

Special Robot Vision Algorithm Test Platform In Virtual Reality Environment

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Abstract—Special robots work in harsh and dangerous environments. It is necessary to build a test environment similar to the real disaster site to verify its operational capability in the actual working environment. However, building the test environment is not only difficult, but also very expensive. So we use virtual reality technology to build a special robot visual algorithm test platform to replace the real test environment. In this paper, we develop a virtual test platform for robots based on Unity3D, which can simulate the visual environment in the underground mine roadway environment. Finally, we carried out experiments on the experimental platform on the vision enhancement algorithm of the robot under the influence of darkness and smoke.

Keywords—Special Robot, Machine Vision, Virtual Reality, Algorithm Test Platform, Unity3D.

I. INTRODUCTION

Special robots can replace human beings working in harsh and dangerous places[1,2]. The environment of special robots is often complex and unstructured. It is difficult to realize the application of intelligent navigation algorithm. Therefore, this kind of robots often adopt the control mode of teleoperation, that is to say, the returned video is enhanced and processed to the operator, and the robot is observed by the operator. Man sends out corresponding control instructions to direct the robot's movement. The vision system of special robots is one of its most important components because of the heavy dependence on visual system for navigation operation. However, field test research is indispensable in the development process of vision system because machine vision program needs a lot of debugging according to the characteristics of the environment and machine vision algorithm needs a lot of training to determine the key parameters. It is very difficult and expensive to build a high degree of reality simulation test environment, so we intend to use virtual reality technology to build the test environment for special robot vision system algorithm verification[3].

Coal mine robot is a typical special robot due to the restrictions of many safety requirements[4]. Electrical equipment must obtain relevant certificates and tests in order to be allowed to enter the underground coal mine for use. The special robot prototype does not have such conditions in the research and development stage obviously. The special robot

prototype can not enter the underground coal mine according to legal procedures for testing. This kind of robot can not complete the design work without experimental verification and training. A variety of simulation platforms can be built on the ground to simulate the underground environment of coal mines. But a test platform not only covers a large area and has a long construction cycle, but also requires a large amount of capital and human investment. Virtual reality based on powerful three-dimensional computing ability can already be realized on a single PC system with the continuous development of computer hardware and software technology. The research goal of this paper is build a virtual test platform for coal mine robots to use virtual reality technology. The first problem to be solved is the choice of virtual reality development platform[5-8].

II. VIRTUAL REALITY DEVELOPMENT TOOL SELECTION

There are many virtual reality development tools, such as RAGE, Cry ENGINE, Unreal, Unity3D and so on. Each development tool has different characteristics[9]. Some are easy to use with graphical programming, some are high-quality and realistic with three-dimensional graphics rendering, and some are open, strong third-party plug-ins are easy to develop quickly. Here we need to select development tools according to the robot test project to be tested. First, we need to analyze the simulated test environment.

A. Coal mine underground environment



(a) Bright (b) Dark
Fig. 1. Coal mine roadway in different locations

The working environment of coal mine robot is underground coal mine. Coal mine is often hundreds of meters underground, which is composed of lanes. The space of lanes is narrow, dark and humid. The underground environment is

shown in Fig.1, Fig.1a is a roadway with good environment and light, and Fig.1b is a roadway with bad environment. We should be able to simulate the scene in the roadway realistically in this test, and realize the virtual reality engine of dark, humid, multi-coal dust and other environmental conditions through special efficiency.

B. Virtual Reality Development Tool Selection

Coal mine robots are mostly remote control robots, are different from other autonomous robot, the main requirements are the human-computer interaction capabilities, improve people through the robot's sensor system and intelligent system to provide environmental information to the operator, let the operator to make a reasonable navigation control decision, this interactive process requires the simulator to produce some high quality images, sound and other needs, using the game engine as the platform for the simulator is a reasonable solution. It can simulate the harsh environment of coal mine due to the main visual environment simulation combined with the characteristics of the underground environment of coal mine. This requires that the development platform of virtual reality has powerful image rendering and game physics engine, which can render high-quality pictures and simulate the effects of moisture. Unity3D, as the most popular game and virtual reality development platform, has the above characteristics[10,11]:

1) Powerful image rendering, physics, sound, network engine. Good quality, high visual simulation, suitable for machine vision intelligent algorithm simulation. Powerful physics engine PhyX is able to achieve a variety of rigid body, flexible body simulation. 5.1 or 7.1 sound field simulation, suitable for voice recognition simulation; online game support. Mature level design routines and characteristics design to carry out complex system and process test design.

2) Open programming interface, data interface, a powerful plug-in support, extremely rich resources. The official website has a large number of developers to devote the model, code, sound, material & tools, through the sharing of resources to quickly build a test environment.

3) Using C #, C++ programming, the code can easily be found in the network, the migration code is simple and quick.

4) Extensive cross-platform support, support almost all of the current computer, mobile platforms, including mobile phones, tablet, computer, game consoles, web pages, etc., with good portability.

III. SIMULATOR DESIGN

This part introduces the structure of the simulation system, the software flow, the construction of the scene, the design of the function, the addition interference factors of the simulation.

A. Simulator architecture

Figure 2 shows the system structure diagram, the core part is the virtual coal mine robot simulator based on Unity3D. It consists of virtual world objects and virtual robots. The virtual world object contains the roadway, fixture, tool, obstacle, personnel, locomotive track, coal dust, etc. The model is made by artificial photo modeling. In order to show a sense of reality, the model uses special Shaders and normal maps, the special effects of coal dusts and damp use particle system to achieve. Since this paper does not involve the kinematics simulation of the robot, the virtual robot in this simulator is implemented by the first-person controller in Unity3D, which can be controlled by the keyboard and mouse.

Between virtual world objects, the virtual camera moves with the virtual robot, observes the virtual world, and sends the data flow of the acquired image to the image processing algorithm. The periphery of the virtual robot simulator is the operator of the video manipulating robot movement generated by observing the simulator. The operator can send remote commands to the virtual robot to perform the action. The video seen by the operator is processed by the image processing algorithm, histogram equalization algorithm[12,13]. Of course, the processed image can also be provided to the artificial intelligence program, through the artificial intelligence algorithm to command the robot to comply the control instructions.

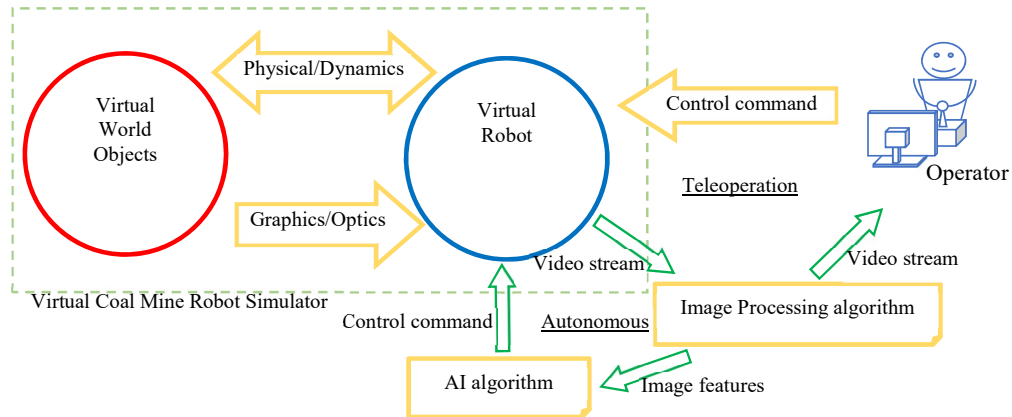


Fig. 2. System diagram

The image processing algorithm has been fully implemented with the OpenCV for Unity plugin[14]. It is essentially an OpenCV .Net package and is capable of implementing in Unity3D, provides dynamic link library package of PC side, Android, iOS, Mac, WSA etc[15,16]. In

this trial, we choose the gray histogram equalization as the experimental algorithm, which is the common image enhancement algorithm of the rescue robot in the dark environment underground.

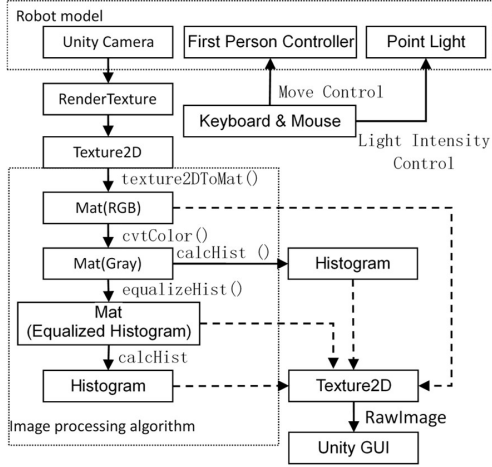


Fig. 3. Simulation flow chart

The whole process of implementation of the program shown in Figure 3. Unity3D built-in camera gives images to the RenderTexture object, and then read the variable Texture2D from the RenderTexture, and then converted to OpenCV's Mat format data. After histogram equalization processing, the Mat datas convert back to Texture2D format and sent to the Unity GUI displayed, it shows the effect in Figure 6,7.

B. Model scene layout

The experiment arranged a virtual coal mine roadway scene, as shown in Figure 4(a)(b), the roadway model contains



Fig. 5. Simulation with different interference factors

C. Histogram equalization

The basic idea of histogram equalization is to transform the histogram of the original graph into a uniform distribution form, which increases the dynamic range of the pixel gray scale value so as to achieve the effect of enhancing the overall contrast of the image. Proceed as follows. All gray levels S_k ($k = 0, 1, \dots, L-1$) of the original image are given.

Count the number of pixels in each gray level of the original image. According to the original image, calculate the gray histogram:

$$P(S_k) = n_k / n \quad (k = 0, 1, \dots, L-1)$$

Where, for the total number of pixels, the number of pixels for the gray level. Then calculate the cumulative histogram of the original image:

$$t_E = EH(S_k) = \sum_{i=0}^k \frac{n_i}{n} = \sum_{i=0}^k P(S_i) \quad (K = 0, 1, \dots, L-1)$$

many features: corners, fork, rail, stone, wood, water pipes, lighting. Using the shotcrete effect, the use of normal mapping to achieve the bump effect. Since this experiment does not involve kinematics analysis, the robot uses the first-person character (capsule) model instead, as shown in Figure 4(b).

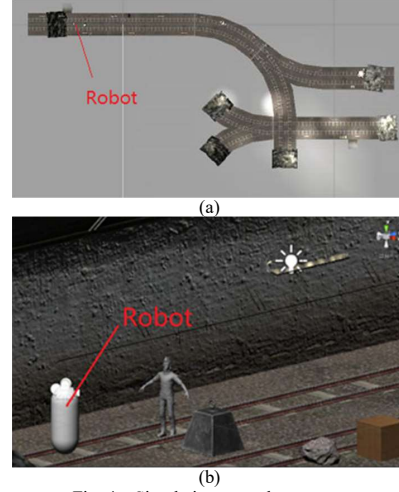


Fig. 4. Simulation scene layout

In order to simulate the real underground environment and ensure the authenticity of the model, here take some special effects such as dark, coal dust, lens water, as shown in Figure 5(a)(b)(c)(d) shown.

Rounding the calculation: $U_k = \text{int}[(N-1)t_k + k/N]$, determine the mapping relationship: $S_k \rightarrow U_k$, count the number of pixels n_k in the new histogram at each gray level. Calculate the new histogram:

$$P(t_k) = \frac{n_k}{n}.$$

In this paper, the algorithm of histogram equalization with computer visual library OpenCV generates the results shown in Table 1,2.

IV. EXPERIMENT

The experiment is divided into two groups, one group for the absence of coal dust interference, the other group in the presence of coal dust interference, respectively, in the simulated roadway light (point light), light intensity set at 0,3,10, All the experiments are in the same roadway position, placed the same obstacles to facilitate the comparison[17].

A. Experiment process

The first group of experiments was carried out under no coal dust interference. As shown in Figure 6(a)(b), here only lists the point light intensity of 0,10 in the two groups of simulator experimental results screenshots. The results of the experiments are given in Section 4.B.

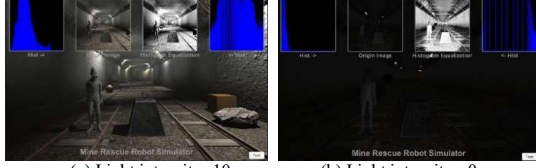


Fig. 6. Simulation of different light intensity without coal dusts

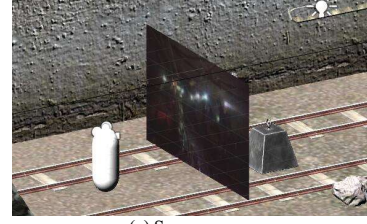
The second group of experiments was carried out under coal dust interference. As shown in Figure 7(a)(b), here only lists the point light intensity of 0,10 in the two groups of simulator experimental results screenshots. The results of the experiments are given in Section 4.B.



Fig. 7. Simulation of different light intensity with coal dusts

In order to compare the simulator scene and the real underground scene, here we use a coal mine under the real

photo placed in the scene, see Figure 8(a), virtual camera to capture the entire image, the simulator real-time calculation of its corresponding Equalized image and two histograms, we can see that the results of Figure 8(b) and Figure 7(b) are very similar.



(a) Scene arrange



(b) Simulator screenshot

Fig. 8. Real photo test in simulator

B. Experiment analysis

In this paper, two sets of experimental results are obtained, respectively, in the case of coal dust interference and no interference, the intensity of the point light to adjust at 0,3,10, the original image and histogram equalization image and two histograms of them.


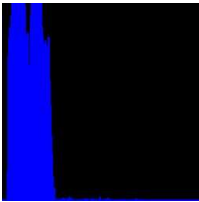

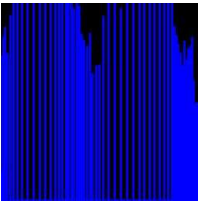



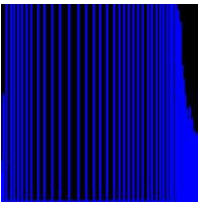

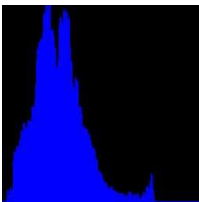

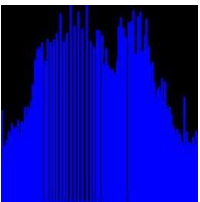
TABLE I. SIMULATION RESULTS WITHOUT COAL DUST

light intensity	Origin image	Histogram	Equalized histogram image	Histogram
0				
3				
10				

As can be seen in Table 1, the light intensity of the first image (light intensity = 10), the original image of the gray histogram slightly concentrated on the left side. The image is more clear after the histogram equalization, histogram distribution is more uniform, all the image details are displayed. With the reduction of lighting conditions, the histogram of the original image is concentrated to the left, that

is, the pixel is concentrated on the lower range of gray. After the equalization, the gray scale of the first and second groups of images is evenly stretched to the entire gray scale, the image quality is improved obviously, the first group of raw images that is difficult to observe the track in the roadway becomes very obvious.

TABLE II. SIMULATION RESULTS WITH COAL DUST

light intensity	Origin image	Histogram	Image of equalized histogram	Histogram
0				
3				
10				

From the three sets of images in Table 2, it can be seen that the increase of coal dust interference factors, due to the robot carrying miner's lamp illuminate coal dust to bring the reflection, so that all the original images brighter than no coal dust one, histogram Shifted to the right by a small amount. Group 1 original map still can not see the ground obstacles, through the histogram equalization, although the impact of coal dust, is still able to clearly identify the ground track, which is very important for robot remote control navigation.

C. Result evaluation

As shown in Figure 9, the image data obtained in the simulator are grouped, where r is the prefix, and the number after r represents the light intensity of the point light source in the roadway, with 0, 3, and 10. Character e represents the use of the square Image equalization of the image, d on behalf of the dust effects image. The evaluation results of each function are obtained by using the evaluation function of TenenGrad, Brenner, Variance, square-gradient, Vollath, window-gradient, Entropic. Finally, an synthesis results are given[18].

From the synthesis results it is easy to see a sort of image clarity, r10e as the brightest environment of the simulation results, clarity evaluation is the highest. More than 40 points are the score of histogram equalization, and no less than 20 points. Under the same conditions, adding coal dust interference is lower than that without adding interference, the light intensity is better than the light weak, the equalization is better than the original.

V. CONCLUSION

The virtual test platform has been built and the corresponding experiments have been carried out. In the experiment, the special effects of virtual reality are used to produce common interference factors such as darkness, humidity and dust in coal mines. Then the video images are captured by virtual cameras. Finally, the influence of

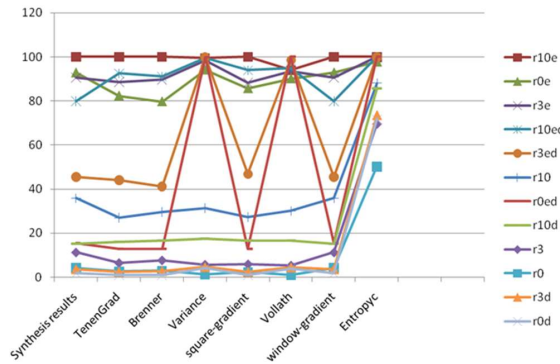


Fig. 9. Results of various definition evaluation functions

interference factors is eliminated in real time by image enhancement algorithm, which verifies that the machine vision algorithm can pass through the virtual. The proposed special robot camera is used to carry out the related experiments of visual navigation in underground mine. This experiment is only in the aspect of robot vision. Next, we will continue to improve the application of virtual simulation experiment of other sensors such as robot voice and obstacle avoidance.

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REFERENCES

- [1] A. Hemanth Reddy, Balla Kalyan, Ch. S.N. Murthy, Mine Rescue Robot System – A Review, *Procedia Earth and Planetary Science*, Volume 11, 2015, Pages 457-462, ISSN 1878-5220.
- [2] Li, Yun Wang; Ge, Shi Rong; Zhu, Hua, Explosion-proof design for coal mine rescue robots, In *Trans Tech Publ*:(2011); Vol. 211, pp 1194-1198.
- [3] HERBUŚ, Krzysztof, et al. Integration of a virtual 3D model of a robot manipulator with its tangible model (phantom). In: *Advanced Materials Research*. Trans Tech Publications, 2014. p. 582-587.
- [4] WANG, Yong, et al. The Encountered Problems and Solutions in the Development of Coal Mine Rescue Robot. *Journal of Robotics*, 2018, 2018.
- [5] LENSCH-FRANZEN, Christian, et al. Testing with Virtual Prototype Vehicles on the Test Bench. *ATZ worldwide*, 2017, 119.10: 36-41.
- [6] Alejandro Malo Tamayo, Israel Lugo Cárdenas, Eduardo Steed Espinosa, Simulation Environment for the Development of Control Algorithms for Air or Water Vehicles, *IFAC Proceedings Volumes*, Volume 46, Issue 30, 2013, Pages 71-78.
- [7] Franck Gechter, Jean-Michel Contet, Stéphane Galland, Olivier Lamotte, Abderafîa Koukam, Virtual intelligent vehicle urban simulator: Application to vehicle platoon evaluation, *Simulation Modelling Practice and Theory*, Volume 24, 2012, Pages 103-114.
- [8] Minzhi LUO, Abdelkader EL KAMEL, Guanghong GONG, Simulation of Natural Environment Impacts on Intelligent Vehicle Based on a Virtual Reality Platform, *IFAC Proceedings Volumes*, Volume 45, Issue 24, 2012, Pages 116-121.
- [9] BARTNECK, Christoph, et al. The robot engine—Making the unity 3D game engine work for HRI. In: *2015 24th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*. IEEE, 2015. p. 431-437.
- [10] JERALD, Jason, et al. Developing virtual reality applications with Unity. In: *2014 IEEE Virtual Reality (VR)*. IEEE, 2014. p. 1-3.
- [11] Xiaokang Wang, Laurence T. Yang, Xia Xie, Jirong Jin, and M. Jamal Deen, "A Cloud-Edge Computing Framework for Cyber-Physical-Social Services," *IEEE Communications Magazine*, vol.55, no.11, pp. 80-85, 2017.
- [12] STARK, J. Alex. Adaptive image contrast enhancement using generalizations of histogram equalization. *IEEE Transactions on image processing*, 2000, 9.5: 889-896.
- [13] Xiaokang Wang, Laurence T. Yang, Xingyu Chen, M. Jamal Deen, and Jirong Jin, "Improved Multi-order Distributed HOSVD with its Incremental Computing for Smart City Services", *IEEE Transactions on Sustainable Computing*, DOI: 10.1109/TSUSC.2018.2881439
- [14] HOWSE, Joseph. *OpenCV for Secret Agents*. Packt Publishing Ltd, 2015.
- [15] PATIL, Pratik P.; ALVARES, Ronald. Cross-platform Application Development using Unity Game Engine. *Int. J*, 2015, 3.4.
- [16] Jin Cui, Lei Ren, Xiaokang Wang, Lin Zhang, "Pairwise Comparison Learning based Bearing Health Quantitative Modeling and Its Application in Service Life Prediction", *Future Generation Computer Systems*, vol. 97, pp. 578-586, 2019. <https://doi.org/10.1016/j.future.2019.03.026>
- [17] Hu Zhu, Tao Xie, Yusheng Guan, Lizhen Deng, Xiaokang Wang, "Hypergraph Matching with an Entropy Barrier Function", *IEEE Access*, Vol. 7, pp. 16638-16647
- [18] Vollath, D., The influence of the scene parameters and of noise on the behaviour of automatic focusing algorithms, *Journal of Microscopy*, 1988. 151(2): p. 133-146.