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A Novel Teleoperation Method for a Mobile Robot Using Real Image Data Records

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***Abstract*— In this paper we propose an innovative robot remote control method which provides the operator with a bird's-eye view image of the robot in an environment which is generated by using position and orientation information of the robot, stored image history data captured by a camera mounted on the robot, and the model of the robot. This method helps the operator to easily recognize the situation of the robot even in unknown surroundings and enables the remote operation ability of a robot to be improved. We also propose the different ways of presenting the synthesized bird's-eye view images to an operator.**

I. INTRODUCTION

In the teleoperation of a mobile robot in a remote site, the controllability of the robot will increase greatly if the operator can easily recognize and understand the situation of the robot in the remote site and its unknown surroundings.

Many studies on the control methods of the teleoperation of mobile robots have been investigated and proposed up till now. System structure in most of the previous studies uses a system where there is a mounted camera on the robot and the operation is usually performed from a remote site using captured images by the mounted camera. If you have ever experienced operating a mobile robot using such system structure, you would agree that it is difficult to operate a robot by only using a direct camera image and controllability of the robot is very different from operating a robot close to you. This is because it is hard to understand the situation of the robot and its surroundings based on only the information of captured images. Unless you are well trained in robot operation, possesses good sense of space perception and are good at imagining the robot itself in the unknown environments.

Obtaining 3D environmental data of the unknown surroundings and constructing it into a 3D model of the surroundings [1], adding extra mechanisms on a robot from where the mounted camera can capture bird's-eye like images of the robot [2], and using vision support of other robots [3] are some of the ways to overcome the teleoperation difficulties. Even though these methods have some disadvantages such as long process time to construct a 3D model of the unknown surroundings and cannot handle dynamically changing environments, increase cost, size, weight, complexity [4] and the number of robots. Another difficulty in the mobile robot teleoperation is the communication efficiency. Sometimes it is hard to send captured images as the data size is usually large in bad communication conditions.

We have developed a innovative teleoperation method which increases the controllability of a robot by using stored images captured by the camera mounted on the mobile robot as spatial-temporal information. This method can deal with the above mentioned difficulties and disadvantages in the teleoperation of mobile robots. Plainly speaking, this is the teleoperation method which uses a bird's-eye view of a robot in unknown surroundings, is synthesized from spatial-temporal information of formerly captured images.

This teleoperation method is developed as a rescue robot technology. Since it is still difficult to develop autonomous robots to function well in real environments with current robot technology, the system structure such as a human operator remotely controlling a robot is one of the realistic solutions which works well in real disaster sites during rescue robot operation [2] [5] – [7]. Although this method is implemented as part of rescue robot technologies, it can also be applied to any moving device such as medical surgery support which uses an optical fiber scope.

Although high mobility of a mobile robot is indispensable for rescue robots in actual disaster sites, it is hard to make full use of the mobility of the robot by ordinary teleoperation methods since the situation of the robot and its surroundings are vaguely known. The proposed method can overcome this problem and can make full use of the locomotion ability of the robot and it can also increases its mobility.

This teleoperation method also introduces several other benefits such as: robustness in low bandwidth communication, real time synthesis of bird's-eye view images because of image-based method and no model construction needed. In addition, it will also reduce blind spots, prevent the operator from getting camera motion sickness, and so on.

In this paper we will explain this novel teleoperation method for a mobile robot using real image data records and different ways of presenting the synthesized bird's-eye view images to an operator.

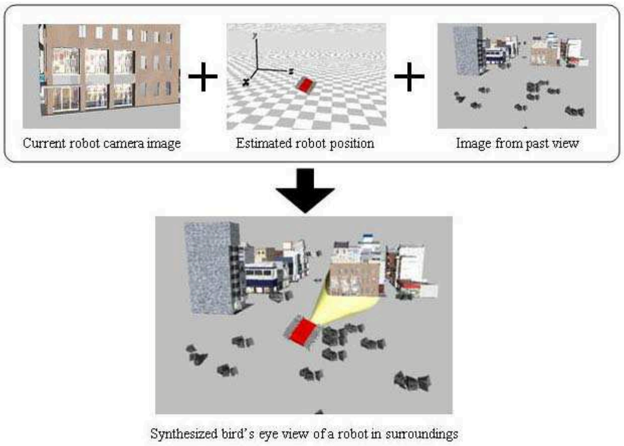


Fig. 1. Overview of the bird's-eye view synthesis.

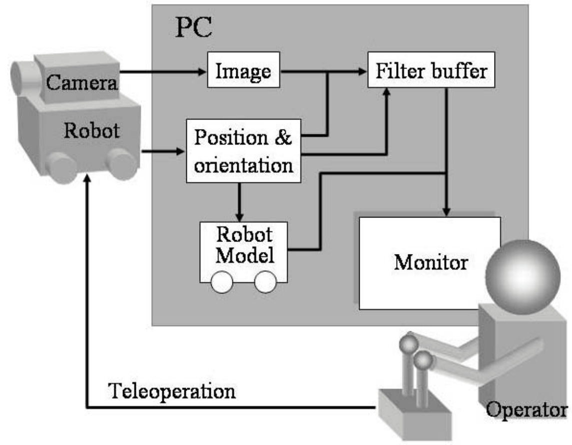


Fig. 2. System overview.

II. SYNTHESIS OF THE BIRD'S-EYE VIEW IMAGES TO IMPROVE REMOTE CONTROLLABILITY

In our work, synthesis of the bird's-eye view images, which improve remote controllability, are conducted using the following technologies:

- Estimation of the position and orientation of the robot
- Image synthesis technique for bird's-eye view images using estimated position and orientation information of the robot and spatial-temporal information which are formerly captured real image data records

That is, we need to know the position and orientation of the robot and its stored real image data records which include formerly captured images associated with the position and orientation of the mounted camera where the image was captured. Overview of the bird's-eye view synthesis is represented in **Fig. 1**. The upper left, center and right pictures of **Fig. 1** are images currently captured by the camera, current position and orientation information of the robot and the selected bird's-eye like image of the robot from real image data records respectively. The bird's-eye view of the robot in its unknown surroundings shown in the bottom picture of **Fig. 1** is synthesized using above information and a CG model of the robot created in advance.

An operator remotely controls the robot using the composite bird's-eye view images which are synthesized according to the process presented in **Fig. 1** using real image data records captured by the camera mounted on the robot and position and orientation information of the robot measured by the sensors. The operator can easily understand the situation of the robot and its unknown surroundings in the teleoperation using these composite images and the remote controllability will increase.

The algorithm for synthesizing the bird's-eye view images is as follows:

Algorithm

1) Obtain position and orientation information of the robot during operation.
2) Store images associated with position and orientation information of the mounted camera when they are captured to the buffer while the robot is moving.
3) Select an appropriate image from the stored real image data records according to the current position and orientation information of the robot and make the position and orientation of the selected image as the viewing position of the bird's-eye view image.
4) Render the model of the robot according to the current position and orientation information of the robot and the selected viewing position.
5) Superimpose the model of the robot viewed from the selected viewing position onto the selected image from the stored real image data records (generation of the bird's-eye view image).
6) Repeat this procedure continuously.

Overview of this system is shown in **Fig. 2**. Images captured by the mounted camera are stored in the buffer as bitmap images along with the associated position and orientation information of the camera when they are captured. When the current position and orientation information of the robot is obtained from the sensors, the most appropriate image to view the robot in the present time is selected from the stored real image data records according to this information of the robot. Then the model of the robot which is viewed from the selected image position is superimposed onto the selected image. The selection of the most appropriate viewing position is according to the position and orientation information of the mounted camera which is stored with the captured images in the buffer. As shown in **Fig. 3**, the selected image is used as the background image of the bird's-eye view image. This background image is not real-time but it is a pseudo real-time image. Because of this system configuration it can handle dynamically changing environments in a pseudo real-time

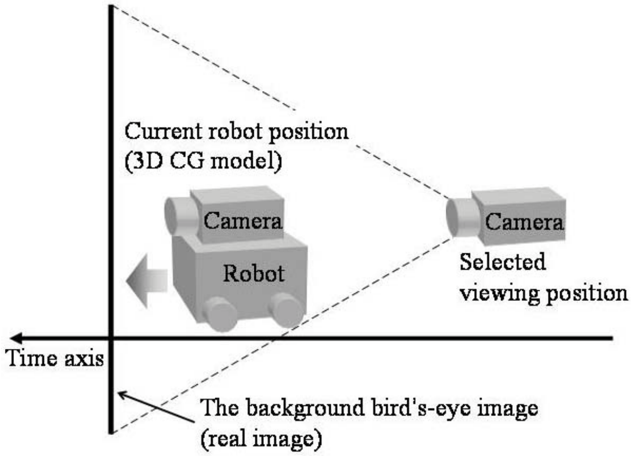


Fig. 3. Pseudo real-time view.

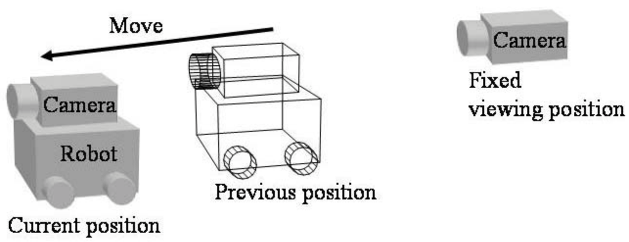


Fig. 4. Teleoperation using a fixed viewing position.

manner. Also this system does not require the construction of a 3D environmental model since this is an image-based method, and it does not take much time to synthesize the bird's-eye view image.

III. Teleoperation of a robot using real image data records

In this section we will introduce the different ways of presenting the synthesized bird's-eye view images to an operator using real image data records.

A. Teleoperation of a robot using a fixed bird's-eye viewing position

In this method the viewing position and the background image for the teleoperation is fixed. An operator can see the robot moving around in its surroundings from the fixed viewing position (**Fig. 4**).

One of the examples of this teleoperation using fixed viewing position is shown in **Fig. 5**. The actual images captured by the camera mounted on the robot are shown in **Fig. 5** (a). The synthesized images using the real image data records and the current position and orientation information of the robot are shown in **Fig. 5** (b). The images that are shown in the same columns in **Fig. 5** are the same time images.

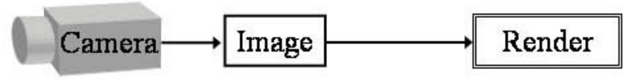


Fig. 6. Real-time image teleoperation.

It can be seen that it is hard to understand and recognize the situation of the robot in its surroundings as well as its environment by only using direct images from the mounted camera in **Fig. 5** (a). It can be said that it is easier to understand the situation of the robot in its surroundings by using the synthesized images from the proposed method in **Fig. 5** (b) rather than the direct images from the mounted camera. The viewing position of the composite images in this example is a fixed point and the image process is conducted off-line. The position and orientation information of the robot is measured by the external sensor.

The proposed teleoperation method enables an operator to easily understand and recognize the situation of the robot in its surroundings which leads to the improvement of the remote controllability. It can reduce the blind spots by representing a model of the robot as a wire-frame as shown in **Fig. 5** (b). It can also prevent the operator from getting motion sickness from the movement of the camera and from also losing sense of direction, especially when the robot is rotating.

B. Teleoperation of a robot using a moving viewing position

For this moving viewing position teleoperation method we will propose four different types of teleoperation methods as follows:

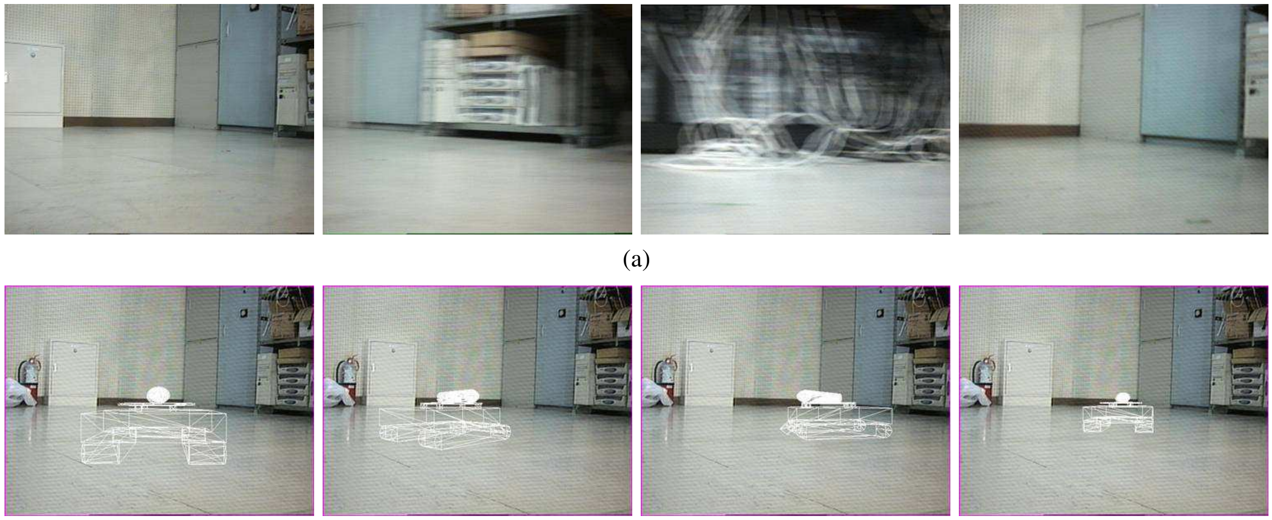
1) Real-time image teleoperation
2) Constant time delay image teleoperation
3) Fixed distance image teleoperation
4) FOV evaluated image teleoperation

We implemented these methods which work in real-time.

1) Real-time image teleoperation: This method uses the direct images that are captured by the camera mounted on the robot and displays those images to an operator for the teleoperation. (**Fig. 6**). This is the most basic teleoperation method.

2) Constant time delay image teleoperation: This method uses the images that are captured before in a set time limit from the current time in the buffer and displays those images to an operator for the teleoperation. These displayed images will realize a viewing position behind the current position of the robot (**Fig. 7**).

In this method a memory space which can store the constant time amount images is prepared in the filter buffer. The oldest image in the buffer is used as a background bird's-eye view image and associated position and orientation information of the image is used as a viewing position. Every time the current frame image is inserted into the buffer the oldest one is erased. The current frame image up to the before set time frame image is constantly stored in the filter buffer.



(a)

(b)

Fig. 5. (a): actual camera images; (b): synthesized images from past camera image data and then the robot position information. Images at each column in (a) and (b) are images at the same time stamps.

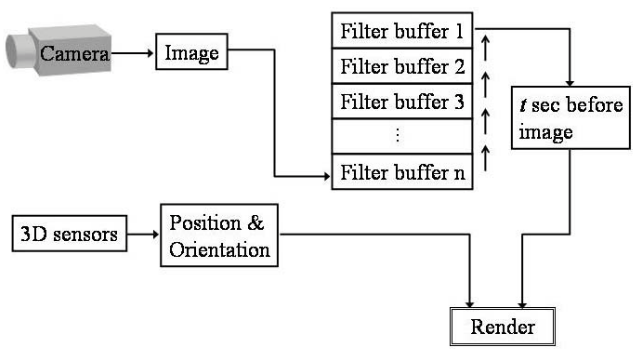


Fig. 7. Constant time delay image teleoperation.

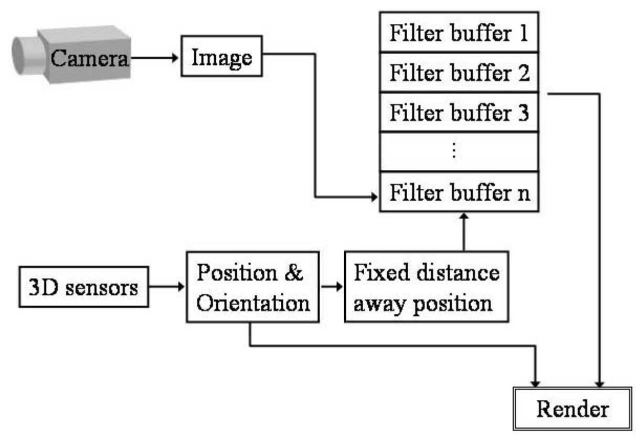


Fig. 8. Fixed distance image teleoperation.

3) Fixed distance image teleoperation: This method uses the images that are captured at the position which is a fixed distance away from the current position of the robot and displays those images to an operator for the teleoperation. (**Fig. 8**). Although in the previous constant delay time teleoperation, when the robot stops the background bird's-eye view image catches up to the current position image and the bird'-eye view image of the robot is unable to be obtained, this never happens in this method. A position at a fixed distance away from the current position of the robot is calculated and an image which is captured from the closest position from it is selected from the buffer as the background bird's-eye view image.

4) FOV evaluated image teleoperation: This method is composed by adding the property that the model of the robot can always be seen in the synthesized image to the fixed distance image teleoperation. In this method the current robot will be seen in the selected stored image from the real image data records is evaluated. That is, check if the robot is in the field of view (FOV) of the selected viewing position or not. An operator can see the robot at all times in the synthesized image and can easily obtain the information about the surroundings from the provided synthesized images.

The FOV of the mounted camera can be represented as shown in **Fig. 9**. This is the top view of the FOV. The origin is the position of the camera. The heading direction of the robot is the same as the x-axis direction of the coordinate system and the y-axis is orthonormal to it. Points in the colored area in **Fig. 9** can be seen from the mounted camera. θ_w rad is half of the horizontal viewing angle. d_{min} mm is the

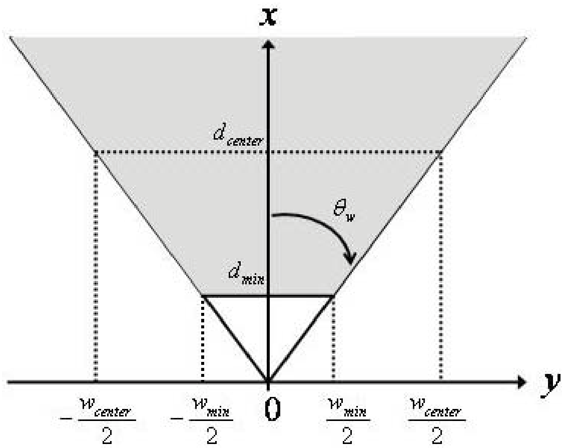


Fig. 9. Top view of FOV.

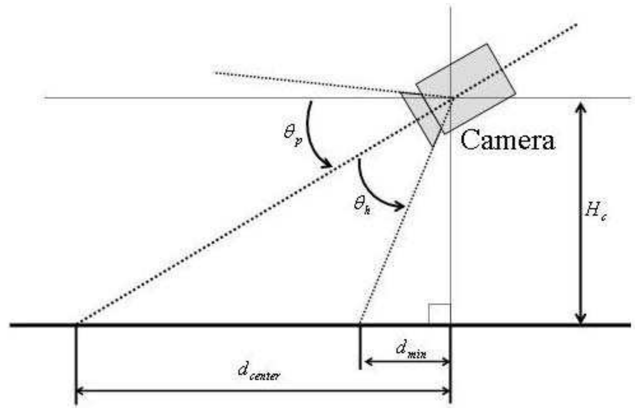


Fig. 10. Side view of the camera configuration.

minimum distance between the point which can be seen from the mounted camera and the projection point of the camera position. It can be obtained as follows:

$$d_{min} = \frac{H_c}{\tan(\theta_p + \theta_h)} \tag{1}$$

w_{min} mm is the horizontal range which can be seen from the viewing position at the distance of d_{min} and can be obtained as follows:

$$w_{min} = 2[\frac{H_c}{\sin(\theta_p + \theta_h)} \tan\theta_w] \tag{2}$$

$$= 2[\frac{d_{center}}{\cos(\theta_p + \theta_h)} \tan\theta_w] \tag{3}$$

d_{center} mm is the distance between the point on the ground which can be seen at the center of the camera image area and the projection point of the camera position. It can be obtained as follows:

$$d_{center} = \frac{H_c}{\tan\theta_p} \tag{4}$$

w_{center} mm is the horizontal range which can be seen from the viewing position at the distance of d_{center} and it can be obtained as follows:

$$W_{center} = 2\frac{H_c}{\sin\theta_p} \tan\theta_w \tag{5}$$

$$= 2\frac{d_{center}}{\cos\theta_p} \tan\theta_w \tag{6}$$

θ_h rad, θ_p rad, and H_c mm are half of the vertical viewing angle, the camera pitch angle, and camera height from the ground respectively (**Fig. 10**).

All the position and orientation information of the mounted camera associated with the stored images in the filter buffer is used in this method. It is evaluated whether or not the robot is in the FOV as shown in **Fig. 9** by using this position and orientation information along with the viewing angle of the camera. Insertion of the captured images into the filter buffer occurs when the robot moves specified distance or specified rotation angles. The stored images in the filter buffer are not captured consecutively. They are captured from the sparsely spread position of the robot motion.

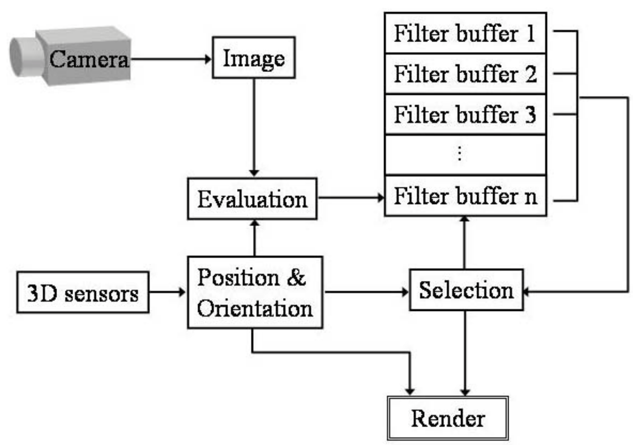


Fig. 11. FOV evaluated image teleoperation.

A bird's-eye viewing position is selected from the stored images. Evaluate whether or not the current position of the robot is in the FOV or not, the colored area in **Fig. 9**, and then select one which shows the model of the robot closest to the center of the image area of the camera. A selected stored image is not erased immediately but remain in the filter buffer short period of time to before being selected again (**Fig. 11**).

One of the examples using this teleoperation method in real-time is shown in **Fig. 12**. The viewing positions are selected automatically according to how close the model of the robot can be seen in the image area. In **Fig. 12**, the external views of the experiment are overlapped onto the left-bottom area in each image. The snapshots of the experiment are represented from the left to the right and from the upper row to the bottom one as time goes by. The background images are switched at the third image in the bottom row.

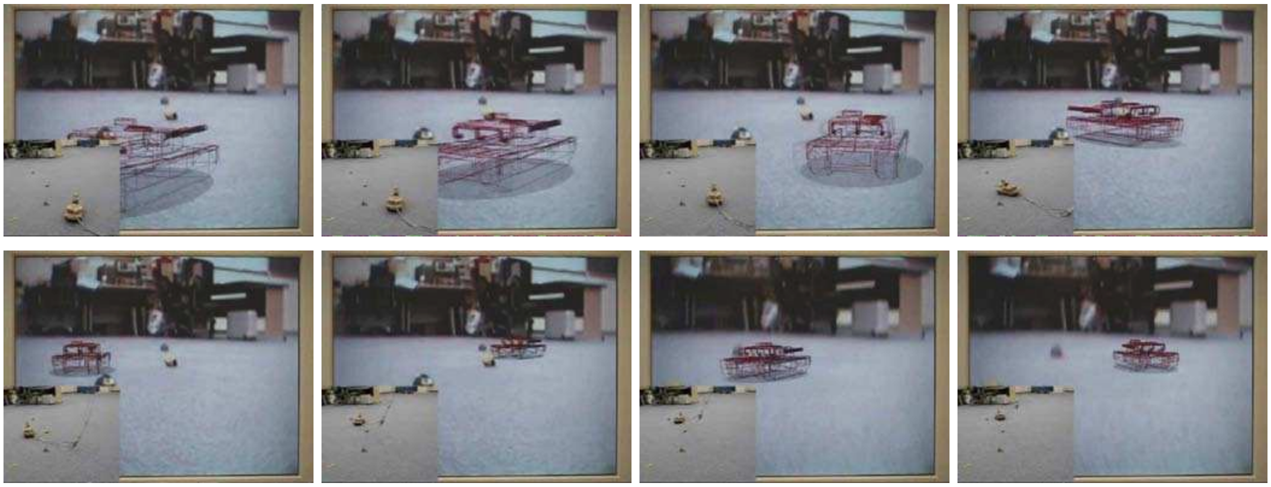


Fig. 12. Example of FOV evaluated image teleoperation. External views of the experiment are overlapped onto the left-bottom area in each image. The snapshots of the experiment are represented from the left to the right and from the upper row to the bottom one as time goes by. The background images are switched at the third image in the bottom row.

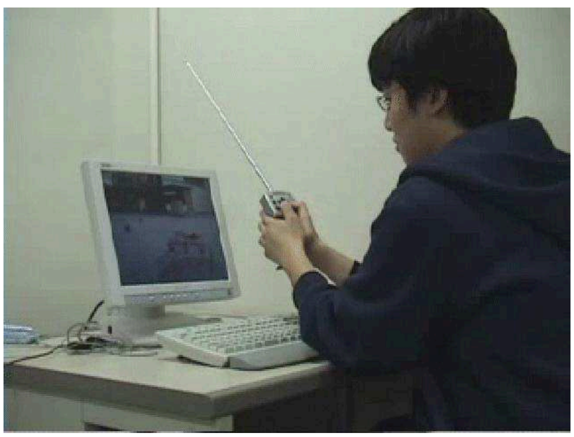


Fig. 13. Operator controlling a robot using FOV evaluated image teleoperation.

The operator uses these synthesized images to operate the robot in remote site (**Fig. 13**). It can be said that the situation of the robot in the surroundings of the remote site can be understood with ease and this helps the operator to control the robot.

IV. Conclusion

In this paper we have presented a novel teleoperation method for a mobile robot using real image data records and the different ways of presenting the synthesized bird's-eye view images to an operator. One of the examples using the proposed method which works in real-time is shown.

The proposed teleoperation method enables an operator to easily understand and recognize the situation of the robot in its surroundings which leads to the improvement of the remote controllability. This teleoperation method will also introduce several other benefits such as: robustness in low band width communication, real time synthesis bird's-eye view images because of image-based method and no model construction. In addition, it will also reduce blind spots, prevent the operator from getting camera motion sickness, and so on. This method not only can be applied to mobile robot teleoperation but also can be applied to any other applications for a moving object such as tele-surgery with an endocsope.

Acknowledgment

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References

[1] M. Lhuillier and L. Quan, Quasi-dense reconstruction from image sequence, *Proc. of EuropeanConferenceonComputervision*, pp.125–139, 2002.

[2] T. Kamegawa, T. Yamasaki, H. Igarashi and F. Matsuno, Development of The Snake-like Rescue Robot "KOHGA", *International conference on Robotics and Automation*, pp.5081–5086, 2004.

[3] R. Murphy, E. Rogers, Cooperative Assistance for Remote Robot Supervision, *Presence*, **5**(2), pp.224-240 1996.

[4] S. Tachi, Real-time Remote Robotics - Toward Networked Telexistence, *IEEE Computer Graphics and Applications*, **18**(6), pp.6–9, 1998.

[5] J. Casper, Human-Robot Interactions during the Robot-Assisted Urban Search and Rescue Response at the World Trade Center, *MS Thesis, Computer Science and Engineering, USF*, April 2002.

[6] R. Murphy, J. Casper, M. Micire and J. Hyams, Assessment of the NIST Standard Test Bed for Urban Search and Rescue, *Proceedings of the 2000 Performance Metrics for Intelligent Systems Workshop*, 2000.

[7] S. Tadokoro, H. Kitano, et al., The RoboCup-Rescue Project: A Robotic Approach to the Disaster Mitigation Problem, *Proceedings of the 2000 IEEE International conference on Robotics & Automation*, pp.4090–4095, 2000.