МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ РФ

Национальный исследовательский Томский государственный университет
Томский государственный университет систем управления
и радиоэлектроники
Болгарская Академия наук
Академия инженерных наук им. А.М. Прохорова
Международная научно-техническая организация «Лазерная ассоциация»
Всероссийское общество изобретателей и рационализаторов

ИННОВАТИКА-2021

СБОРНИК МАТЕРИАЛОВ

**XVII Международной школы-конференции студентов,
аспирантов и молодых ученых
22–23 апреля 2021 г.
г. Томск, Россия**

Под редакцией А.Н. Солдатова, С.Л. Минькова

Scientific & Technical Translations
STT
ИЗДАТЕЛЬСТВО
Томск – 2021

DESIGNING A MACHINE VISION SYSTEM FOR A MOBILE ROBOT TO DETECT AND MARK DANGEROUS AREAS

Majdi Msallam, V.I. Syryamkin
National Research Tomsk State University
majdi.f.msallam@gmail.com

There is no doubt that machine vision systems offer many benefits in many applications, as they improve the ability of machines to adapt and learn. When implementing a new application it is necessary to design a vision system that matches the requirements of the application, as there is a wide range of parameters that must be considered during the design. Our goal in this paper is to learn about these different parameters and define the different requirements for designing a machine vision system for a mobile robot, whose task is to examine different environments autonomously, detect hazardous materials, and mark high-risk areas, in various weather conditions and around the clock.

Keywords: machine vision system, mobile robot, optical sensors, lenses, designing.

Introduction

The use of machine vision systems provides many benefits for a large number of applications. In industrial systems it allows to achieve high automation and increase production efficiency. In addition, it improves the robot's ability to locate and recognize objects, and increases its ability to learn and adapt to the surrounding environment.

In this paper, we conduct a review of a number of literature that includes contributions to the design of machine vision systems, through which we discover the parameters and factors that are taken into account in the design, and accordingly we define the basic requirements for a vision system of a mobile robot, whose goal is the ability to move independently in different environments and to detect and mark areas exposed to pollution (radioactive, chemical, or war remnants). A detailed description of robot's structure can be found in [1, 2].

The history of machine vision systems for robots can be traced back to the 1980s. In [3] it was indicated that machine vision systems were already in use in many applications prior to that date, and they fall under two main applications, namely, industrial robot control and mobile robot guidance. In [4] a survey of developments in vision-based navigation of mobile robots in the 1980s, 1990s and early 2000s is introduced. A clear distinction has been made between structured environments, and unstructured environments. In [5] The issue of autonomous navigation in off-road environments is addressed. It should be noted that the quest to provide mobile robots with a stereoscopic vision system dates back to the 1980s [6–8]. In [9] a vision system was designed for small embedded systems. As it became possible to have low-cost cameras with CMOS sensors in addition to relatively high-speed and low-cost microcontrollers. In [10] a machine vision system was designed based on a methodical design procedure called demand compliant design (DeCoDe). In [11] a vision system was built for a mobile robot in order to recognize and avoid obstacles in real-time. A vision system was designed in [12] that tries to mimic the human visual system in terms of the presence of the foveal, in addition to having rapid movements called saccades that allow obtaining a series of accurate representations of an area. In [13] a survey of the latest developments in the Coal Mine Rescue Robot (CMRR) in the last ten years has been conducted.

The paper is organized as follows: In Section 2 we define a machine vision system, distinguishing it from visual system and computer vision system. In Section 3 we introduce the basic components of a machine vision system and their parameters. In Section 4 we provide some tips for designing a machine vision system, then we define the requirements for the vision system of the considered mobile robot. Finally, in Section 5 we conclude.

Definition of a machine vision system

In the beginning, a distinction should be made between some terms for vision systems. The term "visual system" refers to the system responsible for the visual sensory reception of living organisms, which in humans consists of the eyes and some parts of the central nervous system [19]. This system represents a reference for designing artificial vision systems. For example, in [12] they designed a system similar to the visual system in macaque monkeys due to its similarity to the visual system in humans. The term "computer vision" refers to one of the many fields within the discipline of computer science, it deals with how computers receive visual data in the form of pictures or video and understand this data similarly to the visual system of living things [19].

The term "machine vision" refers to the technologies and methods that allow the system to perform inspection and analysis tasks automatically based on visual information in specific applications such as automatic inspection, control of processes in industry, and robot guidance. In a machine vision system the control theory is applied, and the focus is on the real-time implementation.

Basic components of a machine vision system

The basic components are detailed in the following [14–16].

Lighting. We resort to lighting techniques when the natural lighting conditions in the surrounding environment are insufficient to obtain clear and accurate images of the objects under interest.

Camera. In its simplest form, the camera is a closed box that allows light to enter it through a hole on its wall, so that the rays hit a light-sensitive surface, which leads to the formation of the image.

Modern digital cameras mainly contain the following parts: 1) *Optical sensor*: There are two main types of optical-electronic sensors, they are CCD (charge-coupled device) and CMOS (complementary metal–oxide–semiconductor). The sensor, whether CCD or CMOS, contains a large number of cells that are arranged in a specific order. CMOS sensors are usually cheaper and less power consuming, and are therefore commonly used in cameras that are integrated with small consumer products. 2) *Shutter*: It controls the exposure time, which is the period of time during which an optical sensor is exposed to light in order to capture the image. Shutter is usually located directly in front of the sensor. There are two common types of shutters, rolling shutter and global shutter. 3) *Lens*: It is a set of optical elements in the front of the camera, it controls the path of light coming from the outer environment to the optical sensor. An optical lens is characterized by a its focal length, which is measured in millimeters. 4) *Aperture and diaphragm*: The aperture is an opening located inside the lens to control the amount of light that enters the camera into its optical sensor. The area of the opening is controlled by a special component called the diaphragm. Aperture affects what is called field depth, which is defined as the distance between the nearest object and the farthest from the camera so that they are in sharp focus.

Processing and analysis unit. This is the unit responsible for receiving the captured images and performing a series of operations on them in order to extract a set of information about objects.

Control unit. This unit is a controller that receives the processing results and generates the appropriate control signals to operate all system's components.

Communications. The various components of a vision system must be connected by a network of communications that are compatible with the transmitting device, the receiving device, and the nature of the data to be transferred.

Machine vision system design

General tips. In this section, we provide some guidance for choosing the main components of a machine vision system based on cost and application requirements [11, 12, 18–19]. The lens and the optical sensor highly affect the cost of a vision system. The appropriate shutter type must be specified, which can be rolling or global. The rolling shutter is generally less expensive, especially at higher camera resolutions, but it does not allow for high frame rates. The choice of the appropriate frame rate for the application depends on the nature of the objects to be imaged and analyzed. If they move at high speeds in relation to the field of view, a high frame rate must be chosen so that the shapes in the captured images are not distorted. When designing, we try to look for the lowest resolution and lowest frame rate provided that they are sufficient for the application.

Requirements for the vision system of a mobile robot. The robot under interest is a machine capable of terrestrial-aerial movement, its main task is to detect dangerous areas such as those exposed to chemical or radiation contamination or areas full of war remnants, and then to mark the parts that are classified as dangerous. The robot is supposed to be able to work in all weather conditions and around the clock. To perform these tasks, the vision system must perform the following functions: 1) Building a 3D representation of the area to be examined. 2) Autonomous navigation and obstacles avoidance in real-time. 3) Supporting measuring devices in detecting hazardous materials. 4) Overcoming the problem of poor or unstable lighting.

Based on the functional requirements that have been indicated, some restrictions can be stated on the components of the vision system so that it can perform its functions. In order to build an accurate 3D representation of the area and perform autonomous navigation, the robot must be equipped with a 3D color camera that provides intensity, color, and depth information. The system should also be equipped with a night camera and a thermal camera to deal with poor lighting conditions. There are no harsh requirements for the parameters that determine the specifications of the vision system components.

Conclusion

In this paper, we familiarized with the machine vision system and its basic components, and we conducted a review of a number of contributions regarding the design of this system for different applications, and we got acquainted with the most important parameters that are taken into account during the design. We applied the results of the study in order to define the various requirements for designing a vision system for a robot capable of terrestrial-aerial movement with the task of detecting hazardous materials in various environments.

References

1. Gutsul V.I., Syryamkin V.I., Ilyichev V.N. et al. Patent for invention of the Russian Federation No. 2661295, 2018. [in Russian]
2. Msallam M., Syryamkin V.I.Improving a device for identifying and marking parts of territory with chemical and radio-active contamination // Journal of Physics: Conference Series. 2021. Vol. 1843(1). doi: 10.1088/1742-6596/1843/1/012013.

3. Hall E.L. Fundamental principles of robot vision // Intelligent Robots and Computer Vision XII Active Vision and 3D Methods. Conference Proceedeings. 993. – Vol. 2056. doi: 10.1117/12.150210.
4. Guilherme N.D., Avinash C.K. Vision for mobile robot navigation: a survey // IEEE Transactions on Pattern Analysis and Machine Intelligence. 2002. Vol. 24(2).
5. Obstacle detection and terrain classification for autonomous off-road navigation autonomous robots / Manduchi R., Castano A., Talukder A. et al. // Autonomous Robots. 2005. Vol. 18. P. 81–102. https://doi.org/10.1023/B:AURO.0000047286.62481.1d.
6. Moravec H.P. The stanford cart and the CMU rover // Proceedings of the IEEE. 1983. Vol. 71(7). P. 872–884. doi: 10.1109/PROC.1983.12684.
7. Kriegman D.J., Triendl E., Binford T.O. Stereo vision and navigation in buildings for mobile robots // IEEE Transactions on Robotics and Automation. 1989. Vol. 5(6). – P. 792–803.
8. Ayache N. Artificial vision for mobile robots: stereo vision and multisensory perception. Cambridge: MIT Press, Mass., 1991. 342 p.
9. Rowe A., Rosenberg C., Nourbakhsh I. A second generation low cost embedded color vision system // IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05). Workshops. San Diego, CA, USA. 2005. P. 136–136.
10. Sitte J., Winzer P. Methodic design of robot vision systems // International Conference on Mechatronics and Automation. Harbin, China. 2007. P. 1758–1763.
11. Mane S.B., Vhanale S. Real time obstacle detection for mobile robot navigation using stereo vision // International Conference on Computing, Analytics and Security Trends (CAST). Pune, India. 2016. P. 637–642. doi: 10.1109/CAST.2016.7915045.
12. Huber S., Selby B., Tripp B.P. Design of a saccading and accommodating robot vision system // 13th Conference on Computer and Robot Vision (CRV). Victoria, BC, Canada. 2013. P. 350–357. doi: 10.1109/CRV.2016.48.
13. Zhai G., Zhang W., Hu W., Ji Z. Coal mine rescue robots based on binocular vision: a review of the state of the art // IEEE Access. 2020. Vol. 8. P. 130561–130575.
14. Avdeyuk O.A., Gorbachev S.V., Mukha Yu P. et al. Mathematical methods of informatics in problems and examples. experience in the design of complex systems: a tutorial / ed. Mukha Yu P. and Syryamkin V.I. Tomsk: Tomsk University Publishing House. 2012. 484 p. [in Russian]
15. Syryamkin V.I., Syryamkin M.V., Titov D.V. et al. Adaptive vision systems: monograph. Moscow: RUSAYNS, 2019. 448 p. 2nd ed. [in Russian]
16. Biason A., Boschetti G., Gasparetto A. et al. Design of a robotic vision system // Proceedings of the 7th International Conference on Advanced Manufacturing Systems and Technology AMST '05. 2005. doi: 10.1007/3-211-38053-1_24.
17. Aribowo A., Gunawan G., Tjahyadi H. Adaptive edge detection and Histogram color segmentation for centralized vision of soccer robot // International Conference on Informatics and Computing (ICIC). Mataram, Indonesia. 2016. P. 49–54. doi: 10.1109/IAC.2016.7905688.
18. Zhu Y., Wang X., Xu B. Design of vision-based obstacle crossing of high-voltage line inspection robot // IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER). Chengdu, China. 2016. P. 506–511.