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A NETWORK CAMERA SYSTEM ENABLING LONG-DISTANCE USE OF AUGMENTED REALITY FUNCTIONALITY USING ARTOOLKIT

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Abstract. *This paper describes the development of a network camera system that enables long-distance use of the augmented reality function using ARToolKit. Usually, a USB camera is used with ARToolKit because applications are utilized over a short distance. AR systems that allow long-distance use will expand the applicable situations. In the system developed here, a network camera with a zoom function was combined with an AR system using ARToolKit via virtual USB camera software, and a zoom control system was developed. In the experiment, a linear relationship between the applicable maximum distance and the zoom magnification was obtained, and long-distance use at greater than 90 m was achieved. An attempt to control the detectable markers depending on the distance between the markers and the camera by changing the zoom magnification, that is, zoning by zoom magnification, was demonstrated as an application of the developed system. In the experiment, markers were successfully detected, depending on the zone that was determined by zoom magnification.*
Keywords: Augmented reality, ARToolKit, Network camera, Zoom, Marker, Long distance

1. **Introduction.** Augmented reality (AR) technologies have improved over time by changing their research and development stages through basic research, tools, and applications [1]. These technologies are useful not only for entertainment but also for supporting daily life and work. For instance, improvement of work efficiency and reduction of mistakes in maintenance and inspection services, workload reduction, and improvement of inspection quality in inspection services have been reported [2]. A technique for extracting AR-based spatial and geometric information has been proposed for interactive visualization and design evaluation of virtual objects in a physical indoor environment [3]. Thus, various applications have been proposed, and the development of AR-assisted applications could be further accelerated to support our daily lives and overcome natural disasters.

In general, the main purpose of typical AR applications is the interaction between real and virtual worlds, such as visualization, control of avatars or 3D characters, and instructions for work procedures. In most cases, marker-based AR systems are used on the desk [4, 5], in a room [6, 7], and indoors with natural markers such as exit signs [8, 9], so the applicable distances between the camera and markers are very close or within a few meters. A survey reported that marker-based technology can cover a tracking range of up to 10 m [10]. ARToolKit [11, 12] enables the efficient development of AR-related

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applications. Because an AR environment is expected to be used over a relatively short distance, universal serial bus (USB) cameras are available. In a preliminary experiment using a USB camera with no zoom function (Microsoft LifeCam Studio Q2F-00020), a maximum applicable distance of approximately 3.5 m for square markers, with a side length of 7.5 cm, was reported [13].

To extend the range between a camera and a marker for marker-based AR, a nested marker has been proposed [14]. The nested marker has a recursive layered structure, in which an upper-layer marker consists of four smaller, recursive lower-layer markers. Depending on the range of viewpoint, that is, the distance between the camera and the marker, the layer used for detection can be switched. Its usefulness was shown by a stable estimation of the depth distance and the position of the marker for a distance of up to 800 mm. Although this is a novel approach, its applicable distance is limited.

Aiming at large indoor AR applications, a layered marker has been proposed [15]. The layered marker recursively has a smaller single marker inside; therefore, marker borders depending on the layer level are nested. To avoid inter-marker confusion, unique patterns, such as diamond-shaped patterns, are placed between an outer marker border and the next inside marker border. The effectiveness of extending the tracking distance using a layered marker with five layers and a size of 20 × 20 cm was shown for distances up to 500 cm by comparing the usual single markers of 1.25 × 1.25 cm, 2.5 × 2.5 cm, 5 × 5 cm, 10 × 10 cm, and 20 × 20 cm.

The methods mentioned above can provide reasonable solutions to the extension of the tracking distance. However, approaches using markers with recursive structures inherently require larger markers for a longer applicable distance. The applicable distance is limited by marker formulation and size adjustment. If a network camera with a zoom function can be introduced into an AR environment, it will be possible to construct an AR environment that can be used over a long distance with the usual fiducial markers. Such integration can enhance the applicable distance of developed systems using ARToolKit and can provide applications or functions such as target object detection, event detection based on marker occlusion, and downsizing of marker size to be attached to objects. Our research motivation for developing an AR system enabling long-distance use is based on these expected benefits.

The aim of this study is to create an AR environment using a network camera and ARToolKit, as USB cameras are usually available for developing AR-related applications using ARToolKit. Long-distance use of a marker-based AR environment in terms of measurement is the main focus of this study. The integration of a network camera with an AR environment using ARToolKit is described, and the fundamental characteristics of the integrated system are evaluated through experiments.

In this paper, Section 2 describes the development of a base system by integrating a network camera with an AR environment using ARToolKit. An experiment was conducted to obtain the relationship between the zoom magnification and the angle of view for the network camera. In Section 3, fundamental experiments to evaluate the base system are shown. The evaluation of the delay time between the occurrence of an actual event and the time it is displayed by the system is conducted. Evaluation of the maximum distance between the camera and a marker, depending on the zoom magnification, is described. In Section 4, calibration methods are considered for reducing procedure steps. As a demonstration, Section 5 describes a zoning function of the system by changing the zoom magnification of the network camera. The effectiveness of the developed system is discussed in Section 6. Finally, the conclusions of this study are presented in Section 7.

2. **Development of a Base System.** This section describes the development of a base system consisting of a network camera and ARToolKit [16].

Use of a network camera can be a potential solution to the extension of the applicable distance between the camera and AR marker because the network camera usually has a zoom function for remote monitoring. Making use of the zoom function, a network camera (Canon VB-M44, 1/3" CMOS (RGB), approximately 1.3 million pixels, 20x optical zoom lens, 100Base-TX) [17] was used in the developed base system. Because the ARToolKit version used here (ARToolKit-2.72.1) did not recognize the network camera, the camera was connected to the AR system via the virtual USB camera software ManyCam (ManyCam Studio 6.1.1) [18]. This software can capture the image from a network camera with an IP address and produce the captured image as the output of a virtual USB camera. Using this function, the network camera was combined with a system using ARToolKit on a desktop computer (CPU: Intel Celeron P4500 1.87 GHz, memory: 4.00 GB, OS: Windows 7 Professional 32bit).

Figure 1 shows the configuration of the AR system as a base system. The network camera has a built-in web server and common gateway interface (CGI) programs. The CGI programs enable a computer to control the pan, tilt, and zoom of the network camera, and to read the camera status via web access. Therefore, the related parameters for camera control are prepared in the computer for the CGI programs as shown in the figure. As an example, an overview of the camera control steps through the hypertext transfer protocol request is shown in Figure 1. The pan, tilt, and zoom parameters to be set in the network camera are described in a uniform resource locator and then transferred to the web server. The CGI program receives these parameters and then controls the network camera. Regarding the network camera, the zoom magnification can be set by sending information about the angle of view to the camera. Therefore, an experiment was conducted to obtain the relationship between the zoom magnification and the angle of

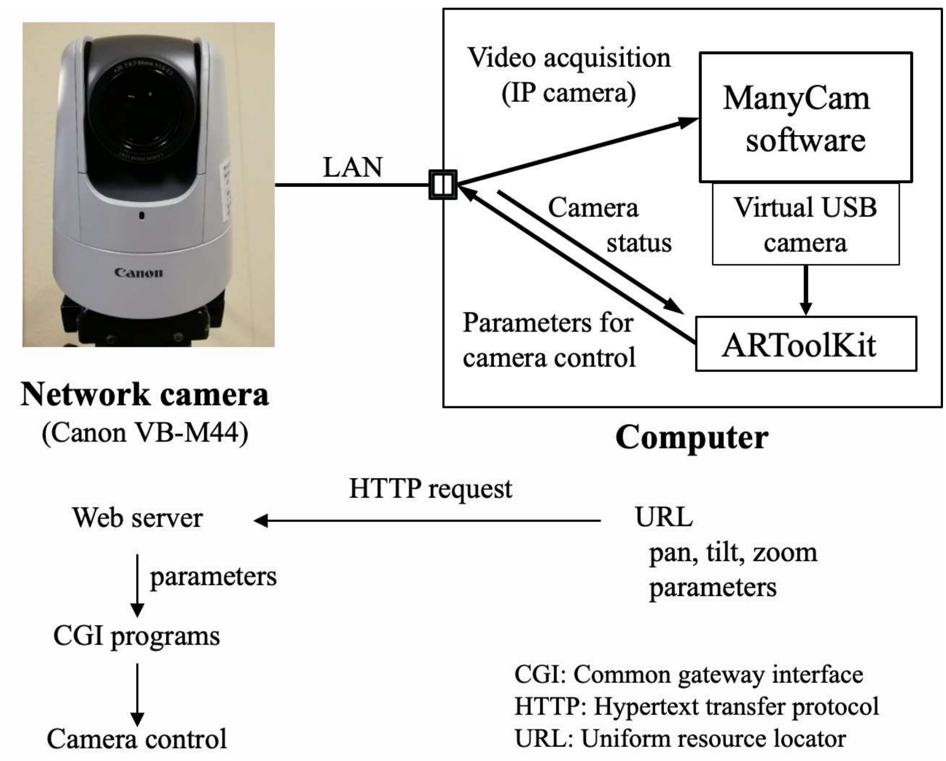

FIGURE 1. Combining a network camera with an AR environment using ARToolKit

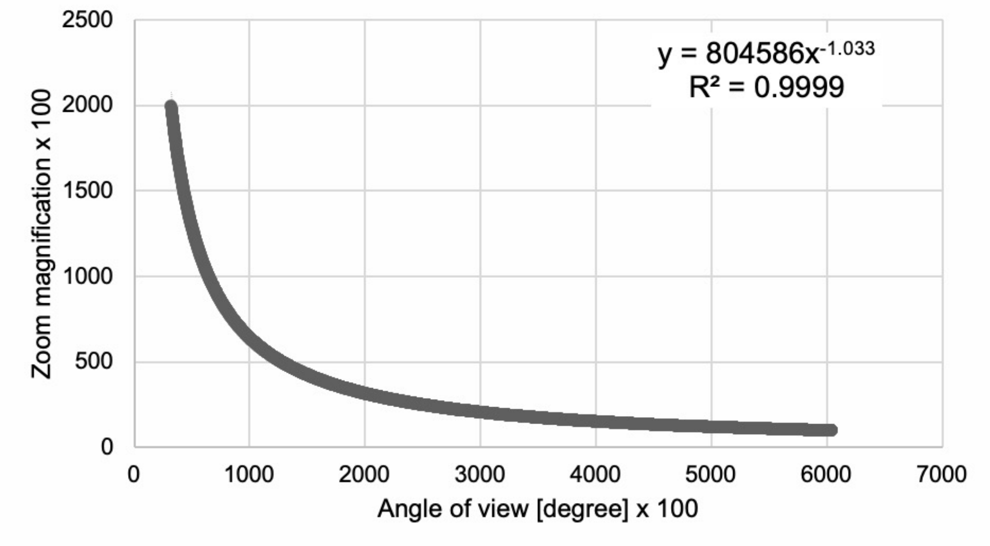

Figure 2. Relationship between zoom magnification and angle of view of the network camera. The vertical and horizontal axes correspond to a zoom-related parameter and angle of view-related parameter, respectively.

view. Figure 2 shows the obtained relationship. In the figure, the parameter values in the camera system are shown. The vertical axis corresponds to the zoom-related parameter, and the actual zoom magnification can be obtained by dividing by 100; for example, the vertical value 1000 corresponds to an optical zoom magnification of 10x. The horizontal axis corresponds to an angle of view-related parameter; the actual angle of view can be obtained from the horizontal value by dividing by 100. The camera maintains the value of the zoom magnification in the storage memory, depending on the value of the angle of view as an input parameter. In the experiment, various values of the angle of view were fed into the camera at intervals of 0.01°, and the resulting zoom magnification values were recorded. Because this measurement process requires many repetitions of parameter setting and recording results, a script program using the Perl language [19] was prepared for automatic measurement. Through this automatic process, the graph in Figure 2 was obtained. From these data sets, an empirical equation that represents the relationship between y- and x-coordinates was obtained using the least squares approximation, as shown in Equation (1),

$$y = 804586x^{-1.033} \tag{1}$$

The high coefficient of determination R^2 value in the figure shows the successful approximation of the acquired data.

3. **Fundamental Experiments.** To evaluate the fundamental characteristics of the base system developed in the previous section, experiments regarding the delay time and applicable distance were conducted.

3.1. **Delay time evaluation.** Evaluation of the delay time between the occurrence of an actual event and the time it is displayed by the system is important for developing applications with this base system in the future. Therefore, the delay time of the developed system was evaluated. The base system was rebuilt on a laptop computer (HP ProBook 650 G1 CPU: Intel Core i5-4210M 2.60 GHz, memory: 8.00 GB, OS: Windows 7 Professional 32bit) considering its easy-to-carry and battery-powered features, which make it convenient for experiments. Figure 3 shows an example of snapshots of a stopwatch (left)

FIGURE 3. Snapshot of a stopwatch (left) and its displayed image (right) on the computer screen via the developed AR camera system

and its displayed image (right) on the computer screen of the developed base system. The displayed image (right) was obtained by capturing the image of the stopwatch via the network camera. Because the displayed image contains information about the time when the image was captured, the time difference between the past time in the captured image and the current time in the snapshot provides information about the delay time. From the experiment, a mean delay time of 0.29 s, with a standard deviation of 0.02 s, was obtained. An additional experiment showed a delay time of 0.18 s for the usual AR system using a non-zoom USB camera (Microsoft LifeCam Studio Q2F-00020) without the virtual USB camera software ManyCam on the same PC platform. The difference in the delay times was 0.11 s. The obtained delay time should be considered in application development using this camera system in the future.

3.2. **Preliminary experiment using a small marker.** Theoretically, a high zoom magnification would extend the applicable maximum distance. In practical use of the developed system, confirmation of the relationship is necessary. Therefore, the relationship was confirmed in a preliminary experiment. Based on the results, the next subsection deals with an experiment to extend the applicable distance.

In the preliminary experiment, a square marker with a side length of 2 cm was used based on the estimation of the maximum distance that can be available in a hallway. The maximum distances corresponding to zoom magnifications of 1x, 2x, 3x, 5x, 10x, and 20x were evaluated. In the experiment, the marker was located at the end of the hallway and the network camera system with the laptop computer was set on a dolly, as shown in Figure 4; then, the dolly was moved away from the marker so as not to alter the illuminance on the marker surface. The maximum distance for each zoom magnification was determined to find the boundary at which the AR object was stably displayed; the mean for two trials was treated as the result. Figure 5 shows the maximum distances corresponding to the zoom magnifications. In the figure, the marker design used in the experiment is also shown for reference. As shown in the figure, an almost linear relationship can be seen between the two parameters: the maximum distance and the zoom magnification.

3.3. **Experiment for extending the applicable distance.** To confirm the long-distance use of the system, a further experiment was conducted. The purpose of the experiment was to compare the actual maximum distance and the estimated distance from an empirical equation obtained from the data for low zoom magnifications, considering

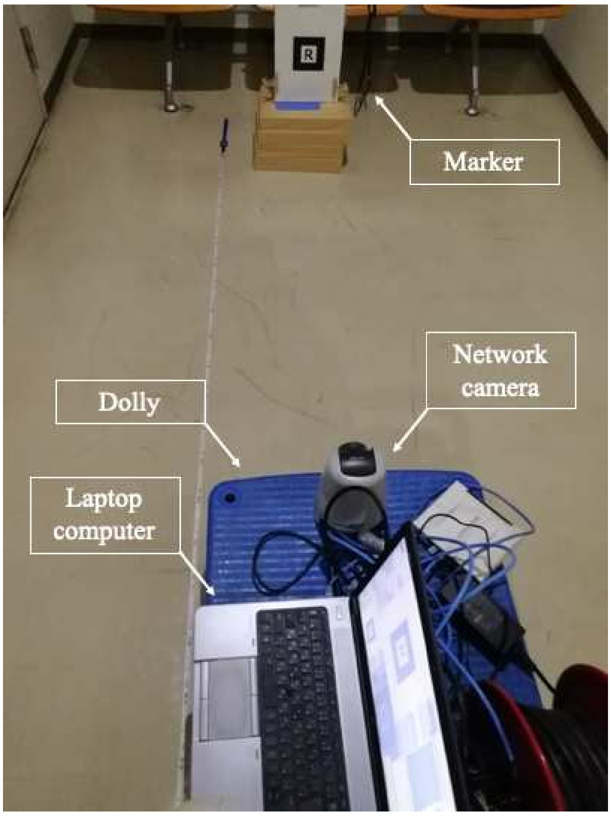

FIGURE 4. Network camera system with the laptop computer on a dolly

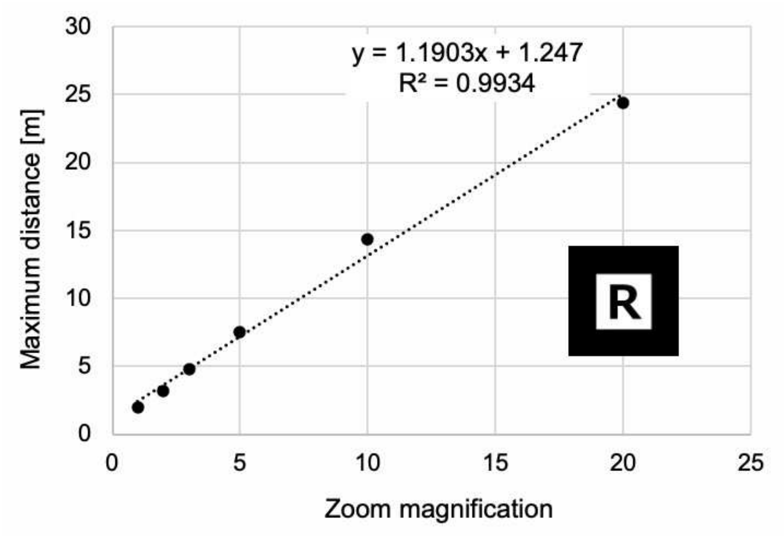

FIGURE 5. Maximum distances between the camera and the marker corresponding to the zoom magnifications when a square marker with a side length of 2 cm was used

the almost linear relationship in the preliminary experiment discussed in the previous subsection. In general, a linear equation can be determined from two data points on a scatter plot. If the linear equation determined from the data for the low zoom magnifications of 1x and 5x can provide a good estimate for the high zoom magnifications of 10x and 20x, then this method allows us to estimate the maximum distances for various zoom magnifications with minimum measurement steps. This estimate can be useful for designing an AR system that enables long-distance use.

In the experiment, square markers with side lengths of 10, 11, and 12 cm were used, and the maximum distances corresponding to the low zoom magnifications of 1x and 5x were obtained in the hallway in the same manner as shown in Figure 4. Table 1 shows the measured maximum distances for low zoom magnifications of 1x and 5x and related empirical equations for the square markers. Each measured value was obtained as the average of two measurements. The right-hand side of the table shows the constants a and b in the empirical equation, which shows the relationship between the maximum distance y and the zoom magnification x obtained from the data shown on the left-hand side. These empirical equations were used to estimate the maximum distance later in Table 2.

Table 1. Measured maximum distances for low zoom magnifications of 1x and 5x and related empirical equations for square markers with side lengths of 10, 11, and 12 cm

	Maximum distance [m]		$y = ax + b$	
Marker size [cm]	for 1x	for 5x	a	b
10	4.83	24.00	4.79	0.04
11	4.96	24.22	4.82	0.15
12	5.04	24.88	4.96	0.08

The actual maximum distances corresponding to the high zoom magnifications of 10x and 20x were measured outdoors because of their long distances. Figure 6 shows a snapshot of the experimental situations; a marker was carried by a person outdoors, and the scene was captured by the camera system. In this snapshot, the square-shaped AR object in green accompanied by the white arrow is located slightly at the bottom right of the marker. Although there is a difference between these locations, the difference cannot be seen in the later experiment shown in Section 5. The distance between the camera and the obtained boundary at which the AR object was stably displayed was measured using a laser range finder (BOSCH Laser Range Finder GLM 150) [20]. Because it was difficult to identify the weak laser spot on the marker during daytime, the distance between the

Figure 6. (color online) Snapshot of experimental situations for long-distance use of the system outdoors. The white arrow indicates the location of the AR object.

camera and the marked point as the boundary was measured using the laser range finder at night.

Table 2 shows the comparison of the estimated applicable maximum distances and the actual distances for the high zoom magnifications of 10x and 20x. Each estimated value was calculated from the empirical equation for the low zoom magnifications shown in Table 1. Each measured value was obtained as the average over three measurements. It can be seen that these values are close to each other for each marker. This result suggests that the applicable maximum distance can be successfully estimated using the empirical equation in Table 1. As shown in Table 2, long-distance use of greater than 90 m was achieved at a zoom magnification of 20x. In general, smaller markers are susceptible to pixel error in image processing. Therefore, the square marker with a side length of 10 cm is considered to have relatively larger errors than the others. Separation of the experiment between the daytime camera estimation and the nighttime laser ranger finder measurement mentioned above might affect the accuracy. Because the applicable maximum distance provides a rough guide for measurement planning, the accuracy appears to be acceptable. Thus, long-distance use of the AR functionality using ARToolKit has been achieved by integrating a network camera with a zoom function.

Table 2. Comparison of the estimated applicable maximum distances calculated using the empirical equations in Table 1 and the actual distances for the high zoom magnifications of 10x and 20x

Zoom	Marker size [cm]	Estimation [m]	Measurement [m]	Relative error [%]
10x	10	47.96	45.46	5.5
	11	48.30	47.41	1.9
	12	49.68	49.16	1.1
20x	10	95.89	89.21	7.5
	11	96.45	94.96	1.6
	12	99.28	95.96	3.5

4. **Calibration Methods for Variable Zoom Magnification.** In the previous section, it was confirmed that the developed base system has the potential to be employed for long-distance use. In this section, calibration methods are considered for reducing adjustment steps because easy setup is an important feature in the practical use of the system.

Before measurement, calibration is necessary to obtain the camera parameters of the system with ARToolKit. The two-step calibration method in [21] was used to obtain the camera parameters for our developed system with improved accuracy. In general, calibration is necessary for each zoom magnification because of the state change in the optical system of the camera. Efficient calibration performance enables practical use of the system. In other words, if camera parameters for a zoom magnification of 1x can be applicable to other magnifications, the number of calibration steps can be reduced. In this section, the following two calibration methods were considered.

- Calibration A: Camera calibration is performed for a zoom magnification of 1x, and its camera parameter set is used for zoom magnifications of 1x, 5x, 10x, and 20x.
- Calibration B: Camera calibration is performed for each of the zoom magnifications of 1x, 5x, 10x, and 20x, and each camera parameter set is used for each magnification.

In Calibration A, the situation using higher zoom magnification is equivalent or similar to that when the marker is closer to the camera. Therefore, the actual distance between the camera and the marker can be calculated by multiplying the zoom magnification value by the estimated distance. In contrast, Calibration B is the typical method, in which a camera parameter set for each zoom magnification is used.

In the experiment, a square marker with a side length of 7 cm was used and placed at the point where the distance from the camera was 4 m. The estimated distance was calculated for each zoom magnification by averaging the distances for 30 frames of the captured images. This task was repeated three times, and the average was used as the estimated distance. The same experimental process was conducted for three days. Figure 7 shows the estimated distances averaged over three days. For low zoom magnifications such as 1x and 5x, the estimated distances were close to 4 m. For high zoom magnifications like 10x and 20x, the estimation error gradually increased. It can be seen that both calibration methods have similar estimation results. The relationship between zoom magnification and angle of view shown in Figure 2 suggests that the zoom magnification is sensitive to the angle of view for higher zoom magnifications. Thus, it is possible that this characteristic affects the accuracy of the distance estimation. As can be seen, the estimation accuracy of Calibration A is comparable with that of Calibration B. Therefore, the results suggest that Calibration A allows us to set up a camera system using fewer preparation steps. Because Calibration A does not require calibration for zoom magnifications except for 1x, it also provides a flexible and convenient method for arbitrary zoom magnification.

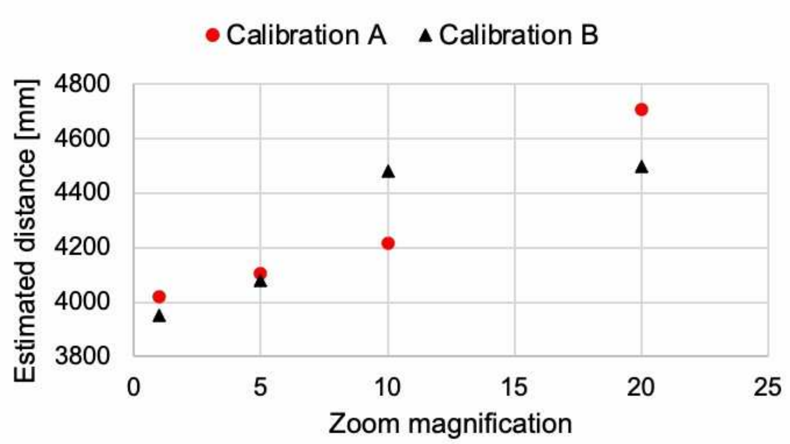

FIGURE 7. Comparison between the estimated distances averaged over three days for Calibration A and Calibration B

5. **Experiments for Zoning Function Making Use of Zoom Function.** In the previous sections, a base system consisting of a network camera with ARToolKit was developed. For practical use, the camera was mounted on an aluminum frame with a tripod, as shown in Figure 8.

One of the advantages of the zoom function is marker detection control, achieved by changing the zoom magnification. For example, a distant marker that cannot be detected by the system can be detected by increasing the zoom magnification; that is, the detection range can be controlled by changing the zoom magnification. If same-size markers are used in the field, markers in a specific area, that is, in a specific zone, can be detected depending on the zoom magnification. In this section, the possibility of zoning for detection by zoom magnification is investigated to demonstrate the effectiveness of the developed camera system. Before showing the zoning experiment, an experiment to detect zoning boundaries is described.

FIGURE 8. Camera system mounted on an aluminum frame with a tripod

5.1. **Experiment to detect zoning boundaries outdoors.** The purpose of the experiment was to obtain zoning boundaries by detecting the applicable maximum distances for the zoom magnifications outdoors and evaluate the estimation accuracy of the distances obtained from the distance-measurement function of ARToolKit.

In the experiment, zoom magnifications of 5x, 10x, and 15x were used. Because the space for this experiment was limited, a zoom magnification of 20x to obtain the applicable maximum distance was not included. Figure 9 shows a marker and two different background images used in the experiment. A typical simple marker with a side length of 7 cm was used because a typical situation provides general results. The marker was printed on the center of an A4 sheet of paper with white and black background images. For each of the zoom magnifications of 5x, 10x, and 15x, the distance between the camera and the obtained boundary at which the AR object was stably displayed was estimated using the distance-measurement function of ARToolKit. Simultaneously, the distance was measured using the laser range finder.

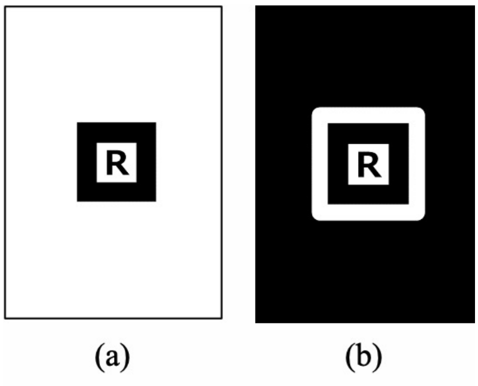

FIGURE 9. Marker and two different background images. A square marker with a side length of 7 cm was printed on the center of an A4 sheet of paper with white and black background images.

Figure 10 shows the applicable maximum distances between the camera and the marker for two different background images. The distance estimated by ARToolKit and the distance measured by the laser range finder are shown in the figure. The estimated distance using ARToolKit is quite similar to the measured distance for each background image.

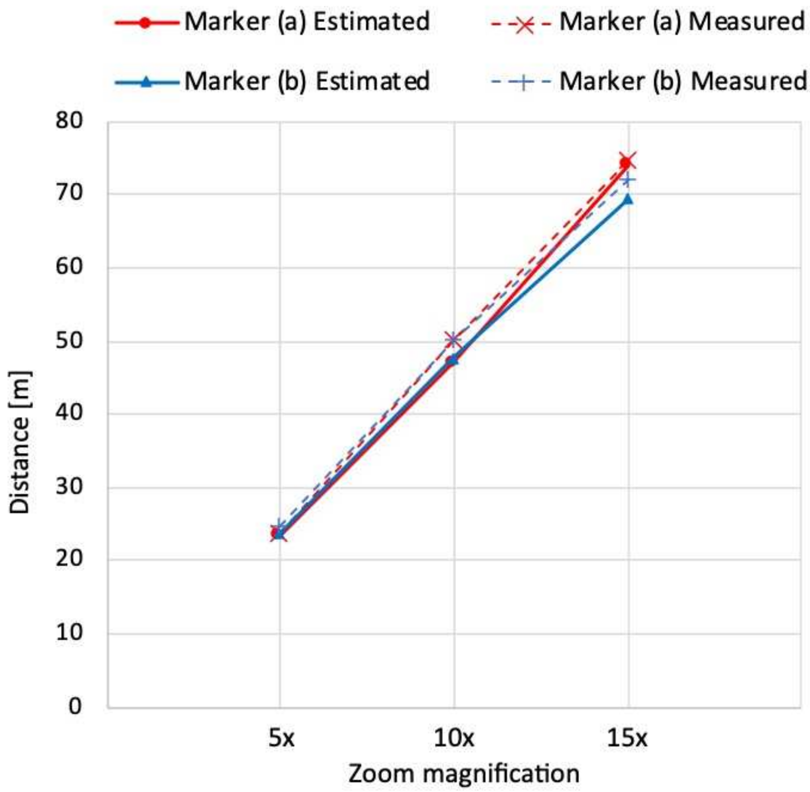

Figure 10. Applicable maximum distances between the camera and the marker for obtaining zone boundaries. The distance estimated by the distance-measurement function of ARToolKit and the distance measured using the laser range finder are shown for each background image shown in Figure 9 and each zoom magnification, that is, 5x, 10x, and 15x.

Table 3. Detailed values of applicable maximum distances for two different background images shown in Figure 9

Markers		Zoom 5x (zone 1)	Zoom 10x (zone 2)	Zoom 15x (zone 3)
Marker (a) in Figure 9	Estimated [m]	23.44	46.97	73.95
	Measured [m]	23.76	50.22	74.84
	Error [%]	−1.3	−6.5	−1.2
Marker (b) in Figure 9	Estimated [m]	23.88	47.59	69.43
	Measured [m]	24.60	50.03	72.16
	Error [%]	−2.9	−4.9	−3.8

Markers (a) and (b) in Figure 9 denote a linear relationship between the maximum distance and zoom magnification. The linear relationship in Figure 10 suggests the generality of the experimental results even though the zoom magnification of 20x was not included. The detailed values of the distances are shown in Table 3.

5.2. **Zoning experiment.** From the results shown in Figure 10 and Table 3, Marker (a) was used, along with the zoning pattern shown in Figure 11. The boundaries for Zones 1, 2, and 3 were determined by considering the maximum distances for Marker (a) in Table 3

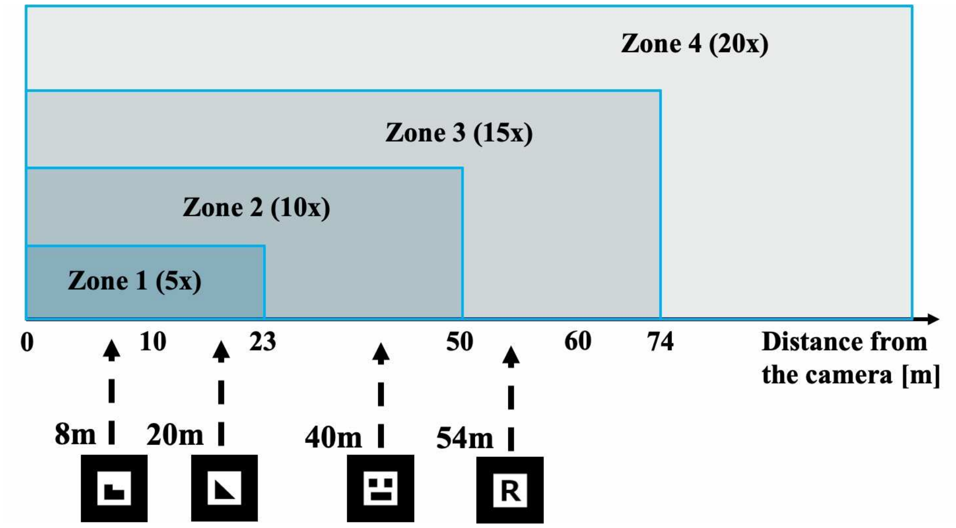

FIGURE 11. Zone design for zoning experiment

FIGURE 12. Experimental setup for zoning experiment. Markers are aligned in the depth direction from the AR camera system.

for various zoom magnifications. To confirm the zoning function, the four markers shown in Figure 11 were located at 8, 20, 40, and 54 m from the camera, respectively. Figure 12 shows a snapshot of the experiment; the AR camera system connected to the PC on the chair is located outdoors. The four markers are aligned in the depth direction from the camera system, that is, from bottom left to top right in the snapshot.

Figure 13 shows a scene with a zoom magnification of 5x. Among the four aligned markers, two markers have their own AR objects: violet (front) and green (back) ones. This result shows successful detection based on zoning because these two markers were located inside Zone 1, as shown in Figure 11. The situation in which the other two markers were not detected is also an important result for the zoning idea.

Figure 14 shows a scene in which the zoom magnification was changed to 15x. In this case, each marker, including the farthest one in Zone 3, has its own AR object, demonstrating successful detection.

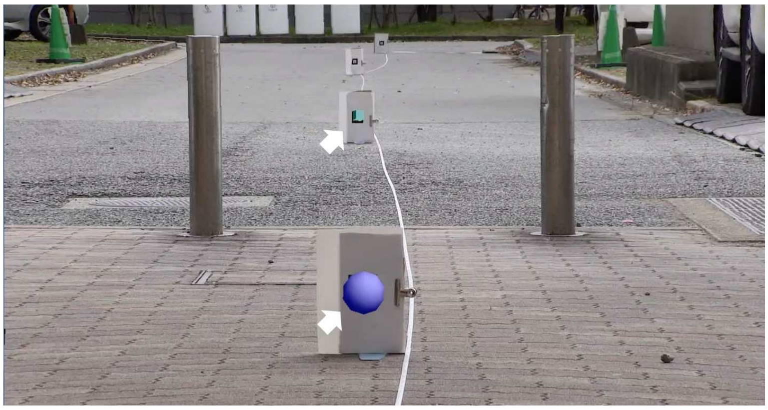

FIGURE 13. Marker detection with zoom magnification of 5x. Markers inside Zone 1 were successfully detected. The white arrows indicate the locations of the AR objects.

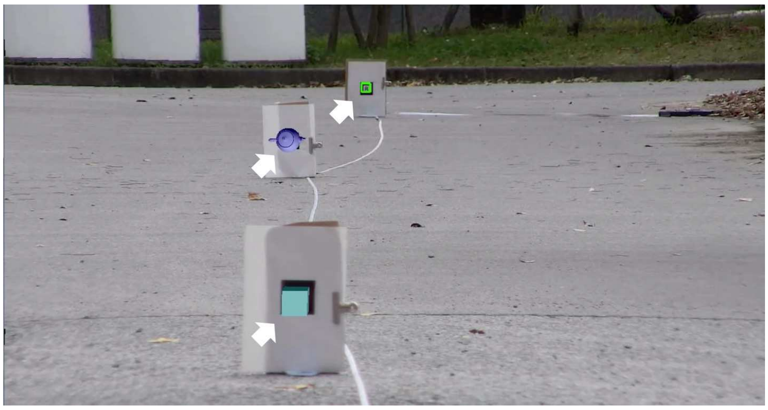

FIGURE 14. Marker detection with zoom magnification of 15x. Markers, including the farthest one in Zone 3, were successfully detected. The white arrows indicate the locations of the AR objects.

Thus, successful results for the zoning function were obtained by controlling the zoom magnification.

6. **Discussion.** As shown in Section 2, a network camera with a zoom function was combined with a system using ARToolKit via the virtual USB camera function. Although there is a delay time of 0.29 s, as shown in Section 3, this system can be applied to phenomena at acceptable speeds. Prediction of state change considering the delay time would work well to some extent, even for phenomena at fast speed. The absence of a need to modify ARToolKit itself is also one of the advantages of our proposed approach.

From the results in Sections 3 and 4, the extension of the applicable distances between the camera and markers was successfully performed by arranging the zoom magnification of the network camera and the size of the markers. Because the results regarding the maximum distance for the low zoom magnifications of 1x and 5x can be used to form a linear empirical equation for the estimation of high zoom magnifications, this strategy provides useful information for designing application systems using the base system developed here. Although Table 2 shows long-distance use of greater than 90 m for a square marker with a side length of 10 cm and a zoom magnification of 20x, longer distances can be achieved using larger markers and higher zoom magnification.

Furthermore, as shown in Figure 7, calibration method Calibration A, which requires fewer preparation steps before use, can provide accuracy comparable with that of the usual calibration method, Calibration B, which is performed for each zoom magnification. In Calibration A, the camera parameters for a zoom magnification of 1x can be applied to other magnifications. The actual distance between the camera and the marker can be calculated by multiplying the zoom magnification value by the distance estimated by ARToolKit, showing a flexible and convenient method for arbitrary zoom magnification, as described in Section 4. This feature not only reduces the preparation steps, but also allows skipping the calibration for high zoom magnifications that require a long-range calibration distance. In other words, the system can be used in a long-distance environment without long-distance calibration after short-distance calibration. This can be a merit in situations such as a disaster scene where approaching a target object is difficult. A combination of the developed system here and drones can enhance applicable situations, for example, carrying a marker and fixing it to a target object.

Section 5 demonstrated the effectiveness of the idea regarding the zoning function by changing the zoom magnification. Thus, the creation of an AR environment using a network camera with a zoom function and ARToolKit provides us with the following benefits.

- Large markers are not necessary because of the zoom function of the camera
- Consequently, the size of a marker attached to a target object can be reduced; as a result, deterioration of the aesthetic appearance of the object can be reduced
- Markers to be detected and processed can be controlled by setting zones
- Computer resources can be saved because the number of markers simultaneously detected can be controlled by setting zones and captured image size, i.e., by setting a region of interest (ROI)
- Remote monitoring is available by making use of network camera functions

The outcomes of this study can be useful for developing application systems as follows:

- Monitoring system for confirming the existence of target objects
- Warning system for the approaching behavior of objects having markers or their opposite behavior
- Event detection system using occlusion of a fixed marker by target objects such as intruders and animals

7. Conclusions.

A network camera system enabling long-distance use of the augmented reality function using ARToolKit was described in this paper. Long-distance use was achieved by integrating a network camera with a zoom function with the system using ARToolKit as a virtual USB camera. The fundamental characteristics of the system were evaluated with respect to future applications. The experimental results showed a good linear relationship between the applicable maximum distance and the zoom magnification. Therefore, as an example, long-distance use of greater than 90 m for a square marker with a side length of 10 cm and zoom magnification of 20x was achieved. An efficient calibration method was also proposed, and it was revealed that the camera parameters for a zoom magnification of 1x can be applied to other magnifications and the calibration cost can be reduced. A demonstration to control the detectable markers depending on the distance between the markers and the camera by changing the zoom magnification, that is, zoning, demonstrated the convincing potential of the developed system.

The characteristics of the developed system presented here can be useful for designing and developing application systems that enable long-distance use of the augmented reality function using ARToolKit in the future. Development of such application systems will be demonstrated in future work.

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