Communication performance of IC tag embedded into concrete for the purpose of information traceability

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ABSTRACT: It is important to develop an information traceability system on the process of concrete production. One method is to record an identification number or the information about the concrete production with wireless IC tag, and to put it into the concrete that has not yet hardened. This method has a characteristic to keep the information inside the concrete itself. On the other hand, this method requires communication performance between IC tag inside the concrete and the IC reader/writer (R/W) outside the concrete.

This paper describes a study on the communication performance of IC tag embedded into the concrete. Eight types of IC tags were embedded into the concrete test specimens at depths from 50 to 300 mm. The communication capability between IC tag inside the concrete and R/W outside the concrete was examined.

1 INTRODUCTION

In the case of industrial products in general, there is a growing demand for assurance of traceability in concrete production/works processes. Concrete is to be shipped from ready-mixed concrete plants to construction sites in the form of pre-hardened half-finished materials. Proper strength and durability can be verified only after its hardening. If concrete properties are found insufficient after hardening, a great deal of cost and labor is required to make necessary repairs. Considering this cost and labor, it can be said that concrete is a construction material that requires a traceability assurance system that is more meticulous than those for other industrial products.

The two important points for assuring traceability are (1) recording and archiving a log of the concrete production process and (2) attaching an identification (ID) number to link the log to the specific product. In general, the ID number is printed on the product or on a seal or plate that is attached to the product. Since concrete is delivered to its user before it is hardened, it is not practical or feasible to print the ID number on the concrete or attach a plate to it. Therefore, we focused our attention on an integrated circuit (IC) tag that could read and write data wirelessly. We are developing a technology to assure traceability of concrete by making use of the IC tag, in which a variety of information regarding concrete production/works is recorded and maintained as shown in Figure 1 (Sugiyama et al. (2010)). Note that in this approach for traceability assurance, it is assumed that the R/W device outside the concrete can read the information in the IC tag embedded inside the concrete.

To verify this assumption, we have investigated whether the R/W device outside the concrete can communicate with IC tags embedded into the concrete test specimens at depths of 50–300 mm.

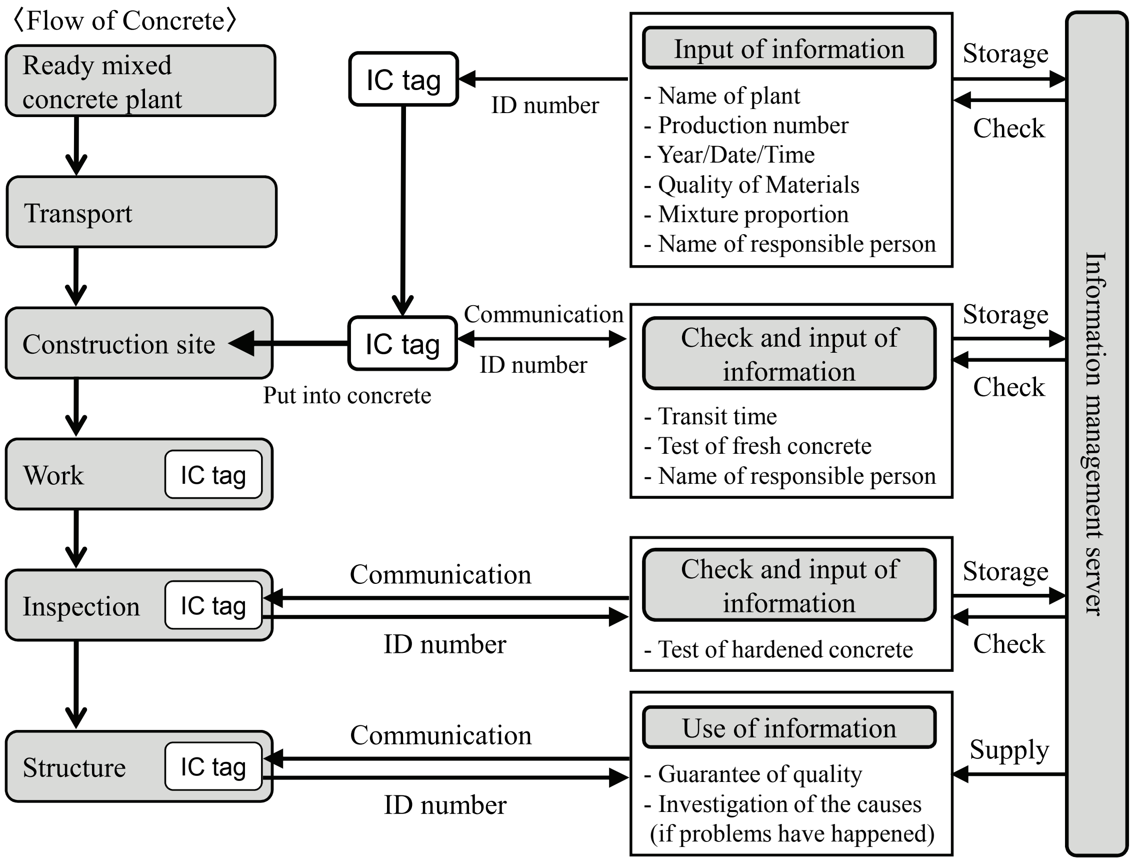


Figure 1. Example of the information traceability system in concrete production/works processes.

2 IDENTIFICATION OF CONCRETE WITH IC TAG

The IC tag is a sort of tag with a writable IC chip and tiny antenna embedded. As shown in Figure 2, when the IC tag receives radio waves from the IC reader/writer (R/W), which is a wireless communication device dedicated to the IC tag, the IC tag generates electric power and returns its ID number. The information corresponding to the ID number can be obtained by sending the number to the information management server that stores such information. It is expected that an IC tag embedded in pre-hardened concrete can be an identification marker indicating that it is secure in the concrete after the hardening, allowing for its indefinite use as the ID number. Note that in this approach for traceability assurance, it is assumed that the R/W device outside the concrete can read the information in the IC tag embedded inside the concrete.

3 EXPERIMENTAL METHODS

3.1 IC tags and R/W

Eight types of IC tags, shown in Table 1, were used in the experiment. Frequencies used in the communication between the IC tag and R/W are in the HF and UHF bands. The HF-band R/W and UHF-band R/W are shown in Table 2.

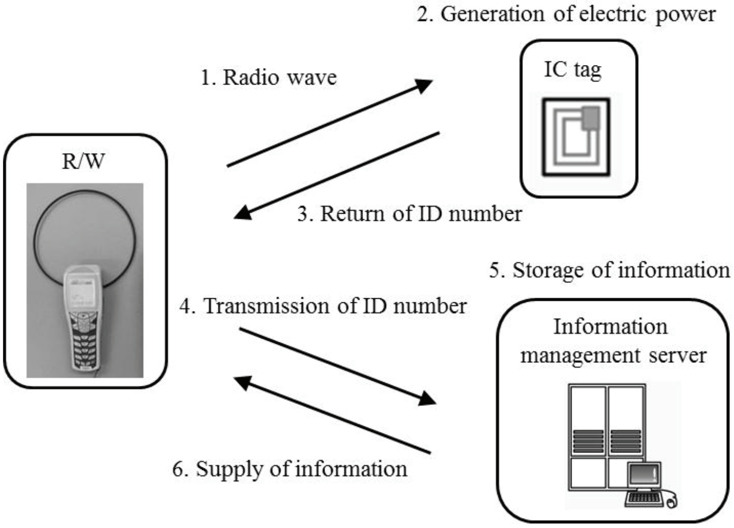


Figure 2. Communication between IC tag and the R/W (the IC reader/writer).

Table 1. IC tags used in the experiment

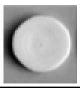
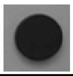
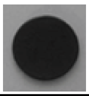
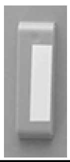
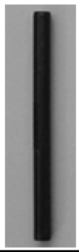
Frequency	HF band (13.56MHz)			UHF band (953MHz)				
Symbol	H1	H2	H3	U1	U2	U3	U4	U5
Photo								
Shape	Coin	Coin	Bullet	Coin	Key ring	Plate	Plate	Stick
Material of case	PBT resin	ABS resin	ABS resin	ABS resin	PPS resin	ABS resin	ABS resin	ABS resin
Size (mm)	ϕ25×3	ϕ21.5×3	ϕ8×22	ϕ30×3	39×35×6.5 (L×W×H)	55×16×7.5 (L×W×H)	102×21×5.7 (L×W×H)	ϕ8×108
Mass (g)	1.9	1.3	1.7	2.5	6.9	5.3	9.8	5.0
Density (g/cm^3)	1.3	1.2	1.5	1.2	1.6	0.8	0.8	0.9
Max. communication range in the air (mm)	170	133	118	1850	1600	2020	5460	4730

Table 2. HF-band R/W and UHF-band R/W

Frequency	HF band (13.56MHz)	UHF band (953MHz)
Photo		
Type	Handheld	Handheld
Size (mm) * Antenna not included	162×58×40 (L×W×D)	200×86×47 (L×W×D)
Mass (g)	217	630
Power (mW)	180	1000

3.2 Concrete test specimens

Concrete with the water cement ratio of 57.0% was used to make the test specimens. As shown in Figure 3, 4, 5, 6 and 7, the concrete test specimens consist of four types: two slab test specimens (concrete slab specimen-1 and specimen-2) simulating floor slab member, and two column test specimens (concrete column specimen-1 and specimen-2) simulating column member.

If an IC tag is put into concrete that has not yet hardened, the IC tag may move anywhere as the concrete flows, making the final location of the tag uncertain. To meet the objective of this study and to investigate the relationship between the depth of IC tags in concrete and the communication between tags and R/W (if the R/W device can communicate with tags), the IC tag was embedded at a planned location in the concrete test specimen. Each type of IC tag was located 50 mm deep into the concrete from the top face of the concrete slab specimen-1 and 100 mm deep from the top face of the concrete slab specimen-2. It was located 150 mm and 200 mm away from the side face of the concrete column specimen-1, and 250 mm and 300 mm away from the side face of the concrete column specimen-2. The IC tags were oriented such that the inside antenna could be perpendicular to the radio waves from the R/W device.

3.3 Measurement of communication range

Two ranges are defined and used as parameters in investigating the communication capability between IC tag inside the concrete and R/W outside the concrete as shown in Figure 8. One is the range from the surface of the concrete to the R/W device and the other is the range from IC tag to the R/W device. The former range is termed as the IC tag detection range and the latter range is termed as the IC tag communication range. When we consider buildings and structures in the real world, the IC tag detection range is important, and the longer this range is, the easier it will be to detect the tag anywhere in the concrete, making it possible to read the information in the tag.

The range of the R/W device from the surface of the concrete test specimen is increased by a step of 5 mm while checking whether the ID number of the IC tag can be read with the R/W device, and the maximum range at which the number can be read is obtained. This measurement is repeated three times, and the average of the measurements is defined as the maximum detection range. The maximum communication range is obtained by adding the depth of IC tag to the maximum detection range. Furthermore, the maximum communication range in the air was measured.

Figure 3. Concrete test specimens (concrete slab specimen and concrete column specimen).

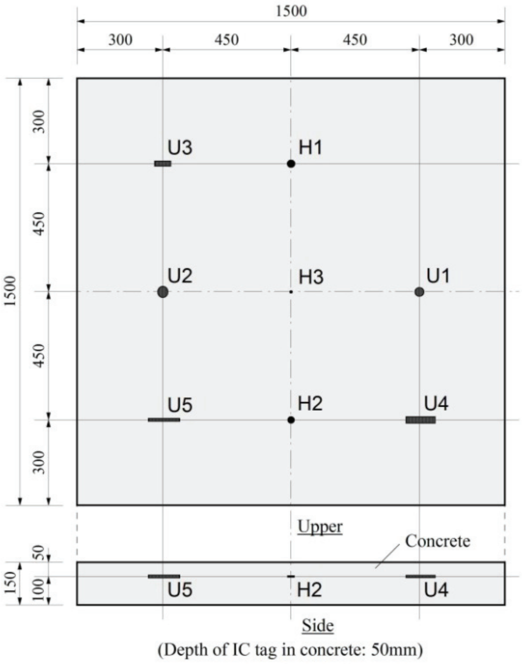


Figure 4. Detail of concrete slab specimen-1.

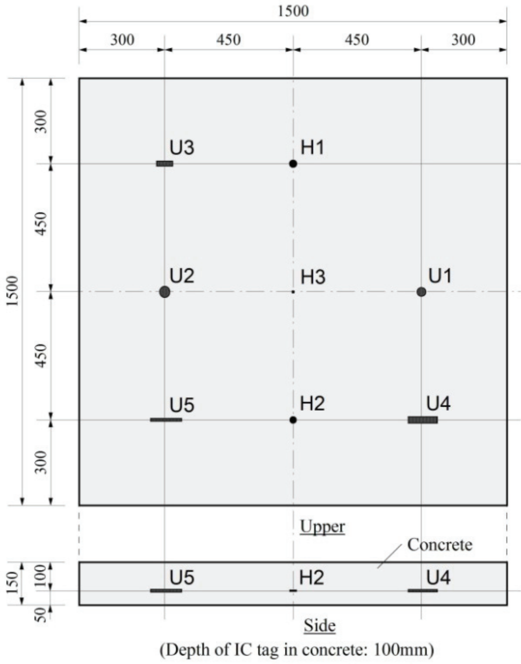


Figure 5. Detail of concrete slab specimen-2.

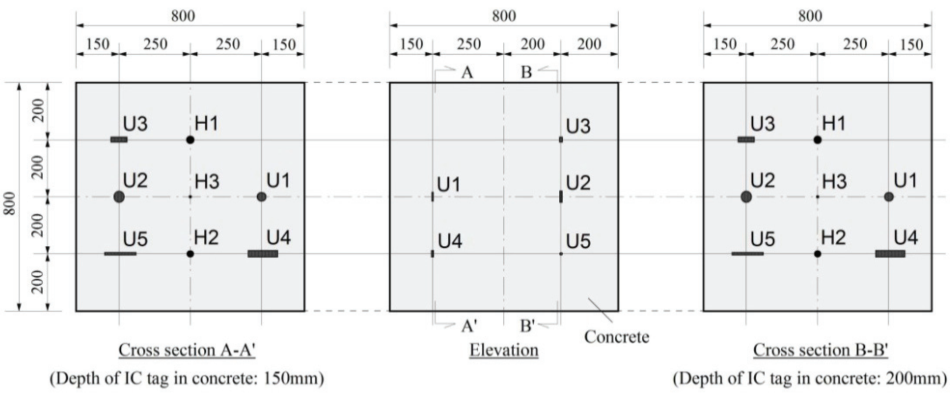


Figure 6. Detail of concrete column specimen-1.

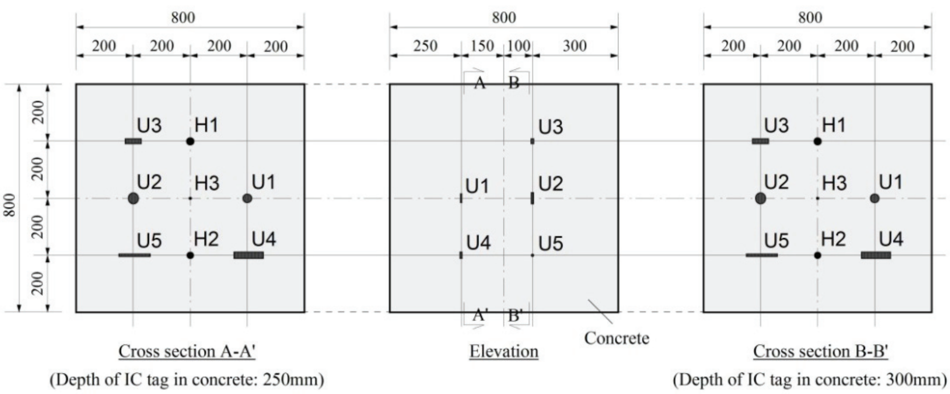


Figure 7. Detail of concrete column specimen-2.

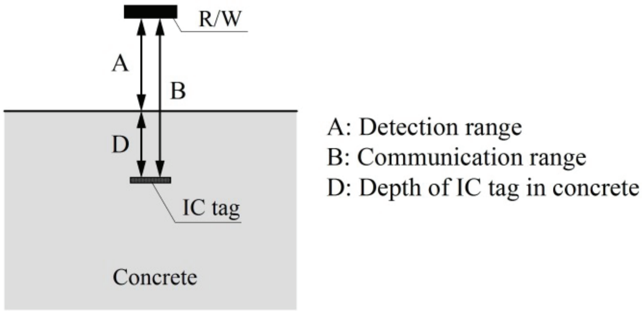


Figure 8. Relation between the detection range and communication range.

4 RESULTS AND DISCUSSIONS

4.1 Communication range of IC tag in the air

The maximum communication ranges of IC tags in the air are shown in Table 1. The maximum communication range with the HF-band IC tag was 170mm or less. On the other hand, that with the UHF-band IC tag exceeded 1600mm. In the radio communication in air, the maximum communication range with the UHF-band IC tag is longer than that with the HF-band IC tag.

4.2 Detection range of IC tag embedded in concrete

Figure 9, 10, 11, 12, 13, 14, 15 and 16 show the maximum detection ranges of IC tags embedded in the concrete test specimens. In the measurements of the communication capability in concrete, H2 tag, H3 tag, U1 tag and U2 tag could communicate with the R/W device at depths of up to 100 mm or less. H1 tag and U3 tag could communicate with the R/W device at depths of up to 150 mm. At the age of 500 days, U4 tag and U5 tag, which are the UHF-band IC tags with a large-size antenna, could communicate with the R/W device at depths of up to 250 mm. No IC tag was able to communicate with the R/W device at depth of 300 mm.

The maximum detection range tends to become shorter when the IC tag is embedded deeper in concrete. At the same depth, the maximum detection range with the UHF-band IC tag with a large-size antenna (e.g., U4 tag, U5 tag) is longer than that with the HF-band IC tag. However, U4 tag and U5 tag are too large from the objective of this study that an IC tag is put into concrete that has not yet hardened.

4.3 Communication range of IC tag embedded in concrete

Figure 17, 18, 19, 20, 21, 22, 23 and 24 show the maximum communication ranges of IC tags embedded in the concrete test specimens. The maximum communication ranges with the HF-band IC tags have no remarkable difference according to the depth in concrete. Therefore, communication with the HF-band IC tag is not adversely affected when the tag is embedded deeper in concrete, showing the range as long as the maximum communication range in the air. On the other hand, communication with the UHF-band IC tag is affected such that the maximum communication range tends to become shorter when the tag is embedded deeper in concrete. That is, concrete between the IC tag and R/W has a significant adverse impact on communication capability.

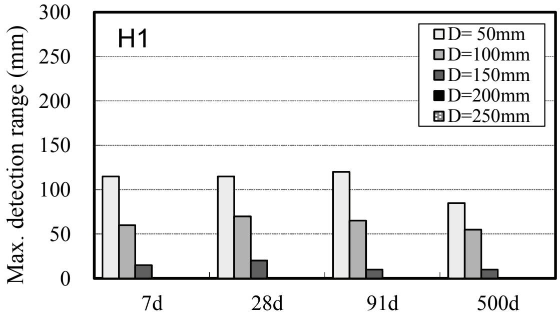


Figure 9. Maximum detection range of H1 tag.

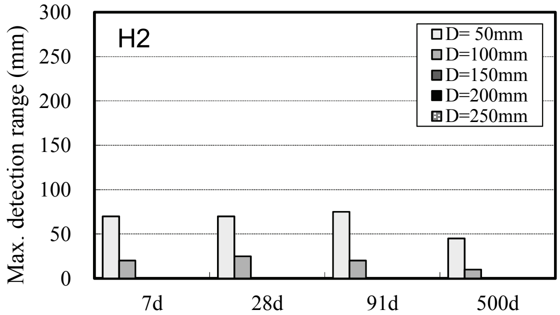


Figure 10. Maximum detection range of H2 tag.

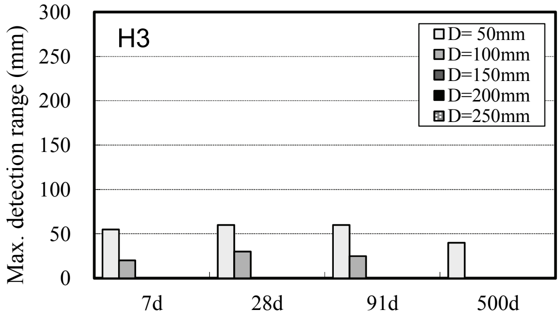


Figure 11. Maximum detection range of H3 tag.

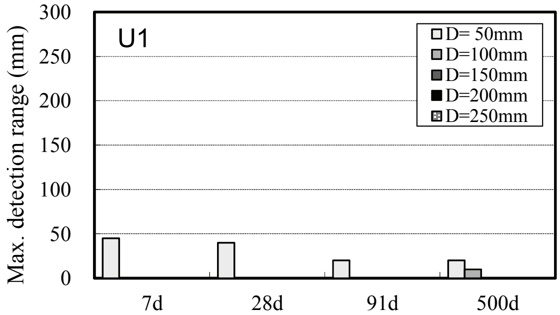


Figure 12. Maximum detection range of U1 tag.

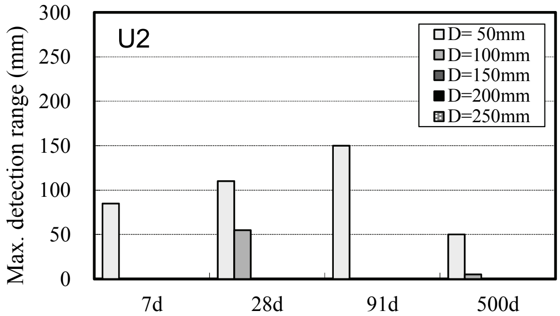


Figure 13. Maximum detection range of U2 tag.

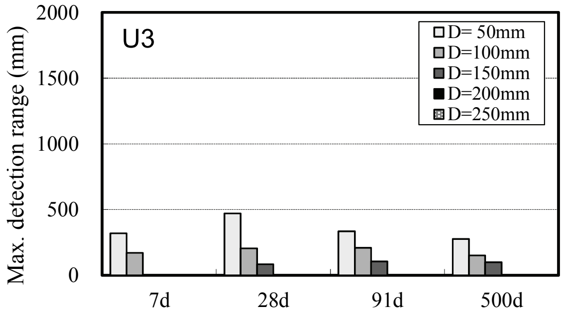


Figure 14. Maximum detection range of U3 tag.

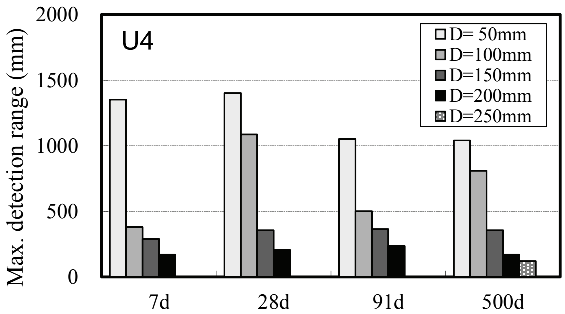


Figure 15. Maximum detection range of U4 tag.

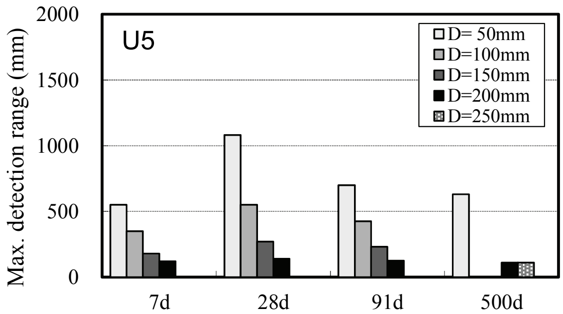


Figure 16. Maximum detection range of U5 tag.

5 CONCLUSIONS

1) IC tag embedded into the concrete could communicate with the IC reader/writer (R/W) outside the concrete.

2) The HF-band IC tag could communicate with the R/W at depths of up to 150 mm. Some of the UHF-band IC tags could communicate with the R/W at depths of up to 250 mm.

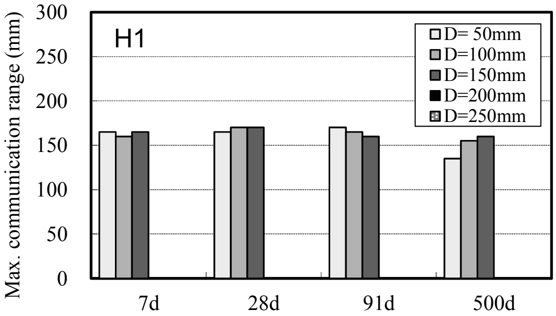


Figure 17. Maximum communication range of H1 tag.

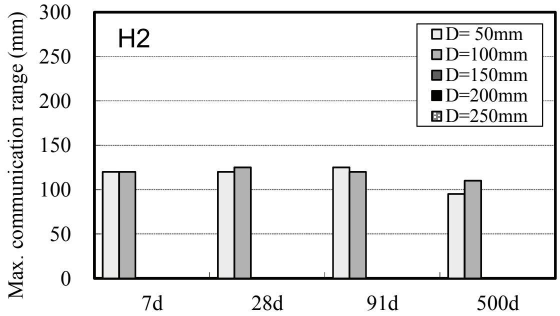


Figure 18. Maximum communication range of H2 tag.

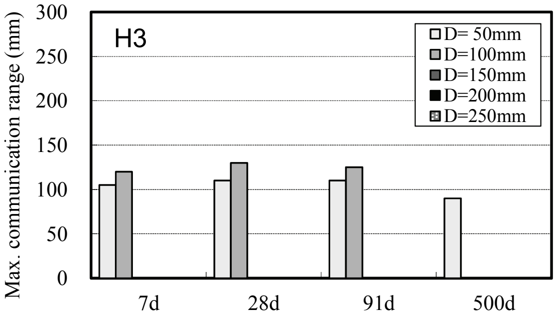


Figure 19. Maximum communication range of H3 tag.

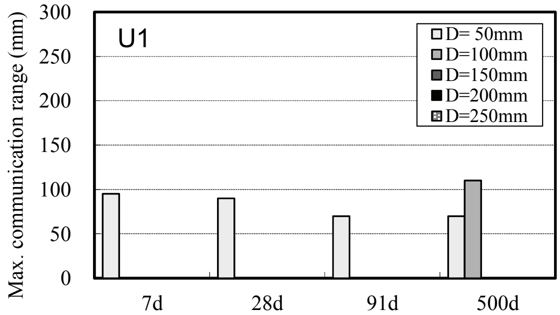


Figure 20. Maximum communication range of U1 tag.

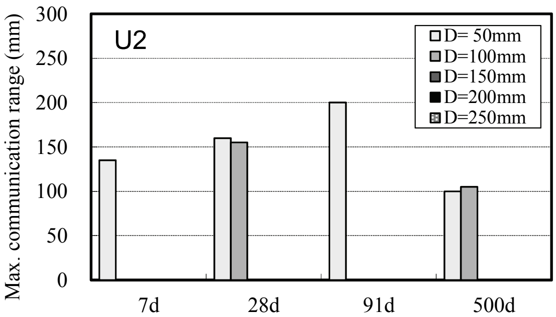


Figure 21. Maximum communication range of U2 tag.

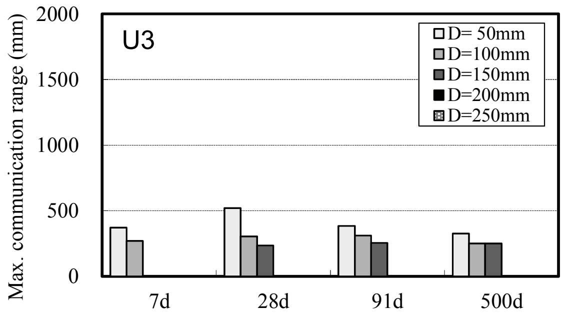


Figure 22. Maximum communication range of U3 tag.

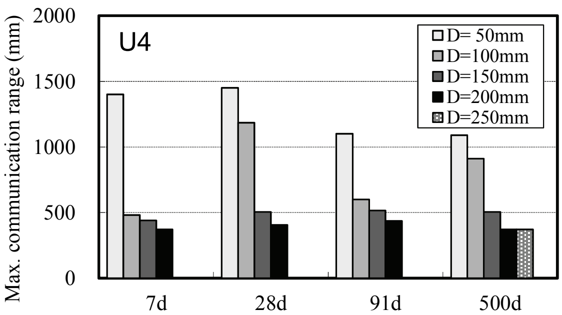


Figure 23. Maximum communication range of U4 tag.

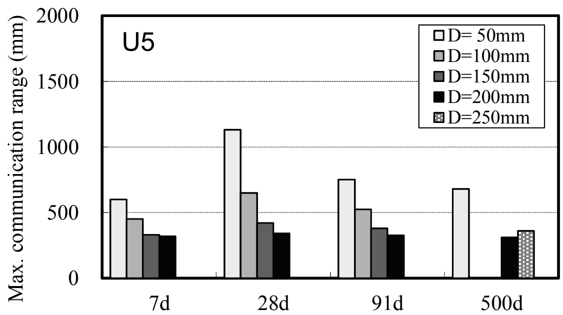


Figure 24. Maximum communication range of U5 tag.

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