Proposal for a Wireless Sensor Network Visualization System Using Location Estimation Technology

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***Abstract*—In recent years, popularization of wireless sensor networks in various fields including smart houses and environment monitoring systems at factories has been expected. However, it is difficult to grasp the structure and connectivity of dynamically changing networks, because sensor networks are connected by radio waves with each other. For that reason, it will be useful if the location of sensor devices and the structure of wireless sensor networks can be confirmed by visual observation at the time of maintenance or troubleshooting. In this paper, we propose a visualization system for wireless sensor networks using a tablet and location estimation technology. In our proposed system, we make it possible to observe the wireless sensor networks by eyes, by displaying the virtual object representing sensor device link information and sensing data, on the screen of the tablet whose location is estimated. We confirmed that the virtual object is superimposedly displayed in the sensor device on the camera screen, by implementing to iPad a prototype of the algorithm to estimate the locational relationship between the tablet and sensor devices.**

I. Introduction

In recent years, short-range wireless communication specifications represented by ZigBee [1] have been standardized, and popularization of wireless sensor networks is expected in various fields such as smart houses and environment monitoring systems in factories. It is expected hereafter that many units of wireless devices will come to be installed in every corner of a house, in proportion as the miniaturization and improvement of performance of the devices further advance.

It is difficult to grasp the structure and connectivity of dynamically changing networks because sensor devices are connected by radio waves with each other. For that reason, it will be useful if we have a system that can quickly confirm by eyes the structure and sensing data of wireless sensor networks in order to improve the efficiency of maintenance activities.

At present, as visualization technologies for wireless sensor networks using Augmented Reality (AR) technology [2], Embodied Visualization with AR for Network Systems (EVANS) [3] and uMegane [4] have been proposed. In these systems, sensor device information is visualized, by recognizing AR markers attached to the sensor device through image processing, and by displaying the virtual object superimposedly by way of calculating the location of the sensor device. Thus, it is necessary to attach special markers to all sensor devices subject to visualization and therefore, these systems are not suitable for use in the ordinary housing environment. In addition, there is another problem that because the virtual object is displayed based on markers, visualization is feasible only for the network structure which is composed of unconcealed sensor devices within the visual field of the camera.

As a result, in order to solve these problems, this paper proposes wireless sensor network visualization system using a location estimation technology. In our proposed system, the location of the tablet equipped with a camera is estimated by using an existing location estimation technology [5]–[9], and the virtual object is displayed based on the relative locational relationship between the sensor device and the tablet. By using this method, it is possible to visualize even the link information to the sensor device which is installed outside the visual field of the camera without special markers.

In this paper, we confirmed that the virtual object can be superimposedly displayed based on the relative locational relationship between the tablet and the sensor device, by implementing to iPad a prototype application that operates based on the recognition that the locations of the tablet and the sensor device are already known.

Herein below, we explain existing visualization systems in Section 2, the outline of our proposed system in Section 3, the prototype system in Section 4, and verification and evaluation in Section 5, and summarize in Section 6.

II. Existing Systems

A. EVANS

EVANS is a wireless network visualization system using AR technology [3]. This system visualizes wireless networks by recognizing special markers attached to the sensor device, using a laptop PC equipped with a Web camera called EVANS node, and display a virtual object on the screen. Moreover, the system can switch the power source of the sensor device by manipulating the virtual object displayed on the EVANS node. The management node collects information such as addresses and sensing data of wireless nodes and manages wireless networks. However, unless markers exist in the positions which can be recognized by the camera of the EVANS node or they are in the right directional position, it is not possible for this system to display the virtual object in the right position on the screen.

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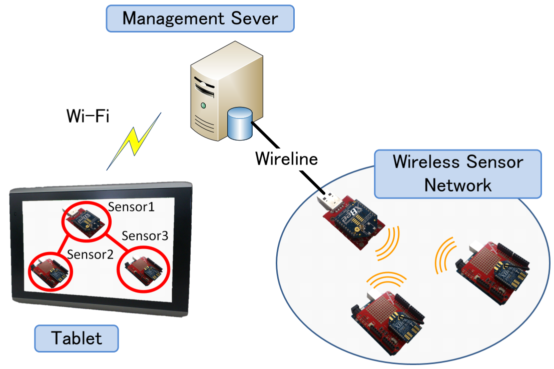


Fig. 1. Configration of proposed system.

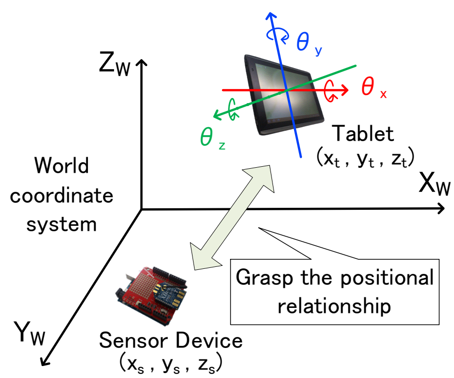


Fig. 2. Coordinate system in the proposed system.

TABLE I
SENSOR INFOMATION ON MANAGEMENT SERVER.

Field Name	Description
PAN ID	Network identification ID
Address	Address of sensor device
Neighbor Device Address List	Address list of adjacent devices
Sensor Type	Type of sensor
Sensing Data	Sensing data
Position	Location coordinates
Timestamp	Renewal time

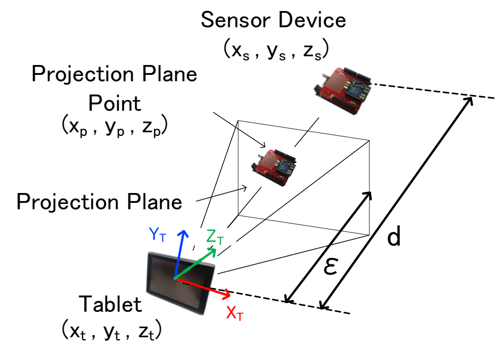


Fig. 3. Projection plane.

B. uMegane

uMegane is a system aiming at easily browsing sensing data of multiple sensor devices without going through a time- consuming operation [4]. This system adopts a Web camera and Head Mounted Display (HMD) as an interface. Special markers are attached to sensor devices like the case of EVANS, and users install HMD and recognize markers of the sensor devices by using the Web camera. At that time, sensing information is displayed around the sensor device on the screen, and users are able to browse the information of the sensor device without getting access to the database directly. In addition, most of the up-to-date information or past information alone can be browsed since its own unique filters called real-time filter and time-machine filter are implemented.

III. PROPOSED SYSTEM

A. Outline

Our proposed system visualizes a wireless network, by displaying the location of sensor devices, sensing data and the link information of the wireless sensor network as a virtual object on the tablet screen positioned in the space by the user. The virtual object is displayed based on the relative locational relationship between the tablet and sensor devices. By this way, the structure of the wireless network can be visualized, without the necessity of attaching visual markers to sensor devices, and even if the sensor devices are installed outside the visual field of the camera or in the shade of certain objects.

Fig. 1 shows the configuration of our proposed system. Our proposed system is composed of sensor devices, a management server, and a tablet. The tablet is assumed to be equipped with a camera function, a 3-axis acceleration sensor, and a 3-axis geomagnetic sensor. Sensor devices are possessed of wireless communication function, and measure temperature, humidity, the intensity of illumination and so on. The management server is connected to Personal Area Network (PAN) coordinator which has the function of managing the sensor network, and manages the data measured by the sensor devices and the neighbor device address list indicating the link relationship of sensor devices, as shown in Tab. I.

B. Locational Adjustment of Virtual Object

In our proposed system, the coordinates on the screen on which to display the virtual object are calculated from the relative relationship between the tablet and sensor devices. The relative position of the tablet and sensor devices is obtained from the locational information and the orientation of the tablet, and the locational information on the position of the installed sensor devices. Fig. 2 shows the spatial, locational relationship between the tablet and sensor devices. The locational information of the sensor devices (x_s, y_s, z_s) is obtained from the management server. The orientation $(\theta_x, \theta_y, \theta_z)$ of the tablet is obtained, by analyzing the accelerator and the geomagnetic sensor mounted on the tablet. The location (x_t, y_t, z_t) of the tablet is estimated, by using the location estimation technology using the radio waves of Wi-Fi access points installed in the surroundings.

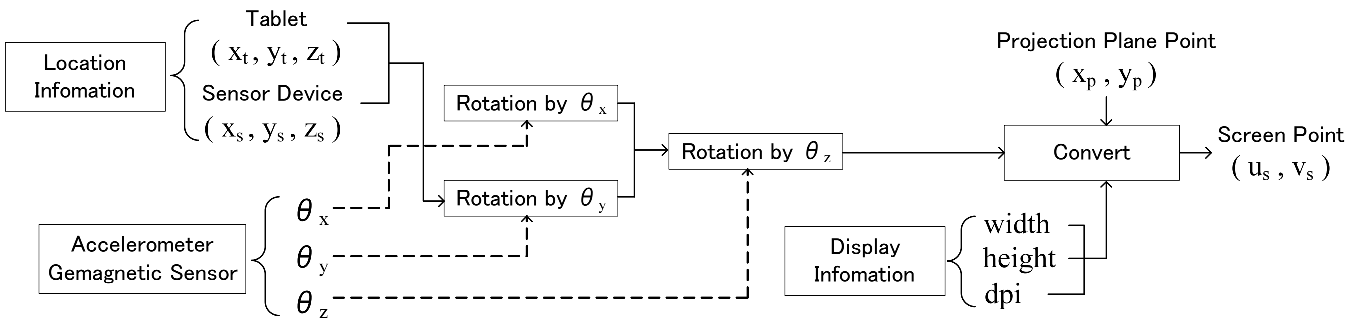
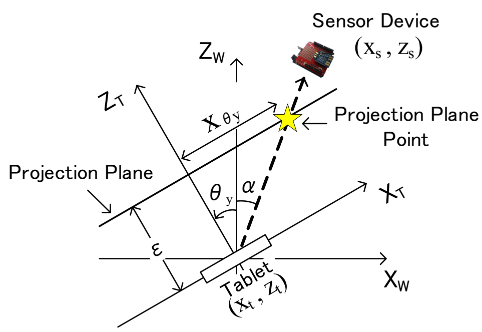
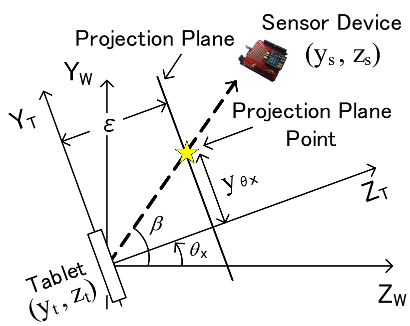


Fig. 4. Procedure of coordinate transformation.





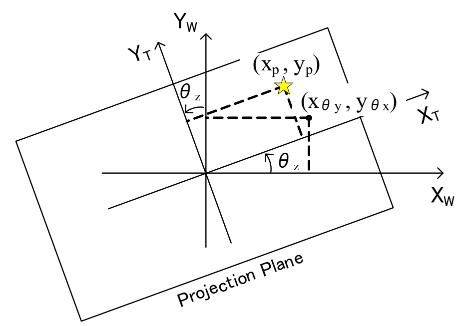


Fig. 5. Roll (Rotation of θ_y around the Y_T-axis). Fig. 6. Pitch (Rotation of θ_x around the X_T-axis). Fig. 7. Yaw (Rotation of θ_z around the Z_T-axis).

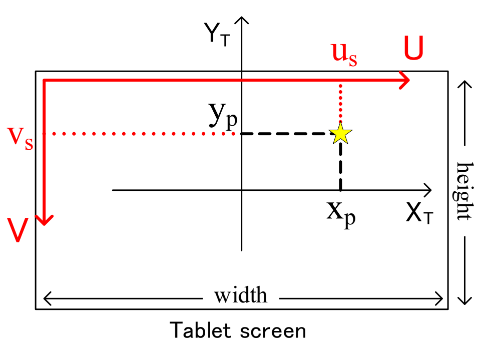


Fig. 8. Relationship between the coordinate on the projection plane and the coordinate on the tablet screen.

C. Display of Virtual Objects

1) Projection Plane: The coordinates on the tablet screen on which to display the virtual object are calculated, by assuming the projection plane between sensor devices and the tablet. Fig. 3 shows the locational relationship of the projection plane. ε is the distance between the tablet and the objection plane, and d is the distance between the tablet and the sensor device. Here, ε is a value determined by the features of the camera mounted on the tablet and is obtained by the calibration of the camera. The coordinates (u_s, v_s) on the screen of the tablet on which to display the virtual object are calculated from the coordinates (x_p, y_p, z_p) of the sensor device on the projection plane, by using the proportionate relationship between the locational coordinates of the sensor device, d and ε in Fig. 3.

2) Calculation Method of Coordinates on the Projection Plane: Fig. 4 shows the flow to calculate the display position of the virtual object. The coordinate of the virtual object on the projection plane, namely (x_p, y_p, z_p), is calculated, by considering the rotation order based on the orientation $(\theta_x, \theta_y, \theta_z)$ for the tablet location (x_t, y_t, z_t) and the sensor device location (x_s, y_s, z_s).

Fig. 5 shows the rotation by θ_y. This is a picture looked down from the right overhead. In this paper, the world co-ordinate system is indicated as X_W, Y_W, Z_W and the tablet coordinate system as X_T, Y_T, Z_T, and the orientation of the tablet, rotating in a counter-clockwise direction is the positive direction for each axis. Here, if the angle created by the line to Z_W and the line of sight from the tablet to the sensor device is named as α, then the coordinate X ($x_{\theta y}$), which is the cross point between the line of sight and the projection plane, is indicated as Equ. (1) from the relationship shown in Fig. 5.

$$x_{\theta y} = \varepsilon \tan(\alpha + \theta_y) \quad (1)$$

Likewise, Fig. 6 shows the rotation by θ_x. This is a picture where the tablet is looked at from the positive direction of X_T axis of the tablet system. Here, if the angle created by the line to Zw and the line of sight from the tablet to the sensor device is named as β, then the coordinate Y ($y_{\theta x}$), which is the cross point between the line of sight and the projection plane, is indicated as Equ. (2), from the relationship shown in

Fig. 6.

$$y_{\theta x} = \varepsilon \tan(\beta - \theta_x) \tag{2}$$

Next, we give a thought to the rotation around the axis Z. Fig. 7 shows the rotation by θ_z. This is a picture where the tablet is looked at from the display side. The relationship between the location of sensor device before the rotation, namely $(x_{\theta y}, y_{\theta x})$ is indicated as Equ. (3).

$$\begin{pmatrix} x_p \\ y_p \end{pmatrix} = \begin{pmatrix} \cos\theta_z & -\sin\theta_z \\ \sin\theta_z & \cos\theta_z \end{pmatrix} \begin{pmatrix} x_{\theta y} \\ y_{\theta x} \end{pmatrix} \tag{3}$$

3) Coordinate Conversion from on the Projection Plane to on the screen: Although the location of the sensor device on the projection plane is calculated by the above procedure, it is necessary to convert the coordinates on the projection plane to the unit ("pixel") used on the camera screen because the coordinates on the projection plane are based on the unit of the world coordinate system. Fig. 8 shows the relationship between the coordinate on the projection plane that is the world coordinate system and the coordinate on the tablet screen. The origin of the XY plane in the projection plane is in the center of the tablet screen. On the other hand, the coordinate origin of the tablet screen is top left of the tablet screen. When the unit for $X_{\theta z}$ and $Y_{\theta z}$ is [mm], the coordinate conversion from on the projection plane (x_p, y_p) to on the tablet screen (u_s, u_s) is indicated as Equ. (4) and Equ. (5).

$$u_s = x_p \times \frac{dpi}{25.4} + \frac{width}{2} \tag{4}$$

$$v_s = \frac{height}{2} - y_p \times \frac{dpi}{25.4} \tag{5}$$

Here, dpi (dots per inch) means the resolution of the screen of the tablet, and 25.4 is a value where 1 inch is converted to mm.

The virtual object is displayed in the position (u_s, v_s), which is calculated based on the above-said process. The virtual object is associated with the address of the sensor device. Wireless links between each sensor device are visualized by connecting with virtual objects according to the neighbor device address list obtained from the management server. Furthermore, when a user touches on the virtual object, information such as sensing data of the relevant sensor device is displayed in a pop up manner.

IV. Implementation

We experimentally created an application for iOS that displays a virtual object on a camera screen, by detecting the orientation of the tablet by using the 3 axis acceleration sensor and 3 axis geomagnetic sensor mounted on the tablet. Fig. 9 shows the configuration of our prototype application. In the visualization module, the display point of the virtual object is calculated, by analyzing values of the acceleration and geomagnetic sensors, parameters of the camera, the locational information of the tablet, and the locational information of the sensor devices. Overlay View is drawn up based on the calculated display point of the virtual object, and the location of the sensor devices is visualized, by displaying it on the camera screen. Parameters of the camera are calculated, by analyzing the picture of the calibration sheet with the camera mounted on the tablet in the process of Camera Calibration. This time, we implement the process that can designate the locational information of the tablet and sensor device as well as the orientation of the tablet, form the exterior file (TestData.csv), for the purpose of verification.

We confirmed the operability of the prototype application based on the configuration shown in Fig. 10. As the sensor device, we used Apple iPad with Retina display (3rd generation) and Sun SPOT [10], that is a wireless sensor network node developed by Sun Microsystems and is built upon the IEEE 802.15.4 standard [11]. Fig. 11 shows the result of the drawing of a virtual object for the case where the locations of the tablet and the sensor device are known in advance. The smaller shape in white color based on the coordinates on the virtual screen is the virtual object drawn. If you look at Fig. 11, you can see that the virtual object is superimposedly displayed on the sensor device on the screen. From this fact, we confirmed that our prototype application works properly in the case where the locations of the tablet and the sensor device are known in advance.

V. Evaluation

A. Comparison with Existing systems

Tab. II shows the comparison of our proposed system with the existing systems, EVANS and uMegane. In our proposed system, there is no prejudice to the indoor landscape, because it is not required to attach markers to the sensor device as the virtual object is displayed based on the relative position between the location estimated by a location estimation technology and the locational information of sensor devices. Furthermore, our proposed system can display link information to the sensor device placed outside the field of view of the camera and also that placed in the shade of certain objects. However, there is a possibility that the virtual object is not superimposedly displayed on the sensor device, depending on the location estimation accuracy of the tablet. Thus, from the viewpoint of the influence of location estimation errors giving on the display location of the virtual object, we examined the permissible range of location estimation accuracy for our proposed system.

B. Accuracy Examination

1) Purpose and method of experiment: In order to find out the degree of location estimation accuracy required for our proposed system, we clarified the relationship between the location estimation error of the tablet and the display error of the virtual object on the tablet screen.

We placed the tablet on the origin of the world coordinates, and the sensor device on the axis Z, and we considered the display location of the virtual object as the true value. Then, we set the errors contained in the location of the tablet in 3 patterns of 10 cm, 20 cm and 30 cm, and measured the location aberration of the virtual object resulting from each location estimation error. On that occasion, we defined the error in the

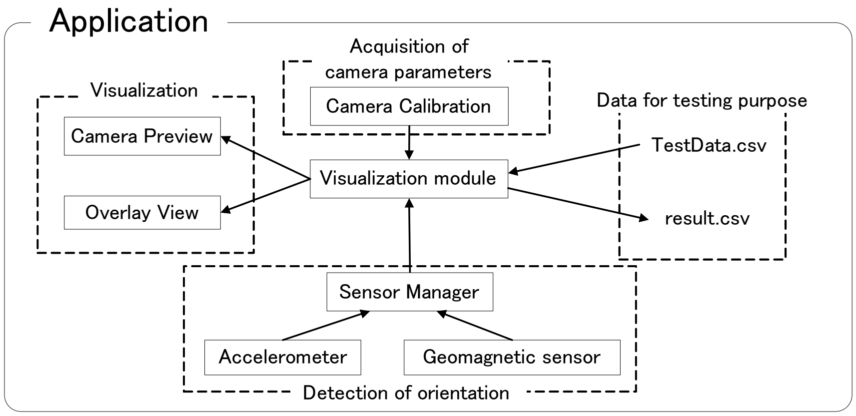


Fig. 9. Module configuration of the prototype.

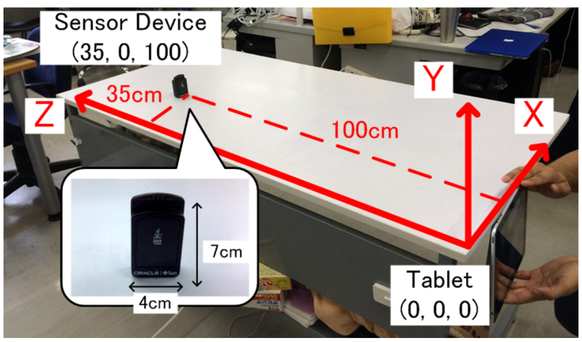


Fig. 10. Placement of sensor device and tablet.

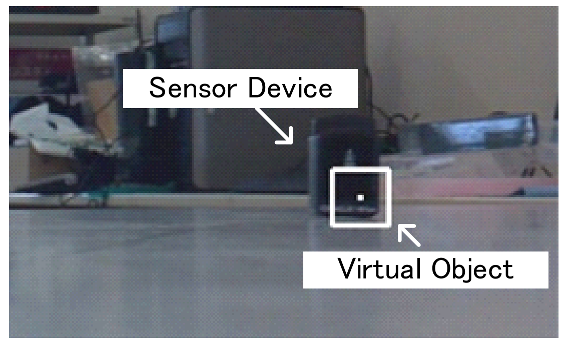


Fig. 11. Result of the drawing of a virtual object.

distance between the display location and the true value of the virtual object as the display error of the virtual object, and obtained the display error (pixel) per 1 cm of location estimation error of the virtual object.

2) Relationship between the location estimation error and the display location of the virtual object: Fig. 12 shows the display error of the virtual object for each estimation error of the tablet. This graph indicates the results of display errors when the distance between the tablet and the sensor device is increased from 3 m to 10 m at intervals of 0.5 m under the conditions of adding intentional errors of 10 cm, 20 cm and 30 cm to the locational information of the tablet Axis X, as well as the formulae where the results are approximated by the involution average. From the graph, we can see that in proportion as the intentional errors increase by 2 times, 3 times, and so forth, the coefficients of the approximation formula also increase by 2 times, 3 times, and so forth. From this fact, the location estimation error of the tablet and the display error of the virtual object can be expressed as the Equ. (6).

$$e_{view} = 5.9358 e_{loc} d^{-1} \quad (6)$$

Here, d in Equ. (6) is the distance (meter) between the tablet and the sensor device, e_{view} is the display error (pixel) of the virtual object, and e_{loc} is the location estimation error (cm).

3) Examination: We examine the permissible range of location estimation errors from the relationship between the location estimation error and display location of the virtual object. Based on our preliminary experiment, we confirmed that when we took a picture of the sensor device Arduino Uno (7×5.5 cm) [12] placed at a distance of 1 meter away by using our prototype application, the picture was shown on the screen of the camera in the size of about 155 $\times$ 125 pixel (Fig. 13).

It will be ideal if the center of the sensor device on the screen is displayed in a way that it perfectly overlaps the center of the virtual object, but if we assume that the usage of our proposed system is for visualization of the wireless sensor network, there will be no problem in using our contrived application for that purpose, as long as the virtual object is displayed in the vicinity of the sensor device. Thus, as shown in Fig. 13, we assume that the display error of the virtual object is permissible, to the extent that the center of the virtual object exists within a square 250 pixel on a side centered on the sensor device on the screen.

Next, we consider the case of applying existing location estimation technologies to our system. It is said that when we use the existing location estimation systems using the access point of wireless LAN [8] or Ekahua RTLS Controller [9], we

TABLE II
COMPARISON BETWEEN OUR PROPOSED SYSTEM AND EXISTING SYSTEMS.

	Our Proposes System	EVANS	uMengae
Marker	Not necessary	Necessary	Necessary
Location estimation	Necessary	Not necessary	Not necessary
Advance preparation	Registration of location information	Registration of marker	Registration of marker
Visible range	Entire area	Within the range of camera	Near sensor
Link display	All links	Some links	Not display
Device operation	Can not be operation	Can be operation	Can not be operation

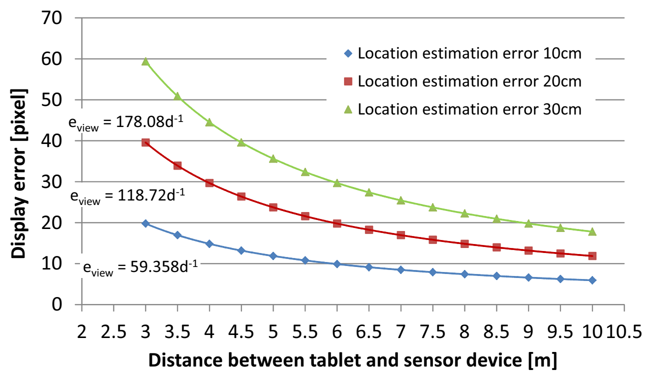


Fig. 12. Relationship of display error and position estimation error.

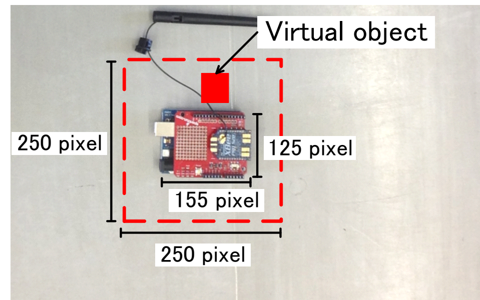


Fig. 13. Permissible range of display error of a virtual object.

can get an accuracy with an error of about 1 m if the radio wave condition is stable. Based on this assumption, if we make $e_{loc} = 100cm$ cm and if the virtual object is displayed within a squire of 250 pixel on a side centered on the sensor device on the screen, the value d that satisfies $e_{view} = 125$ is 4.75 m or more.

Accordingly, when we apply existing location estimation technologies, we will be able to display the virtual object in the position with no strange or wrong feelings, as long as the distance between the tablet and the sensor device is 4.75 m or more apart. Thus, we think it possible to utilize our proposed system in a rather large living room or in commercial facilities. In the meantime, if and when the location estimation accuracy of the tablet has improved in future, we will be able to utilize our proposed system in a smaller space.

VI. SUMMARY

In this paper, we have proposed a system to visualize the wireless network by displaying AR objects based on the relative position between sensor devices and the tablet location that is detected by using the location estimation technology. With our proposed method, it is possible to visualize the wireless link to the sensor devices existing within as well as outside the range of camera and also the information of the sensor devices placed in the shade.

We also examined the permissible range of the location estimation accuracy required for out proposed system, based on the relationship between the location estimation error of the tablet and the display error of the virtual object. It was found out that when the distance between the tablet and the sensor device is as close as 1 meter, a very high location estimation accuracy of 20 cm is required. When we experimentally applied existing location estimation technologies to our proposed system, it was confirmed that as long as the distance between the tablet and the sensor device is about 4.75 meters or more apart, the existing location estimation technologies could effectively be utilized for our system.

Hereafter, we will further examine various methods to utilize our proposed system in a smaller space, by combining our system with the autonomous positioning mechanism [13].

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