Automatic Tracking Camera System for Construction Machines by Combined Image Processing

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Abstract -

The damaged area caused by disasters must be restored as soon as possible. So, remotely controlled construction machines are used to execute this dangerous work, safely.

In the remote construction, machine operators always watch images of the working field from pan-tilt monitoring cameras controlled by camera operators. Then, the automatic camera control system without camera operators is expected for machine operators.

Based on the above requirement, we are developing an automatic tracking camera control system for construction machine operators by using image processing. The most difficult point for this system is to realize a stable outdoor object detection by image processing. So, we proposed a new image processing method which is a combination of "Improved template matching" and "Moving object detection". From experimental results, we confirmed that the proposed method is improved about the robustness of outside construction machines tracking.

Keywords -

Unmanned construction; Camera tracking; Image processing

1 Introduction

A lot of disasters occur in Japan. So, the damaged area must be restored as soon as possible. However, the workers cannot approach the area because of dangerous. Therefore, the remotely controlled construction machines are used to restore there. In the remote construction, machine operators always watch images of the working field from pan-tilt monitoring cameras to control the construction machines. Therefore, the machine operators need to be helped by camera operators. Then, using an automatic camera control system without camera operators is expected for machine operators.

Based on the above requirement, we are developing an automatic tracking camera control system for construction machine operators. In order to track the construction machinery, it is necessary to detect the position of the heavy machine.

There are several methods to detect a construction machine and its position.

One is a method using UWB (Ultra Wide Band). In this method, an active electronic tag is mounted on the construction machine, and the receiving antenna is installed in the construction area. Based on the communication time between the tag and the antenna, the position of the construction machine is measured [1].

There is another method using BLE (Bluetooth Low Energy) technology [2]. In this method, a Bluetooth oscillator is installed in the construction area. The position of the device which has an antenna is measured based on the received radio wave intensity. The location of the installed antenna and the oscillator must be known accurately for this method. However, accurate installation of sensors at the desired positions in disaster areas is difficult.

The research of object tracking using a TOF (Time-of-Flight) camera is also conducted [3]. The TOF camera can get depth information of the acquired image, and track the desired object in the image based on this information. However, this method needs the TOF camera, and the effectiveness of this method is confirmed in the limited environment like on the belt conveyor. So, it is considered that the detection of the construction machine by this method is difficult in the actual disaster area.

In the actual disaster area, GPS is normally used to detect the position of the construction machine. However, unfortunately, some construction machines do not have GPS sensors. Usually, cameras are always used in unmanned construction. Then, we set our target to develop an automatic tracking monitor camera system for construction machines only using image processing.

Many methods have already been proposed for object tracking by image processing technology. However, camera tracking of construction machine based on image processing is difficult because of the following reasons.

- Generally, image processing is weak in outdoor environment. But, construction machines are used in outdoors, mainly. Depending on the weather and brightness change of the day, the color of the heavy machine recorded by the video camera changes.
- The construction machine changes its orientation during its works. So, its image recorded by the camera changes when the machine turns. Furthermore, since the heavy machine has a complicated shape and its appearance image changes drastically depending on its orientation.

As described above, camera tracking for construction machine in various environments by image processing is difficult. Therefore, we considered a solution, and proposed a new image processing method which is a combination of template matching and motion detection. Generally, template matching is weak to the change of the target shape. So, we added the detection of moving object process for our method to overcome the weaknesses of template matching. Our proposed method is explained in detail from the next chapter.

2 The Problem of Image Processing for Object Tracking and Its Resolution

2.1 The Problem of Image Processing for Object Tracking

Color based object tracking is one of the simplest method for image processing based tracking. The method is robust in changing of object's shape and turning of object. In addition, construction machines have conspicuous color, so this method seems effective for construction machines tracking. But, The problem of image processing for object tracking object detection by image processing and color based object tracking is difficult for outdoor objects because the object color data is affected by the sunlight. Furthermore, the recorded color data of construction machine and sand by video camera is sometimes very similar. Then, color based object tracking is not suitable for construction machine tracking.

Some tracking methods which are not color based tracking are provided by OpenCV libraries. These methods are MIL, TLD, MedianFlow, KCF, and Boosting [4]. We tried using these methods for construction machine tracking practically, and confirmed that these methods are not appropriate for it. Because, the speed of these image processing methods is slow, and the tracking by using these methods sometimes failed when the construction machine turns for changing its moving direction and input camera image drastically changes.

It is found that the accuracy of kernel based object detection is high in the construction site [5]. However, based on our trial, the processing time of KCF method which is one of the kernel-based methods was long, then we considered other simple methods.

As another object tracking method, there is a moving object detection using background subtraction method [6]. This method is robust for the above problems in the fixed camera image, but it cannot track the object when the camera is moving, because all camera image moves with camera's moving.

2.2 The Basic Idea to Resolve the Problem of Object Tracking by Image Possessing

Object tracking by image processing is achieved by the continuous detection of object in a camera image. This study proposes combination of two detection methods for robust object tracking. One of them is a template matching which is a simple and fast object tracking method. The other is a detection of moving object using background subtraction method. Generally, object tracking using template matching method prepares a template image for its target, beforehand, and tries to track it by searching the most similar area with the template image. Therefore, the template matching is weak in the appearance change of tracking object. In the construction machine tracking, the target machine moves and its appearance taken by the camera changes, so we considered that the combination method of template matching object tracking and moving object detection can track the construction machine, robustly.

First, we confirmed the ability of template matching based camera tracking method. This method can track construction machine in some cases, but it sometimes fails when the appearance of the construction machine changes drastically. This is a common issue of the image processing based object tracking methods. However, this method is effective for object tracking under camera moving situations.

Next, we confirmed the ability of construction machine detection based on the moving object detection by using background subtraction method. When the construction machine is moving in the captured image, this method certainly detects it. But, needless to say, this method cannot detect the construction machine when it is stopped, or camera moves.

The advantages and disadvantages of these two methods are confirmed, then we decided to combine these two detection methods for construction machine tracking. This combination method tracks the construction machine by using the result of moving object detection when the construction machine is moving, and the result of template matching based detection when the camera is moving. By combining these two methods, the system can track construction machine even if its appearance changes drastically.

Some people may think that the tracking camera moves continuously during its object tracking and moving object detection method cannot be used for construction machine tracking. However, it is no problem because the tracking camera does not move continuously in our target situation. There are two ways of construction machine tracking by the camera. One of them is a method for capturing the construction machine always at the center of camera screen by moving the camera continuously. The other is a method for capturing the construction machine not out of the camera screen by moving the camera with some intervals. In this case, the camera is stopped until the construction machine moves near the edge of the camera screen, and moved before the construction machine is out from the screen. In the actual construction site, the latter method is used for the remote control operation of the construction machine. If the former method is used, the machine operator cannot recognize the speed of the construction machine because of the camera's moving. Therefore, we adopted the latter method in our study, and we could use the moving object detection process based on the background subtraction method for the construction machine tracking.

3 The Trucking Method Combining Template Matching and Background Subtraction.

3.1 The Tracking Method Base on The Template Matching

Template matching is an object detection method in the camera image. It finds an object image part which matches the template image. In the construction machine detection, a template image of construction machine is prepared, and the construction machine image part is found from the image acquired by the camera. Even if the completely matched part with the template image is not found in the camera image, the most similar part is detected as the construction machine. Repeating this process in real time, we can track the target construction machine, continuously. However, object tracking by template matching is weak when the image of tracking object drastically changes. We made an experiment of construction machine tracking using template matching, and found that the tracking of the construction machine failed in several second after it start moving. Therefore, we improved the tracking method using template matching.

We updated template images in real time, so the tracking robustness has improved more than before. Generally, the template image is prepared in advance and the same template image is used during its process, but in this method, the template image is updated as the progress of the tracking process. The detailed process is explained as follows:

First, rectangular template image is selected in the camera image by dragging the mouse. The most similar part with the selected template image is detected from the next frame image acquired by the camera. A new template image is created from the detected image and this process is repeated for continuous tracking. By using this improved method, we could track the construction machine continuously. However, when the distance between the construction machine and the camera changes and the construction machine image size changes, or when the appearance of the construction machine drastically changes due to its turn, the similar matching part with template image disappears and the template matching method fails to track it. We also improved the processing speed of template matching based object tracking method. Matching process is executed only around the template image not for whole screen image because the construction machine moves gradually in the screen.

3.2 Object Detection by Background Subtraction

Template matching based object tracking cannot track the object when the construction machine moves hard. Therefore, we focused on the movement of the object and adopted the background subtraction method which is a typical motion detection method.

Background subtraction is a method which compare two images and extract the different parts. It can extract the changed part by comparing the current frame with the past frame of the camera image. So, it is possible to detect the moving objects and used for motion detection. However, in case when the camera moves or zooms and the whole screen changes, it is difficult to detect the moving objects. We tried to detect construction machines using background subtraction. The moving parts were extracted by comparing the images, but we could not detect the construction machine as one moving object. Figure 1 shows the result of moving construction machine detection using the background subtraction. The white points indicate the extracted parts which the frame image changes.

From background subtraction method, only the moving object edges are extracted in many cases as shown in Figure 1, so we improved this method. The background subtraction data obtained in the past several frames were overlapped and made an image like afterimage (Figure 2). After that, the expansion process is added to the overlapped image (Figure 3). As a result, moving parts can be extracted, clearly. However, moving parts are not yet recognized as one object at this point. Then, labeling is added to this image for recognizing the connected parts as one object. The rectangle in Figure 4 shows the recognized moving object by labeling process.

From the above results, we confirmed that it is possible to detect moving objects by using background subtraction method. Of course, when the camera moves and the whole screen image moves, or plural objects exists in the camera image, it is difficult or not able to detect the target construction machine, accurately by this method.

3.3 Proposed Combination Method of Template Matching and Background Subtraction

The improved template matching based object tracking method can track the construction machine, continuously. However, when the size or appearance of the construction machine image acquired by the camera changes, the

Figure 1. The results of object detection by background subtraction

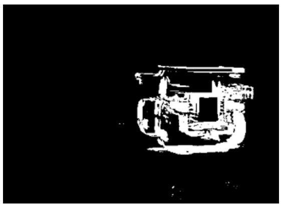

Figure 2. The result of past several frames overlapped image

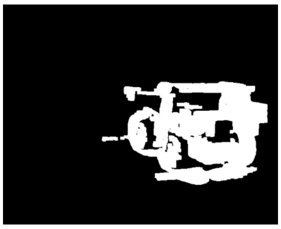

Figure 3. The result of expanded image

Figure 4. The result of moving object detection by background subtraction

matching part with template image includes some errors, and finally the template matching method fails to track it due to their accumulation. On the other hand, background subtraction method can detect and recognize the overall shape of the construction machine accurately when it is moving. But, the background subtraction method cannot detect the object when the camera is moving, or the target object is not moving.

Therefore, we considered to combine the template matching and background subtraction for the construction machine tracking. When the moving construction machine is detected by the moving object detection method, its result is compared with the result of improved template matching based method. If these two results are similar, the matching template is updated based on the result of moving object detection method.

The improved template matching method finds the most similar part with the template in the camera image, and draw a rectangle at the detected area. And, the moving object detection method finds the moving part, and draw a rectangle surrounding the moving object. When the results of rectangles from the moving object detection method and improved template matching method are similar, the template image is updated by replacing to the image of the result of moving object detection method surrounded by the rectangle. In other words, when the results of two methods are similar, the result of moving object detection is used preferentially as the updated template image. The degree of similarity of two results is determined using IoU (Intersection over Union) [7].

This method has the following three great advantages.

The first advantage of this method is that the object recognition ability is improved to the appearance change caused by the object turning. The main reason why the improved template matching lost tracking the construction machine is that the visible surface becomes invisible for its turning, that is, a big change of its appearance has occurred. Therefore, it this case, the construction machine can be tracked by the moving object detection method.

The second advantage is that the size of the template image becomes variable for the object recognition. In the template matching method, the template image size cannot be changed because of its algorithmic limitation. On the other hand, the image size of the construction machine detected by the moving object detection method changes. It changes gradually, because the construction machine approaches to or leaves from the camera gradually. So, the template image size acquired by the combination method also changes gradually. Here, the template image is generated from the result of moving object detection method based on the background subtraction similar to the result of template matching method.

The third advantage of this method is that this combination method prevents detection failure which is likely to occur in background subtraction method. In general, it is difficult to use background subtraction method when the camera moves. Also, if another moving object exists while the tracking object is stopping, the detection failure is caused in the background subtraction method. In the combination method, when the camera moves, the entire screen image acquired by the camera moves, and it is detected as one moving object. In this case, the result of moving object detection method is not similar to the result of improved template matching method, then the system recognizes that the detection failure occurs, and its result is ignored. The improved template matching method is less affected by the changes of the surroundings. So, even if the camera or another object is moving, it keeps tracking the target construction machine.

This combination method is better to be able to compensate for the each disadvantage of the combined two methods, and use their advantage points.

4 Evaluation Experiments

We conducted some experiments to confirm the effectiveness of the proposed method. In the experiments, we used a radio- controlled heavy construction machine model, and recorded its moving images by the fixed video camera. The experiments were conducted to evaluate whether our proposed combination method can track the heavy construction machine model in the video image or not. Tracking failure will occur in the moving object detection process of the combination method when the camera moves. In this case, the system will recognize it and the result of moving object detection will be ignored. Therefore, we also executed the experiment to confirm whether the proposed combination method can track the heavy machine model even the camera moves.

4.1 Robustness Confirmation of The Proposed Method

We prepared a video image of heavy construction machine model which includes large distance change between the object and the camera, and large orientation change by the turning of object, and made comparative tracking experiments using only improved template matching method and combination method. The experimental results are as shown from Figure 5 to Figure 12. The left figures of each row are the results of tracking only by the improved template matching, and the right figures are the results of tracking by the combination method. In these figures, the detection results are shown by the bold lined red rectangles, which are used as the updated template images in the next detection process. (The thin lined red rectangles show the image processing area around the template images for their speeding up.)

4.1.1 Results of Tracking Experiments Only Using Improved Template Matching Method

The initial template is set by the manual mouse operation on the beginning image of the movie. The heavy construction machine model is tracked by the improved template matching method at the beginning phase. It is shown in Figure 5.

However, when the heavy construction machine model approaches to the camera, the detection result does not cover the whole detected object because the improved template matching method cannot change the size of template shown in Figure 7. In other words, we confirmed that this method is not good for the distance change between the object and the camera. In addition, when the heavy construction machine model turns, the position of red template rectangle gradually deviates from the object, and finally it becomes impossible to detect the object. It is shown in FIgure 9 and 11.

4.1.2 Results of Tracking Experiments Using Combination Method

From the results of combination method, we can confirm that the tracking of heavy construction machine model is completely succeeded. After the object starts moving, the initial template image is updated and fitted to the external shape of the object shown in FIgure 6. Figure 8 shows the detection result by the combination method when the object approaches to the camera. This result shows that the moving object detection method can change the rectangular size. In other words, we confirmed that this method is good for the distance change of the object and the camera.

Figure 10 and 12 show that the continuous detection of the heavy construction machine model is succeeded even the object changes the moving direction by its turning. This result shows that the moving object detection method can update the template properly, and continuous tracking is achieved. In other words, we confirmed that the combination method is robust for the appearance change by the object turning. Comparing with the improved template matching based tracking and the tracking by the combination method, we confirmed that the ability of the proposed tracking method is greatly improved.

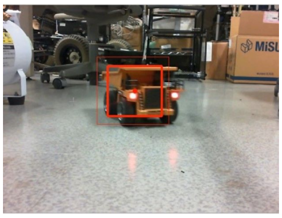

Figure 5. The result of improved template matching method at the beginning phase

Figure 6. The result of combination method at the beginning phase

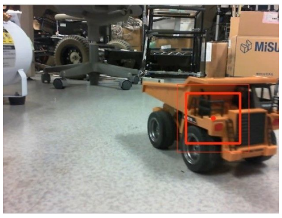

Figure 7. The result of combination method when the object is approaching to the camera

Figure 8. "Combining method" at closing

4.2 Confirmation of The Influence of Camera's Moving

Tracking the heavy construction machine model only by moving object detection method is difficult when the camera moves or the object is stopping. Therefore, we made an experiment to evaluate the tracking ability of the proposed method by using the video image of these situations. Figure 13 shows the result of the experiment

Figure 9. The result of improved template matching method at the small turning

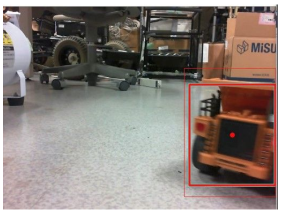

Figure 10. The result of combination method at the small turning

Figure 11. The result of improved template matching method at the big turning

Figure 12. The result of combination method at the big turning

when the camera and the object is stopping. In the right figure, white dots show the detected parts of the changing. As shown in Figure 13, some moving objects are detected (shown by small blue squares), but the heavy construction machine model is properly detected (shown by red square). This result shows that the combination method ignored the detected moving objects because they are not similar to the result of improved template matching method. Figure 14 shows the result of the experiment when the camera is moving. We can confirm that almost all area of the screen is white from the right figure, and the light blue rectangle surrounds the entire screen from the left figure. In other words, when the camera is moving, the whole screen is detected as one moving object. However, the heavy construction machine model is surrounded by the red rectangle and properly detected. This result also shows that the combination method ignored the detected moving objects including whole screen because they are not similar to the result of improved template matching method. And, we confirmed that the proposed method can track the object robustly in these situations.

4.3 Features of Proposed Combination Method

In this section, the features of the improved template matching based tracking and tracking by the combination method are summarized. Table 1 shows the comparison of

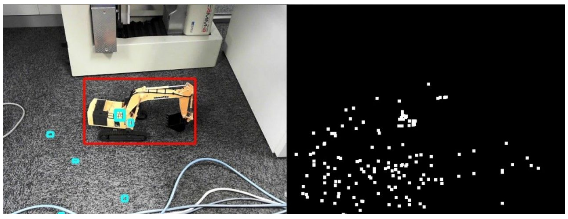

Figure 13. The result of moving object detection method when the camera is stopping

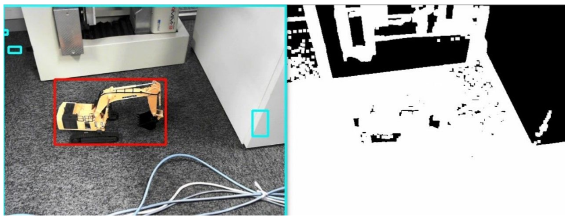

Figure 14. The result of moving object detection method when the camera is moving

the tracking ability in various assumed situations. Table 1 shows tracking accuracy in various situations.

About the tracking only by the improved template matching method, high tracking ability is achieved when the camera or the object moves on the plane parallel to the imaging surface of the camera (for example, move leftwards or rightwards, or move up or down in the camera image). This is because the appearance of the object on the camera image does not change significantly. On the other hand, high tracking ability is not achieved when the object is turning, or moving toward or from the camera, because the visible surface changes drastically. However, the proposed combination method is robust about the turning motion and the translational motion which changes the distance between the object and the camera.

Table 1. Features of Improved Template Matching Method and Proposed Combination Method

Situations	A	B
pan-tilt of camera	◎	◎
Zoom in-out of camera	△	△
Moving heavy machine right and left	○	◎
Moving heavy machine back and forth	△	◎
Turning heavy machine	△	○

A : Improved template matching method

B : Proposed combination method

◎: good ○: not bad △: not good × : bad

5 Conclusion

We proposed the robust camera tracking method for construction machines by image processing which is combining the improved template matching method and the moving object detection method. The proposed method compensates each weak point of both methods by adopting the reliable result according to the situation. By using this method, we succeeded to track the moving objects in outdoor environment where color-based tracking is difficult.

The monitoring of heavy construction machine is very important in unmanned construction site. This camera tracking system will be used instead of the camera operator. So, this system will contribute the improvement of unmanned construction technologies.

In near future, we will confirm the effectiveness of this method at the actual construction work site.

References

[1] Jochen Teizer, Davis Lao, and Menache Sofer. Rapid automated monitoring of construction site activities using ultra-wide band. In *Proceedings of the 24th ISARC*, pages 23–28, Kochi, India, 2007.

[2] Matthias Neges, Mario Wolf, Markus Propach, Jochen Teizer, and Michael Abramovici. Improving indoor location tracking quality for construction and facility management. In *Proceedings of the 34th ISARC*, pages 88–95, Taipei, Taiwan, 2017.

[3] Omar Arif, Matt Marshall, Wayne Daley, Patricio A. Vela, Jochen Teizer, Soumitry J. Ray, and John Stewart. Tracking and classifying objects on a conveyor belt using time-of-flight camera. In *Proceedings of the 27th ISARC*, pages 203–212, Bratislava, Slovakia, 2010.

[4] Introduction to opencv tracker. On-line: https://docs.opencv.org/3.1.0/d2/d0a/tutorial_introduction_to_tracker.html, Accessed: 31/01/2018.

[5] Ioannis Brilakis, Man-WooPark, and GauriJog. Automated vision tracking of project related entities. *Advanced Engineering Informatics*, 25:713–724, 2011.

[6] Marek CHOVANEC. Computer vision vehicle tracking using background subtraction. *Control and Management Systems*, 1, 2005.

[7] Adrian Rosebrock. Intersection over union (iou) for object detection. On-line: https://www.pyimagesearch.com/2016/11/07/intersection-over-union-iou-for-object-detection/, Accessed: 31/01/2018.