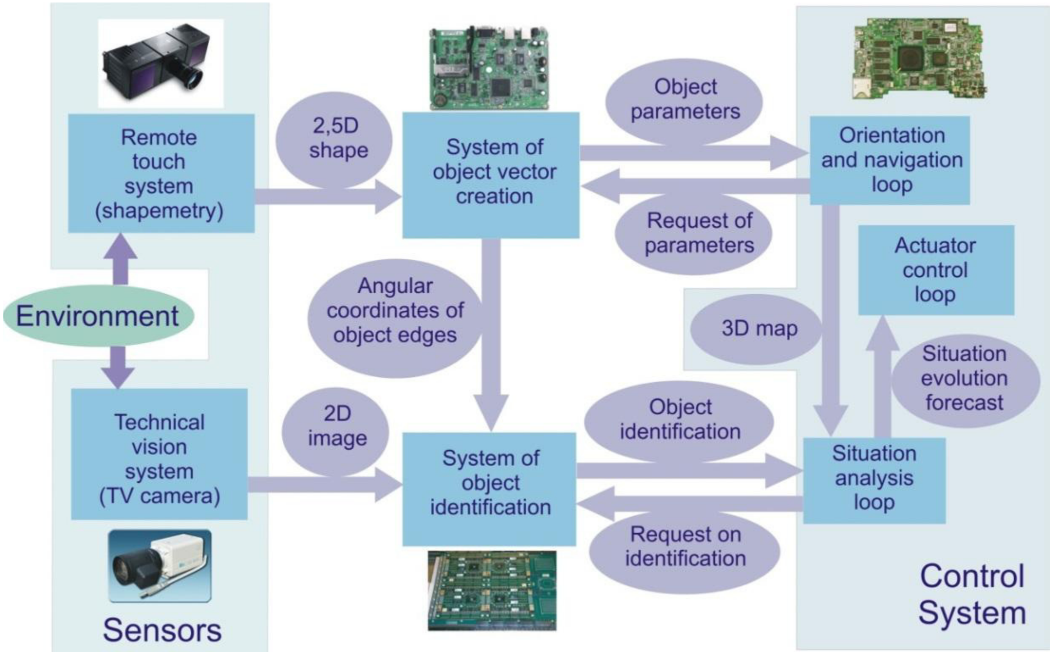

Fig. 2. Architecture of visual data processing for autonomous robotic system.

In the recognition channel, respectively, it is also reasonable to separate two processors, one of which ensures object identification and the other performs underlying surface analysis for revealing zones of conditional pass ability (sand, snow, or water). The considered approach is rather universal because it does not depend on a number of obstacles and on a specific navigation task.

Additional way to speed up the process of environment analysis is related to dividing a system of remote “sense of touch” (coordinate data gathering) into static and dynamic subsystems. Navigation mobile robotics requires minimum information on obstacles (location, overall dimensions) and maximum information on the underlying surface (inclination, presence of small defects, as well as parameters of tenacity and firmness).

When a robotic vehicle is static (before start of motion) the “sense of touch” system must have maximum resolution for reconstruction of the 3D image and planning the initial part of the route. The dynamical subsystem must contain an ordinary device for monitoring inclinations and small defects of the surface. The simplest way to realize such device is to use a structured illumination source in a form of laser line, which is inclined to the underlying surface and looks forward along the motion direction, and a camera located above the source.

Vehicle motion in such scheme operates like a scanning system. The angle of laser beam incidence to the underlying surface may be smoothly varied with velocity increase. Analysis of the line curvature in this case may be strongly minimized. The zones, where line inclination or its local defect exceeds the acceptable predetermined (by the vehicle pass ability) value, are marked as zones of impassability.

The dynamic subsystem must also minimize the analysis of objects, which look like obstacles for motion. For each object in a frame, the subsystem estimates a distance to it and its angular sizes. By comparison of results with previous information, it defines a type of obstacle (static or moving object, stable or variable shape). The definition is aimed at revealing influence of the object on robot motion safety and possibility of collision exclusion.

4. Conclusion

The suggested approach allows us to cut significantly the time of 3D update and to ensure the information supply for safe high-speed motion of mobile robotics in an undetermined medium. Algorithmic and hardware separation of the situation analysis processes followed by transition from exact calculations to estimations opens up new possibilities for enhancing dynamics of mobile robotics. At the same time, the object-oriented perception of environment creates favorable conditions for development of cognitive and self-training robotic systems [8].

To reach the specified goals, we must determine a format of data for information exchange between 3D sensor and central processor. Also, it is necessary to create an algorithm of image decomposition to objects with criteria on impassability zone revealing. In this case, the suggested approach of combining systems of active and passive computer vision with simplified estimation of distances to obstacles is able to ensure analysis of dynamic situation in real time. Such combination opens new prospects for design of autonomous mobile robotics.

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