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Article

Performance of UWB Wireless Telecommunication Positioning for Disaster Relief Communication Environment Securing

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Abstract: When an earthquake or a large fire has occurred, it is difficult to secure communication networks for rescue in the building due to the destruction of commercial communication networks. Although analog radio systems such as VHF (very high frequency) and UHF (ultra-high frequency) are used for rescue operation in general, communication failure occurs in closed spaces, causing difficulties in smooth rescue operations. When the communication infrastructures have been destroyed in a building in the disaster, an emergency wireless telecommunication environment should be constructed to secure a safer disaster response environment. In this study, along with comparison of the performances of diverse communication frequencies, UWB (Ultra-Wide Band) wireless telecommunication networks were evaluated under five building indoor environment conditions including open spaces. UWB communication modules were fabricated to satisfy the IEEE (The Institute of Electrical and Electronics Engineers) 802.15.4a standard performance to measure distances in which communications are possible according to the indoor environment for each of six channels with different UWB communication frequencies. The results indicated that the distances in which communications are possible for each the six channels were average 15.5 m, maximum 20 m in open spaces; average 17.33 m, maximum 20 m in corridors; average 15.3 m, maximum 20 m in indoor office environments with office fixtures; average 4.33 m, maximum 6 m in vertical spaces of stairs; and average 6.5 m, maximum 17 m in closed horizontal spaces with a fire door. In this case, the communication performance and distance performance were shown to be the most excellent at a frequency (Centre Frequency) of 6489.6 and a band of 5980.3 – 6998.9 MHz, which is UWB 7ch. In conclusion, it is judged that if UWB communication modules are installed in the disaster area at intervals of 20 m and multi-channels are used, communication environments can be constructed even in closed spaces

Keywords: Disaster Telecommunication; Rescue; UWB (Ultra-Wide Band); Enclosed Space; Wireless Telecommunication

1. Introduction

Buildings in modern society are becoming higher and bigger, and the resultant overpopulation of building users can lead to heavier casualties when a fire or disaster has occurred. In the case of South Korea, to overcome the limitations of disaster situation management using existing TRS (Trunked Radio System) voice communication networks, the construction of nationwide disaster safety communication networks utilizing the PS-LTE (Public Safety-Long Term Evolution) technology that would enable multi-services including voice, text message, and video services was planned in 2015. However, communication environments using LTE network also have shortcomings because communication services are not supported in closed indoor environments and huge amounts of projects costs are necessary for the installation of additional facilities for the construction of self-networks and maintenance, etc. in cases where independent disaster networks are constructed. It has been reported that to secure about 90% of the entire country as PS-LTE service areas in South Korea, a

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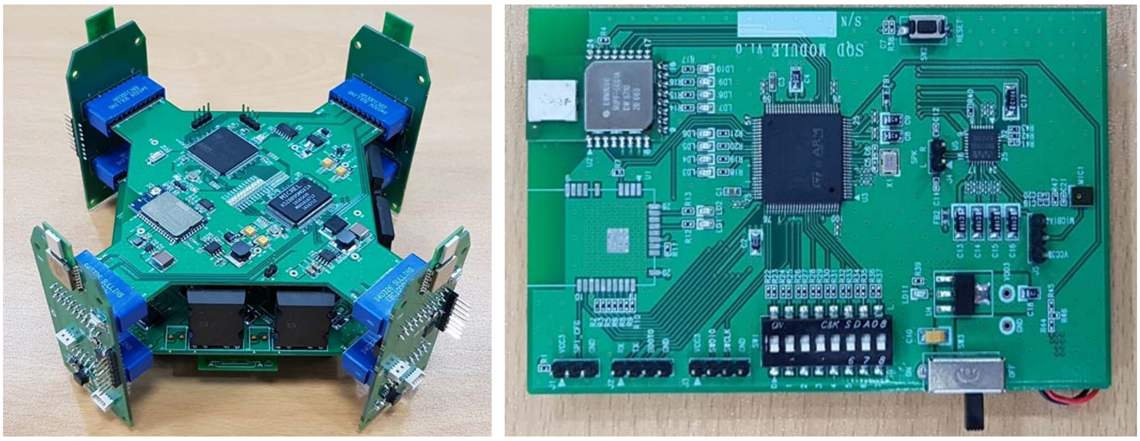
project cost budget close to 2 trillion won would be necessary along with huge amounts of budgets in future for maintenance [1]. Constructing communication infrastructures in disaster environments to enable communications even in closed spaces can be said to be essential for firefighting activities along with the safety of firefighters who perform rescue missions. Therefore, disaster prevention and safety related information communication solutions for firefighting and search and rescue of those who should be rescued in disaster and extreme situations fire scenes and collapse sites have been studied by several researchers [2,3]. Kim, Y.D. et al. conducted a basic study on Wi-Fi based communication connection methods in closed spaces and conducted an experimental study on radio waves and transmission in indoor environments and closed spaces [4–7]. In the case of communication environment construction in disaster sites, the construction of wireless emergency communication infrastructures with better convenience for use and mobility is more effective than constructing wired communication infrastructures. However, since wireless telecommunication technology propagates signals into the air because of its physical nature, communication failures such as attenuation, collision, disconnection, and radio interference may occur. In particular, communication failures can occur more frequently due to high temperature and thick smoke environments such as fire scenes, closed indoor structures, and obstacles [4]. In the case of robot utilization in Fukushima nuclear accident area, there have been cases where remote control failures occurred due to problem in connection with external communications [8]. UWB is a technology that transmits a large amount of digital data at a low power in a super-wide band and a short distance range using a transmission frequency band of several GHz or more. In the international standard IEEE 802.15.4a, UWB is a technology to transmit massive digital data in ultra wide bands and short distance sections using transmission frequency bands exceeding several GHz. The international standard IEEE 802.15.4a reports that in cases where wireless telecommunications are used at short distances not exceeding 20 m, UWB can transmit data at speeds exceeding 100 Mbps/sec. and can measure distances [9–12]. The UWB wired/wireless base station modules and wireless telecommunications modules are designed to facilitate communication between the rescue worker and the command post and to locate the rescue worker when the existing communication base has been disabled during indoor fire or collapse. In this study, the positioning performance of those UWB communication methods that have not been applied to the construction of communication networks for closed environments, among existing kinds of wireless telecommunications will be evaluated. The communication performance will be evaluated for a total of six indoor environments such as closed indoor corridors, closed indoor spaces where obstacles exist, stairs, states where the fire door and glass door have been closed, including the open-space UWB communication positioning standard measurement environment.

2. Experimental device and experimental method

2.1. Experimental equipment

For the analysis of the wireless telecommunication positioning performance in closed spaces in buildings, UWB communication modules were fabricated to satisfy the IEEE 802.15.4a standard performance as shown in Figure 1 (a) is a base station module for communication with the UWB wireless module and (b) is the UWB wireless module for communication with rescue workers. The main specifications of the UWB wireless communication modules are radiation power –10 dBm and RF Band 3.5 6.5 GHz as shown in Table 1. The frequency bands of the UWB wireless telecommunications modules are a total of six standard frequency channels as shown in Table 2 and support band widths from 499.2 MHz to 1331.2 MHz.



(a) (b)

Figure 1. This is a figure,UWB Wireless Telecommunication Module: (**a**) UWB Radio Repeater. (**b**) UWB Module.

Table 1. Main Specifics of UWB Wireless Telecommunication Module

Item	Specification
RF band	3.5 GHz to 6.5 GHz
Data rates	110 kbps, 850 kbps, 6.8 Mbps
Network	Rs-232, Spi, i2c etc
Weight	52 g
Radiation Power	-10 dBm (0.1 mW)

Table 2. Frequency bands (MHz) of the UWB wireless modules by channel

Channel	Centre Frequency	Band
1	3494.4	3244.8 - 3744.0
2	3993.6	3774.0 - 4243.2
3	4492.8	4243.2 – 4742.4
4	3993.6	3328.0 – 4659.2
5	6489.6	6240.0 – 6739.2
7	6489.6	5980.3 – 6998.9

2.2. Experimental conditions and experimental method

The developed wired / wireless base station module and UWB wireless telecommunication module are used to secure the communication lines between the rescue workers and the command post and to locate the fire workers in cases where the existing communication base has become inoperable when an indoor fire has occurs and whether the communication signal activation is valid or not should be judged. Figure 2 shows experiments for signal positioning measurement for the UWB wireless module. The outdoor open space is used as a test site for comparison and Figure 2 shows the program and operation screen for the evaluation of the positioning performance for a total of six indoor environments such as the passage, closed indoor space where obstacles exist, stairs, states where fire door and glass have been closed. The details of the structural spaces for individual experimental environments are as shown in Table 3. Figure 3 is a side view for positioning in vertical stairs. A UWB radio repeater was installed on the stair landing and UWB modules were installed on individual floors for measurement. For the positioning of the UWB wireless modules, signals were measured at every cm up to about 20 m from the wireless module repeater. The wireless modules were installed on the

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floor in the case of horizontal spaces and were installed on stair landings in the case of environments where corridors, which are horizontal-vertical spaces as with stairs, are connected to stairs, to measure communication signals with telecommunication modules. In general buildings, the partitions between corridors and indoor spaces are fire walls or simple walls, and the doors are usually glass doors and fire doors. Therefore, to test the mutual communication between the corridors and the partitioned spaces, the glass door and the fire door were closed before the communication positioning experiment was conducted. The frequencies used for UWB signal positioning in the six types of spatial environments are UWB standard frequency 6 channels (1ch, 2ch 3ch, 4ch, 5ch, 7ch) as shown in Table 2 and the band ranges by frequency were also specified. Therefore, the performance was examined by evaluating the difference between the distance information calculated between modules by frequency as shown in Table 2 and actual distance information and the distance measurement success rates.

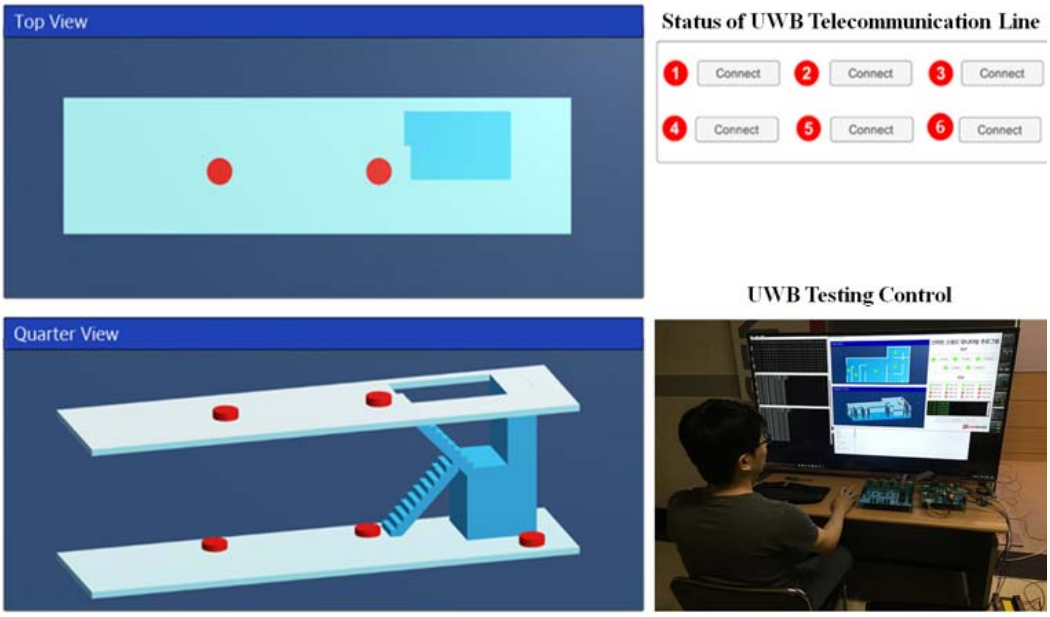

Figure 2. Setup for UWB telecommunication module and evaluation for performance evaluation

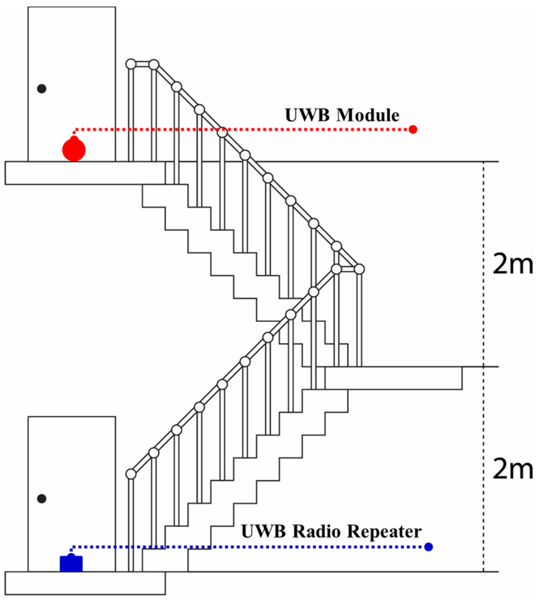

Figure 3. A Lateral View of Stairs Sector with installed UWB Module

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The performance of the UWB wireless module was evaluated by calculating the distance information by calculating the time for the wireless telecommunications module to receive the data packets transmitted from the wired / wireless base station module as the time of flight (ToF). In addition, 130-byte data packets were transmitted for distance measurement, and the distance measurement success rate was calculated by counting cases where all data were successfully received without radio wave reflection or errors occurring in data transmission/receiving. The numbers of time of attempts to transmit signals closer to 0 were judged as indicating better communication environments and performance.

Table 3. Test Environment in Each 6 sectors for UWB RF Module

	Space			
Sector	Width(m)	Length(m)	Height(m)	Obstacle
Open space	-	-	-	None
Pathway	2.5	32.0	2.4	None
Indoor room	6.2	12.5	2.4	Arranged normal OA furniture with 1.5 m height
Stairs room	2.4	5.0	20.0	Concrete stairs
Glass door	1.8	-	2.1	between pathway and office room
Fire door(steel)	1.8	*	2.1	between pathway and office room

3. Results and discussion

3.1. Open space

The positioning measurement in a horizontal open space where no obstacle is present was experimented in an open space with no obstacles to test the distance measurement performance. Since this experiment is conducted in a space with no obstruction, it becomes the reference experiment to test distance measurement and communication performance later. The distance measurement showed the accuracy in cm units. When positioning measurement was conducted in an open space with no obstacles, as shown in Figure 4, channels 2, 5, and 7 could measure distances 20 m and when they could measure distances, they succeed in measuring the distances by attempting 6 10 times. The communication and distance measurement performance was judged later based on the number of times of attempts at this time.

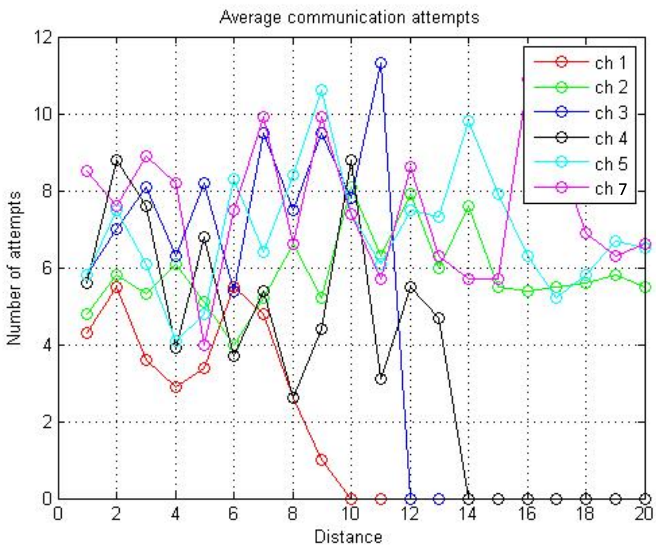

Figure 4. Result of ToF Measurement for UWB at Open Sector

3.2. Corridor

When positioning was measured in a spatial environment with no obstacles in a corridor in a closed space, as shown in Figure 5, channels 2, 5, and 7 could measure distances up to 20 m while channels 1 and 3 could measure distances, which are around 5 m longer compared to open spaces and channel 4 shoed a performance similar to that in the open space. In addition, since the numbers of times of attempts for measurement of channels 2, 5, and 7, which could measure up to 20 m, are distributed in a range of 10 to 15, it could be seen that the signal performance in the communication environment was relatively lower than that in the open space.

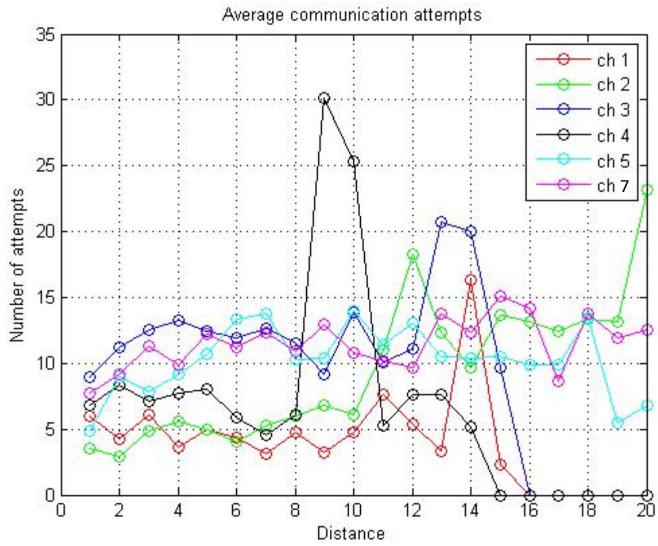

Figure 5. Result of ToF Measurement for UWB at Corridor Sector in Enclosed Indoor

3.3. Office

When positioning was measured in an indoor office environment where various furniture and fixtures existed in a closed space, as shown in Figure 6, channels 5 and 7 showed similar measurement performance as that in open spaces while channels 1, 2 and 3 showed generally lower measurement performance.

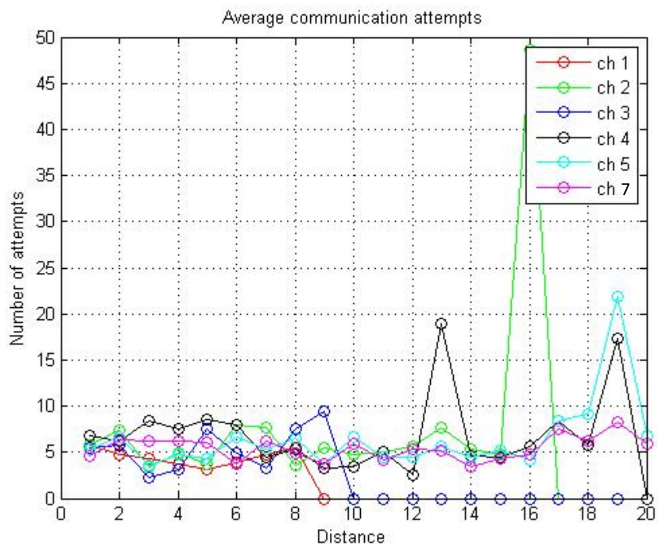

Figure 6. Result of ToF Measurement for UWB at Office Sector in Enclosed Indoor

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However, channel 4 showed improved measurement performance on the contrary. Channel 4 had a band width of about 1 GHz and showed higher distance measurement communication success rates by avoiding obstacles when the band width was large. In addition, we found that the number of attempts increased instantaneously when the measurable distance decreased. This was identified to be attributable to the fact that more errors occurred when distance measurement became impossible.

3.4. Vertical stairs

Positioning was measured in a vertical stairs space which is used as evacuation stairs in the closed space. As shown in Figure 3, the height between stair landings for going down one floor made by simulating the experiment environment was 2 m and UWB modules were installed on the stairs landings for measurement. In the results of the positioning measurement, only the channel 7 measured the largest vertical height downward reaching 4.5 m as shown in Table 4, and other channels could measure up to a height of 4m.

Table 4. Distance and Number for UWB Contacting between UWB Radio Repeater and Module

(a) Distance of TOF Measurement						
Test No.	1ch	2ch	3ch	4ch	5ch	7ch
1	205	193	164	197	165	203
2	482	468	429	450	431	433
3	0	0	0	0	0	448
4	0	0	0	0	0	0
(b) Trying Number for Contacting between UWB Radio Repeater and Module						
Test No.	1ch	2ch	3ch	4ch	5ch	7ch
2	6.4	11.2	5.2	7.1	10.9	7.1
4	4.2	9.7	37.4	5.6	12.6	9.0
6	0	0	0	0	0	8.7
8	0	0	0	0	0	0

3.5. Glass door and fire door

Positioning was measured in environments where office spaces separated by corridors and reinforced concrete wall structures, glass doors, or fire doors were installed in closed spaces. When the experiments were conducted in spaces divided by 8 mm thick tempered glass doors and 1.5 mm steel plate class A fire doors, respectively, as shown in Figure 7 and Figure 8, channels 1 to 5 could not measure distances exceeding 5 m at the maximum in both the glass door and fire door environments while channel 7 could measure distances up to 17 m in the glass door environment and up to 10 m in the fire door environment. However, the differences between the actual distance information and the measured distances were at least 2 m. This can be considered attributable to the fact that the glass door and the fire wall acted as obstacles leading to the multipath phenomenon of UWB radio waves so that the radio waves were transmitted/received after going around longer distances than the actual distance.

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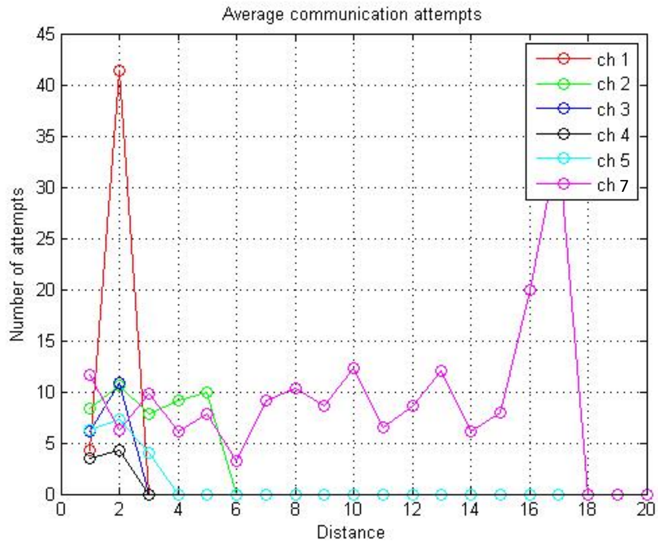

Figure 7. Result of ToF Measurement for UWB at Office and Pathway Sector with Closed Glass Door

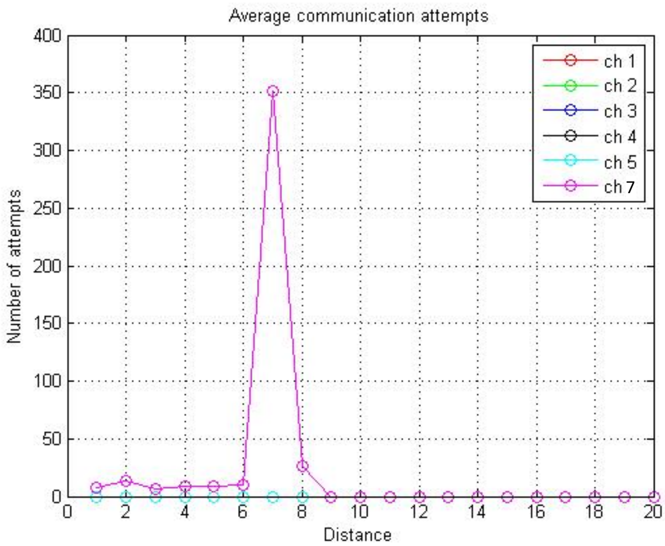

Figure 8. Result of ToF Measurement for UWB at Office and Pathway Sector with Closed Fire Door

In the results of experiments in the above six environments, as shown in Figure 9, the communication performance and distance measurement performance of channel 7 with frequency 6489.6 MHz and band width 1081.6 MHz were shown to be the best in general, and it was identified that the number of attempts for communication increased when obstacles existed in the same closed space leading to poorer communication performance and shorter measurable distances. Also, it could be seen that the communication reachable distance was remarkably shorter in emergency stairs, which is one of the main evacuation routes, compared to other environments. In this study, the wired / wireless base station modules were arranged at a intervals of about 20 meters for measurement of communication with the wireless telecommunication module and distances and the errors between actual distances and the distances information obtained using ToF were found to be about 50 cm. It is considered that the distance errors can be reduced by accumulating indoor environment measurement analysis experimental data to used analyzed correction values.

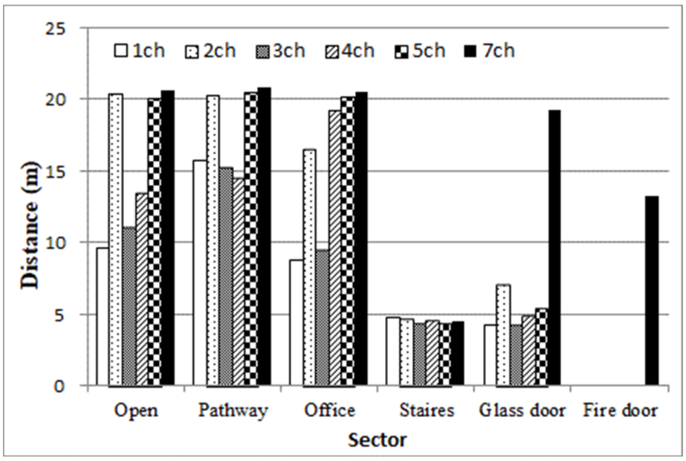

Figure 9. Result of Telecommunication Distance for UWB in each 6 Sectors

4. Conclusion

When a fire or disaster has occurred, casualties can be minimized only in cases where firefighters and rescue and emergency workers immediately respond and conduct activities. However, in cases where the communication infrastructures have been destroyed, communication connections using TRS (Trunked Radio System, frequency common communication) and LTE (Long Term Evolution) communication networks are impossible in closed spaces. The absence of rescue workers' communication connection can lead to increases in casualties due to errors and delays in responding activities and can bring about risks to rescue workers' safety. Through this study, the following conclusions on UWB communication module performance evaluation were drawn.

- A performance evaluation method was presented for the UWB communication module developed to construct closed indoor communication environments using UWB wireless telecommunication networks, which transmit massive digital data with low power in short distance sections.
- Experiments in 6 spatial environments showed that the communication performance and distance measurement performance of channel 7 with frequency 6489.6 MHz and bandwidth 1081.6 MHz are the best.
- It was shown that the installation spaces for the UWB communication module could be 20 m as communication and distance measurement are possible in 20 m and that communication environments can be constructed in closed spaces in cases where multi-channels are used.
- In particular, the communication distance at stairs was measured to be about 5 m indicating that the communication module should be installed at intervals of two story building height for smooth communication at vertical stairs.

Hereafter, we will conduct experiments in the heat and smoke situations in the indoor fire situation to investigate the possibility of using the UWB communication network.

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