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Virtual simulator of visual sensing for coal mine rescue robot

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Abstract. It is almost impossible to repeat debug real-time machine vision processing algorithms for the coal mine rescue robots in coal mines, but some robot's algorithms development needs to do it. The robot works in dark and damp environment where prone to gas explosion and dust explosion, relies on video remote operation. Limited by the coal mine safety standard, prototypes is difficult to test in the real roadway environment, and it can not repeat the same scene several times to complete the image processing algorithm comparison test.This paper introduces our new virtual coal mine robot simulator(VCMRS) based on Unity3D. VCMRS enables the machine vision algorithm to run in real time with the video of remote control in a realistic simulation roadway environment. In this paper, the image histogram equalization algorithm is used in VCMRS to realize the real-time video processing, which proves the effectiveness of this method.

Key words. Coal mine rescue robot, virtual simulator, histogram equalization, video remote control.

1. Introduction

It is almost impossible to repeat debug real-time machine vision processing algorithms for the coal mine rescue robot in coal mines, but some robot's algorithms development needs to do it. Coal Mine Rescue Robot is a kind of special robot designed for the rescue task after the coal mine disaster[1], works in the dark, damp,

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muddy, flooding, gas, coal dust environment where prone to gas explosion and dust explosion[2][3], relies on video remote operation. The dangerous environment and the limitations of coal mine safety standards have caused it to fail to have a repeated test in the real roadway[4]. But the debugging is necessary, only a large number of repeated algorithm testing and debugging can make it robust, especially the machine vision algorithm tests, needs to compare the advantages of the different algorithm in the same scene, and there has not such conditions in the real coal mine environment[5].

Therefore, how to find a less limited and similar to the actual conditions of the experimental method is very important, which is the reason that a lot of robots laboratory using simulation software to verify their algorithm[6]. But the general simulator is to solve the physics and kinematics problem of the gap between simulation and the real world, a little solve the systemic and functional simulation problems, usually can not simulate interactions completely among sensors, drive systems, navigation systems and human-computer interaction systems[7]. The game engine focuses on sensual and interactive effects, without modules of sensors, drivers, kinematics, dynamics for the robot. But the game engine generally has a more powerful physical engine, which can develop the above modules through programming[8].

Due to the limit of many security restrictions, the cycle and cost of development of coal mine rescue robot's prototype are quite large, and many sensors can't be used but the explosion - proof camera[9], so functional verification before prototype production is particularly important. Most of the current coal mine rescue robots can only rely on explosion-proof cameras for navigation, the importance of the image sensor algorithm is obviously, so the focus of the simulator design on the image sensor algorithm simulation[10]. This paper mainly introduces the usage of the virtual coal mine rescue robot simulator (VCMRS) developed by China University of Mining and Technology, which aims to simulate the sensing systems[1], intelligent algorithms and virtual environment to improve the the traditional experimental method for the performance verification of the prototype manufacture.

2. Simulation tools selection

Computer simulation has always been an important topic in the field of robots[11]. There are many companies, organizations and individuals who have done a lot of work in this area, and the purpose is to evaluate their usability through the simulation system before the technical solution is actually deployed to the real equipment[12]. Usually, the evaluation is completed through a series of tests. The common robot simulator mainly include the kinematics, dynamics and physics of various sensors, so the tests are mainly concentrated on these areas. At present, there are commercial simulator, open source simulator, game engine used as robot simulator. Common is as follows[11]:

1. Open source: MissionLab, Player/Stage/Gazebo, SimRobot, USARSim, MRPT

2. Commercial: Webots, Microsoft Robotics Studio, V-REP

3. Game engine RAGE, Naughty Dog Game, The Dead Engine, Cry ENGINE, Avalanche, Anvil, IW Engine, Frostbite, Unreal, Creation, Unity3D

How to choose a tool, you need to start from the real needs of the robot, the first need to have a certain understanding of the running environment of the robot.

2.1. Coal mine underground environment

(a) Bright (b) Dark

Fig. 1. Coal mine roadway in different locations

The coal mine consists of roadways and working faces. Due to the complex geological conditions of underground space, many underground rivers and cracks, resulting in the coal mine environment is very bad. Space is limited, dark, humid, there is a lot of coal dust in the roadway due to the need of ventilation. Disaster-prone mining face and driving face of the coal mine, the environment is particularly bad, not only the existence of the above situation, there are many collapse in the roadway cause many obstacles. Figure 1 shows two real underground photographs, Figure 1(a) for the good environment and better light conditions roadway, Figure 1(b) for the bad environment and dark roadway, coal mine rescue robot performing the task often need to run in Figure 1b environment. In such a harsh environment, the main sensor of the robot - the camera, is susceptible to the effects of watering and coal dust, and the light source carried by the robot will also be affected. Therefore, the simulation of coal mine rescue robot, the focus is to simulate the harsh operating environment and the impact on the sensing system.

2.2. Simulation tool

Based on the characteristics of the coal mine environment and the structure of the robot, the simulator should focus on the visual simulation of the robot, so the simulator should focus on the simulation of the harsh environment of the coal mine. Here we chose the game engine as a coal mine rescue robot simulation platform for the following reasons:

1. At present, most of the robot-specific simulators are designed for a variety of physical, kinematic, sensor algorithm designed a common platform, focusing on theoretical calculations, the focus on SLAM, kinematics, AI navigation, etc., the calculation is very powerful , but to build a realistic simulation environment is not as powerful as the game engine.

2. Coal mine rescue robots are mostly remote control robot, they are different from other autonomous robot, the main requirements is 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.

Compared to other game engines, the choice of Unity3D is the following reasons:

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 games support. Mature level design routines and characteristics are designed 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.

Of course, as a simulator of the robot, the commercial game engine also exists some problems:

1. Commercial software, needs to pay.

2. Lack of a variety of robot accessories (sensors, actuators, etc.) simulation module, requires a lot of development work.

In summary, we chose Unity3D as a coal mine rescue robot vision sensor simulation system development platform.

3. Simulator designs

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.

3.1. Simulator architecture

Figure 2 shows the system structure diagram, the core part is the virtual coal mine rescue 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. 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.

The image processing algorithm has been fully implemented with the Opencv for Unity plugin. 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. In this trial, we choose the gray histogram equalization as the experimental algorithm, which is the common image enhancement algorithm of the coal mine rescue robot in the dark environment underground.

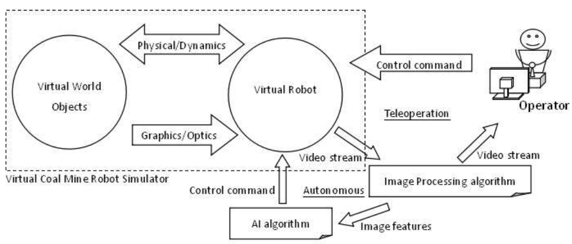


Fig. 2. System diagram

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.

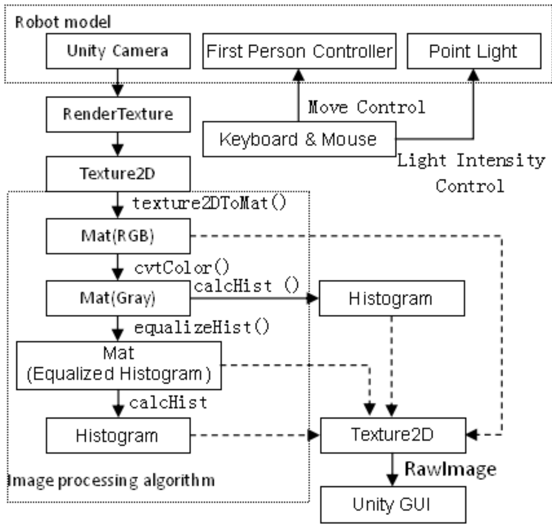
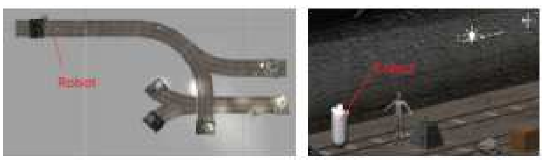


Fig. 3. Simulation flow chart

3.2. Model scene layout

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



(a) (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.

4. 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,

(a) Generally (b) Watering (c) Coal dusts (d) Dark

Fig. 5. Simulation with different interference factors

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.

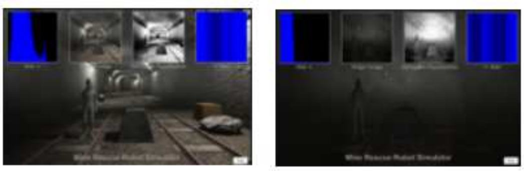
4.1. Experiment process

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 4.2.

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 4.2.

(a) Light intensity=10 (b) Light intensity =0

Fig. 6. Simulation of different light intensity without coal dusts Fig.7 Simulation of different light intensity with coal dusts



(a) Light intensity = 10 (b) Light intensity = 0

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.

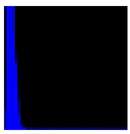
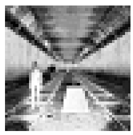
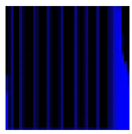
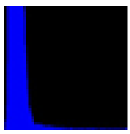
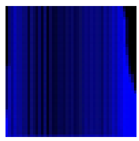
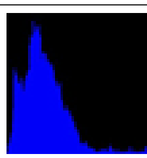
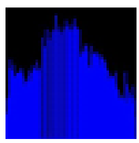
(a) Scene arrange (b) Simulator screenshot

Fig. 8. Real photo test in simulator

4.2. Experiment analysis

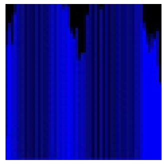
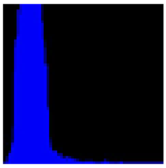
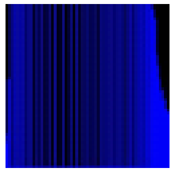
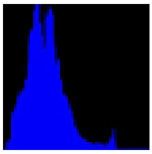
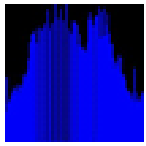
In this paper, two sets of experimental results are obtained, respectively, in the case of coal dust interference and no interference, the intensity of the point light to adjust at 0,3,10, the original image and histogram equalization image and two histograms of them.

Table 1. 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 2. 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.

4.3. 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, Entropyc. Finally, an synthesis results are given.

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.

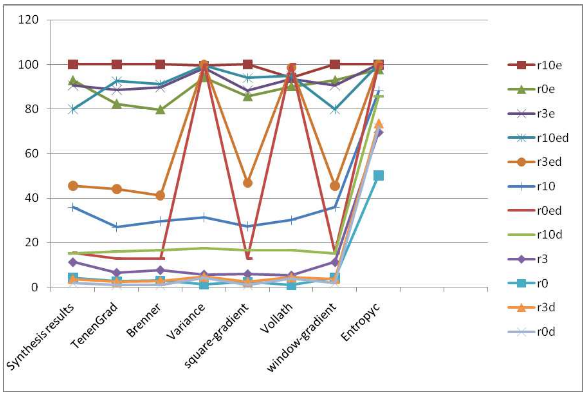


Fig. 9. Results of various definition evaluation functions

5. Conclusion

In this paper, a virtual coal mine rescue robot simulator based on Unity3D is proposed, which can simulate the underground environment accurately and adopt the image extracted by the virtual camera in the simulator to carry on the histogram equalization process, through the image quality evaluation software comprehensive evaluation, verification can simulate the algorithmic effect of field experiments. Through the experiment, it is verified that the game engine can realize the simulation of the real-time image processing algorithm of the robot. These simulations can reproduce a variety of different image algorithms under the same, customizable conditions, give accurate test comparison results, and reduce the experimental error due to differences in the scene. Next, we will increase the number of other sensor modules in the simulator and implement real-time testing of artificial intelligence algorithms with closed-loop control strategies.

Competing Interests

The authors declare that they have no competing interests.

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