Experiments for utilizing GNSS in a shore area Sensor Network

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Abstract

Modernized GNSS such as new GPS signals updated GLONASS and coming Galileo promises higher quality and higher reliability for users. Powerful technologies such as Internet, ubiquitous network technology and sensor network has been used to promote a safe and more secure lifestyle. This report describes experimental trials to combine these technologies namely GPS and Sensor Network into a high-performance system. GPS is used to enlarge the communication range, resolving the service area limitations, as a wider service area is required at shore areas compared to urban area. GPS position datum is also used as primary network routing information to get practical Sensor Network. Another application is the under water Sensor Network. Accurate GPS position and time are used to establish stable and high reliability underwater acoustic Sensor Network. This paper describes the background of the project "Harbor area Marine Ubiquitous Sensor Network", preliminary consideration and testing. Radio and acoustic communication is the main focus of this preliminary experiment.

Keywords: Marine Sensor Network; Underwater Communication; Buoy Attitude; Harbor Area, PPS;

1. Introduction

In-car GPS navigation and GPS mobile phone spread rapidly in Japan. When we use modernized GNSS to more positively, communication or a network is necessary. On the other hand, ubiquitous society progresses with development such as a computer, broadband Internet, and a wireless network. We planned a research project of "Marine ubiquitous sensor network especially at harbor and shore area" which put "contribution to industrial activation of harbor area" that utilized GNSS based on these backgrounds in mind.

In 2005, investigation of user demands was carried out in order to make use of a sensor network for container circulation or marine products traceability. As a result, most applications could be settled using ubiquitous sensor net technology on land.

Then the following basic problems were studied for advancement of harbor area sensor network.

a. Node density of a sensor network is not very high, but distance between nodes is long
b. In many cases battery exchange is difficult.
c. Many applications are in open sky areas, which is suitable for utilizing GNSS to provide accurate location and timing.
d. If an underwater sensor network can be established, an applied range becomes wider.

This paper includes the project background, wireless communication over/under sea surface, and preliminary evaluation experiment. Experimental trials described here are basic and fundamental for feasibility study during the just beginning stage. As one of the purposes of this project is to utilize the modernized GNSS infrastructure by using advanced receiver technology, precise GPS position and timing are used to improve communication performance. Highly accurate GPS time is used to extend radio communication distance, and also to gain higher performance for underwater acoustic communication. Study of sensors or sensor fusion is not reported in this paper.

2. Ubiquitous sensor network

2.1 U-Japan

In 2000, the Ministry of Internal Affairs and Communications (MIC) of Japan launched e-Japan policy as IT strategy, expanding the infrastructure for broadband Internet. MIC started ubiquitous policy u-Japan in 2005 successively in order to promote practical use of the IT infrastructure. Mainly led by U.S.A. in 1900's, research and development of a sensor network was done for military purposes. However, from 2000, it attracted attention as a base technology to realize an ubiquitous society[1]. MIC announced "An investigation study final report about ubiquitous sensor network technology" in July 2004, and as a result, there are many working forums, societies and projects for ubiquitous sensor network research in Japan now. Many international symposium and workshops of related theme are held. For example, these are INSS (International Workshop on Networked Sensing Systems), SenSys[2], and KJUS 2005(Korea-Japan Joint Symposium on Ubiquitous IT System)[3,4].

2.2 Wireless network and GNSS

Standard Sensor networks have following features in general: (1) Network with a large number of sensors, (2) Composed of sensors, RF transceiver and battery, (3) Real world oriented services based on location-awareness and context-awareness[5]. Consequently, standards are essential for low-cost and high quality. The international standardization for sensor network has been developing rapidly. IEEE's (Institute of Electrical and Electronics Engineers, Inc.) wireless network classification based on ISO (International Standards Organization) standards is shown in table 1.

Recent wireless network standards use dedicated technology to get network speed and quality. There are OFDM (Orthogonal Frequency Division Multiplex) and MIMO (Multiple Input/Multiple Output), for example.

Table 1. IEEE standard of Wireless network

Wireless network classification by communication distance

Name	Distance	Organization for Std.	Note
Short distance (not only for network)	(Very near)	Individual for the purpose	RFID, DSRC(ITS),NFC Extremely weak power
PAN (Personal Area Network)	Approx. 10m	IEEE 802.15	Bluetooth SIG (IEEE 802.15.1) UWB (IEEE 802.15.3a) ZigBee Alliance (IEEE 802.15.4) Sensor Net UWB (IEEE 802.15.3a)
LAN (Local Area Network)	Approx. 100m	IEEE 802.11 (Wi-Fi Alliance)	IEEE 802.11b (11Mbps) IEEE 802.11a/g (54Mbps) IEEE 802.11n (next generation)
MAN (Metropolitan Area Network)	2~10km	IEEE 802.16 (WiMAX Forum)	IEEE 802.16(135Mbps) IEEE 802.16-2004(approx.37Mbps) IEEE 802.16e (approx.75Mbps)
WAN (Wide Area Network)	10km~	3GPP 3GGP2	3G: W-CDMA, 3.5G: HSDPA CDMA2000 EV-DO, EV-DO Rev.A

These types of complicated functionability are normally implemented on the silicon chip SoC (System On Chip), to increase cost competitiveness. As these chip's R&D cost is more increased, these SoC LSI must be mass-produced by large semiconductor manufacturers. In another words, global standardization is essential.

A wireless network standard devised for sensor network use, IEEE 802.15.4 (ZigBee, low speed UWB) has capability of ad hoc networking which is able to constitute network topology called as "star", "tree" and "mesh". This network is suitable for small, low price, low consumption electricity. High-speed communication is not always required. According to the target specification of Zigbee, communication maximum speed is 250Kbps, and range is 30-70m, and battery life is assumed over 1 year. The cost of ZigBee chip is expected to become less than one dollar in future.

GNSS can provide accurate position and time. Even in-door GPS positioning became possible by high sensitivity GPS receivers[7], and modernized GPS will provide more quick and accurate RTK solutions[8]. Commercial GPS has potential capability to provide relative time accuracy better than 10-20ns[6]. However, a GPS receiver requires more power consumption than a normal sensor node, and the cost is relatively high. Recently, with the aid of recent semiconductor technology and receiver technology progressing, GPS receiver power consumption lowered, and TTFF shortened as well. For example, recent GPS receivers can have a warm-start TTFF of fewer than 6 seconds and power consumption is 120mA/3V using the latest Ni-MH pack of 2400mAh, possible fix times would be 600 times. If position is obtained 6 times per day, 100 days would be available. This value is practical for some applications. Short TTFF requires network aids in this case. In the other hand, a sensor network requires the sensor node position and time. It is intended to make use of the ability of GNSS while respecting wireless sensor network standards, and aim for a study of a practical sensor network in harbor areas. The object of study now is a stage of basic research for performance enhancement of radio means rather than a study of a network itself.

3. Harbor area marine ubiquitous sensor network (HAMSN)

At the beginning of this project, it was examined how effective ubiquitous computing application could be realized in a harbor area by utilizing recent GNSS. A figure of the concept at that time is shown at Fig.1. Sensor network technology consists of many technological elements such as wireless network, routing, localization, sensor fusion, power-saving, etc. In the harbor area, the issue was simplified. The solution is as follows.

- Network area must be relatively wide in spite of fewer node numbers
- Power-saving requirement is sometimes critical, but may be resolved by the help of solar batteries.
- Localizing issue is solved by using modernized GNSS in many cases even as ad hoc network.
- Many applications are expected if an underwater sensor network realized.
- The following GNSS technologies were thought in particular to be effective for problem solving.
- Measured GPS time is very accurate, 50ns or better level accuracy is practical by even commercial receiver.

HAMSN studies the possibility of a suitable wireless network assisted by GNSS and also studies the possibility of a network under water by acoustic communication. This paper describes the entrance of these studies.

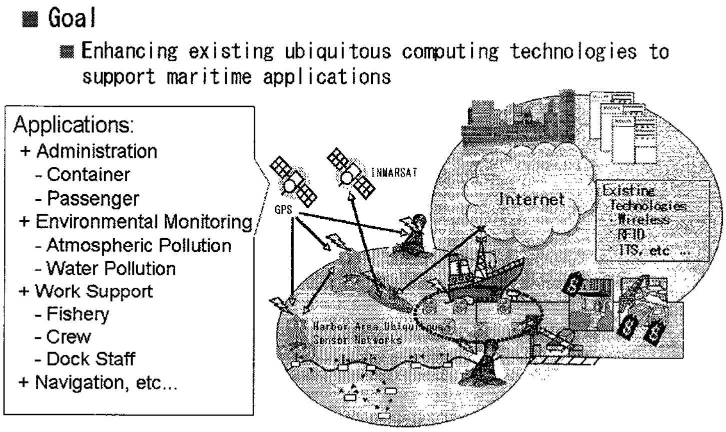

Figure 1. Basic concept of HAMSN

3.1 Extremely weak power Radio

We have been studying extremely weak power radio which is defined as radio power lower than electric field 500μV/m at 3 m by Japanese radio regulations. The distance is usually around dozens of meters from several meters. When a practical sensor network is realized in a harbor area, the freely usable communication line is helpful for control sequence establishment and for emergency use. It is also useful for conventional remote sensing. It was already studied about getting long distance by the help of GPS 1PPS signal at base band[9], but future study is needed to get longer distance capability. Our target is "1km by using extremely weak power radio".

Table 2. Specification for Evaluation

Carrier Frequency	10MHz
Transmitting Power	-43.5dBm
Modulation	BPSK
Data Rate	10k,1k,100bps
Band width	20kHz
Rx. Antenna Gain	-18.1dB
Receiver Gain	20dB
Noise Figure	5dB

The aim is great S/N improvement by keeping completely coherency between transmitter and receiver. Transmitting carrier is simply made from a GPS receiver 10 MHz clock which includes 10-20ns relative error between them[6], for frequency and phase are easily detected by coherency at receiver. Evaluation system specifications are shown in Table 2. Some analysis about propagation was studied as follows.

The carrier is 10 MHz and the parameter baseband signal is 10 k, 1 k, and 100 bps. The bandwidth is 20 kHz assuming that a crystal filter is used. Free space propagation loss L_f is given by

$$L_F = 20\log\frac{4\pi d}{\lambda} \qquad (1)$$

with wavelength λ and distance d. Reflection loss L_R is given at the height h_t and h_r of the transmitting antenna and the reception antenna.

$$L_R = 20\log\left|2\sin\left(\frac{2\pi h_t h_r}{\lambda d}\right)\right| \qquad (2)$$

Therefore, propagation loss L is given as follows:

$$L = L_F + L_R \qquad (3)$$

When using the dipole antenna of length $\lambda/32$ was grounded, both antenna height is 1 m. Also, antenna gain G_a is about -18 dB of both the transmitting, and reception together. The P_{in}, which is received by the receiver, is given by G_a and L;

$$P_{in} = P_t - L + G_a \qquad (4)$$

where P_t is the transmitting power. On the other hand, receiver noise electric power P_n is given by

$$Pn = 10\log(kTB) \qquad (5)$$

where k is Boltzmann coefficient, T is absolute temperature (= 290K) and the B is the band width of the filter (=20kHz). CNR is given as follows:

$$CNR = P_{in} - P_n - N_f + G_r \qquad (6)$$

Gr is receiver gain and N_f is noise figure on the receiver. As the result, E_b/N_o is given by

$$E_b / N_o = CNR + 10\log(R_c / R_d) \qquad (7)$$

where R_c is 10 MHz and R_d is the speed of the baseband.

When distance is 1km, speed is 100 bps, Mod is BPSK

$$E_b / N_o = 15.6dB = 36.6$$

At non-coherent case, substituting it into the next formula, as γ =E_b/N_0, if ς (direct/reflection power ratio) = 1

$$BER = \frac{1}{2}\frac{1}{1+\frac{\gamma}{1+\varsigma}}\exp\left(-\frac{1}{1+\frac{1+\varsigma}{\gamma}}\varsigma\right)$$

$$\cong 1\times10^{-2}$$

At coherent case, approx. 3 db is added to E_b/N_0.
E_b/N_0 become to 19 dB =79.6
BER = 4.6 x 10 $^{-3}$

A merit of coherent carrier communication is the point that improvement of carrier acquisition ability will be expected as well as this in fact.

3.2 Wireless network

This paper reports preliminary evaluation tests of IEEE 802.15.11b (WiFi) and IEEE 802.15.14 (ZigBee) at the harbor area. IEEE 802.15.14 device, which has capability of asynchronous two-way communication, was also tested in this experiment. The communication speed versus distance was evaluated. The result showed maximum communication distance was 50-60 m, almost same as on land.

WiFi Communication distance on the sea surface was evaluated by using active Tag (T2 tag: www.aeroscout.co.jp) which transmit WiFi compatible signals. It has normal passive RFID function for many applications at sub-meter distance (Figure 2, 3). The active tag (RFID) is also useful in sensor networks[4].

Configuration of the trial is as follows (Figure 4).

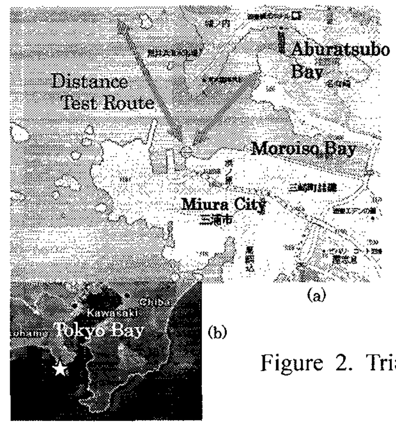

Figure 2. Trial area

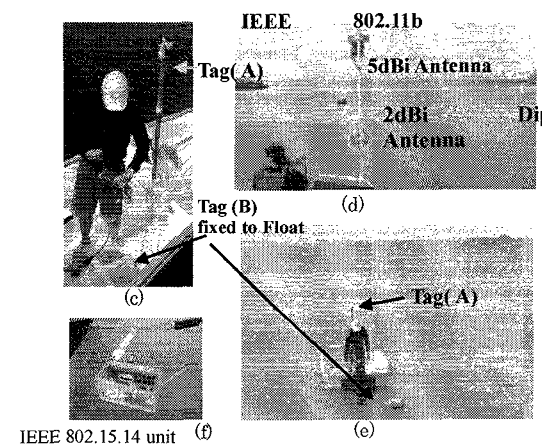

Figure 3. Evaluation trial at small bay area

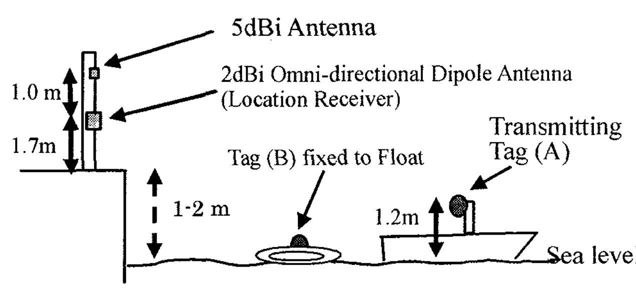

Figure 4. Evaluation trial at small bay area

In the catalog specifications, T2 tag service distance is 200 m (outdoor), and the output power is set to 19mW.

The trial at sea indicated longer distance than specified (Table3)

According to these results, the WiFi device has long distance communication capability at sea, and it is very usable for relatively wide area networks. Communication distance close to the surface of the sea has to be examined more to study the Fresnel zone effect by influence of sea waves at the time of stormy weather.

Table 3. Maximum distance

Max. Distance	T2 tag height	Receiving antenna
410-470m	1.2m	2dBi Omni-derectional
590-640	1.2m	5dBi derectional (135deg.)
210-260m	0.1-0.2m	5dBi derectional (135deg.)

At this experiment, if h_1=4 m, h_2=0.2 m, d=210 m (on a float), 1st Fresnel zone radius r_1 becomes 80 cm as d_1=200 m, d_2=10 m, ψ = 1.14 degree (figure 5).
Wave height is often comparable to 1st Fresnel zone.

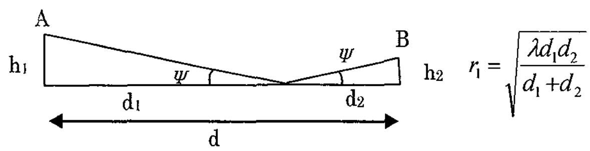

Figure 5. 1st Fresnel zone

3.3 Buoy position and Transducer

A highly precise position of the buoy's upper part is measured by the latest RTK GPS and a wireless radio network. A supersonic wave device is to be placed on the buoy's lower part in the water. A three-dimensional position measurement of the buoy is necessary for this task.

Transducer's position must be accurate because wavelength of ultrasonic is critical for performance improvement ($\lambda \cong 5cm$, if f = 30 kHz, v=1500 m).

Say attitude of buoy is Azimuth ψ, Pitch θ, Roll ϕ, and transfer matrix from RTK GPS to transducer's position $C(\psi,\theta,\phi)$, small attitude errors ($\Delta\psi,\Delta\theta,\Delta\phi$) increase with the RTK GPS position errors.

If measured attitude data has small errors $(\Delta\psi,\Delta\theta,\Delta\phi)$, a linear equation can be applied as follows[11].

$$C(\psi+\Delta\psi,\theta+\Delta\theta,\phi+\Delta\phi)=C(\psi,\theta,\phi)+\frac{\partial C}{\partial\psi}\Delta\psi+\frac{\partial C}{\partial\theta}\Delta\theta+\frac{\partial C}{\partial\phi}\Delta\phi$$

Increased position error becomes approximately 3cm when buoy length is assumed 1.5m, ψ,θ,ϕ 10degree, $\Delta\psi,\Delta\theta,\Delta\phi$ 0.8 degree.

Two types of attitude measurement methods were examined. One is GPS attitude measuring, the other is inclinometer with magnetic compass which recently uses accelerometers developed by MEMS (Micro-Electro-Mechanical Systems) technology. As for attitude measuring, many evaluation tests are necessary concerning static and dynamic accuracy in practical environments.

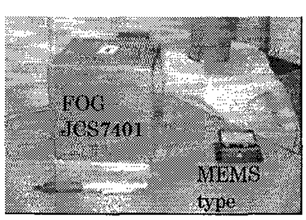

Figure 6 Attitude measuring device

Figure 6 shows the tested attitude measuring devices, one is high accurate FOG (Fiber Optic Gyro), and the other is a small size MEMS type. Performance for this device must be tested at relatively calm sea as it was originally developed for static attitude.

Figure 7 shows an image of a sensor network Buoy.

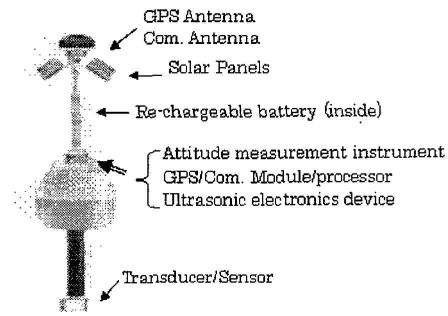

Figure 7 Image of Buoy

Test results are shown in Figure 8. The difference between MEMS type and high accurate (0.1deg accuracy) type is almost 1degree at slow dynamics. The Eva. Kit of MEMS type is very small, but it has approximately 1 W power consumption. This device has a self-alignment function with a magnetic compass, and it is easy to use because it is very compact and light, but dynamic performance must be more examined.

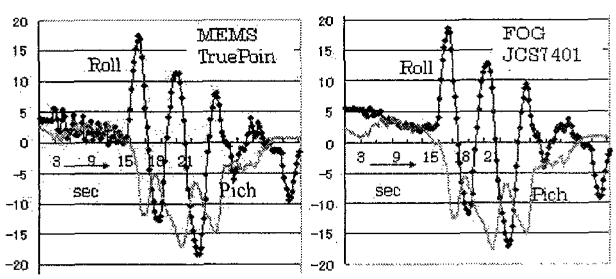

Figure 8. Test example

Sensor network-use buoy has many functions.

a) Wireless radio network which is connected with ship or shore stations.
b) Underwater acoustic (ultra sound) communication of buoy-to- buoy and buoy-to-bottom sensor.
c) Position fixing of sensors[12]
d) RTK GPS precise positioning and timing
e) Attitude measuring.
f) Position transferring to underwater transducer/sensors.
g) Power system to keep networking operation long time.

This buoy is used as a sensor network component.
Figure 9. shows an image of the configuration.

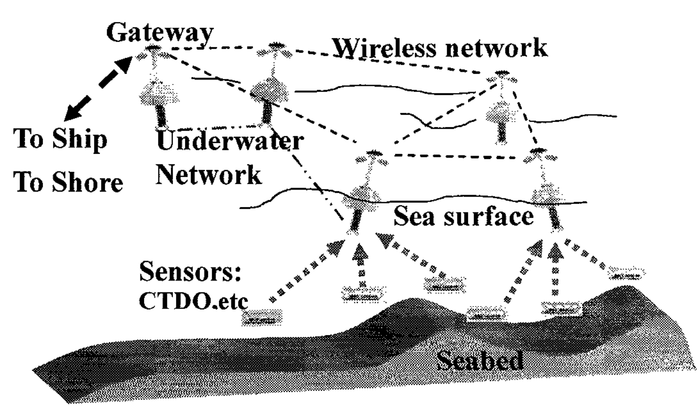

Figure 9. Image of sensor network component

3.4 Underwater acoustic communication

Underwater acoustic (UWA) communication systems are widely used in the field of telemetry. However, both size and required power of the system are not suitable for the purpose of this sensor network. And, hence, an adequate UWA communication system for this sensor network system is prepared.

3.4.1 Characterization of UWA communication

Compared with the wireless radio communication, there are some difficulties in the underwater acoustic communication since the sound velocity; 1500m/s is much slower than the speed of the magnetic wave, $3x10^8$ m/s. At such a low phase velocity, the sound velocity is affected greatly by environmental conditions such as temperature or eddy in the sea. The UWA communication system has to meet the multipath fading due to reflection from the sea surface or the sea bottom first.

3.4.2 Experimental setup and results

A block diagram of the modulator and demodulator is shown in Figure 10. T represents the delay time. Delay detection is applied and the DSP (TMS320C6416, TI Incorporated.) is employed. Figure 11 shows the dimensions and configurations of the receiving and transmitting transducers. The resonance frequency of the transducer is 40 kHz and the transducer is non-directive. In many reports, PSK modulation is employed for the purpose of high-speed data transfer. The sensor network does not require such high data transfer. As the bandwidth of the transmission signal increase, the directivity of the transducer is different from non-directive. And, hence, there is a limitation of the bandwidth in the transmission signal. In our system, the transmission data is modulated by minimum shift keying (MSK). In the modulation, the center frequency is 33 kHz, the shift frequency is 1 kHz and the FSK rate is 2 kHz. The transmission data is 4 bit or 8 bit. The input voltage of the transmitter is 12 Vp-p at constant. This UWA communication is tested at the Toyosu canal. Figure 12 shows the location of the transmitter and the receiver at the canal. The example of received waveforms is shown in Figure.13. In Figure 13, 4 bit length data is sent. The reflection wave from the surface or the side bank in the canal appears in the end of the direct received data. The distance between the transmitter and the receiver varies 1m, 5 m and the data length is 4 bit and 8 bit. Each data is sent 15 times. The communication results are indicated in Table4. In Table 4, the bit error rate (BER) is calculated. In the case of 5 m of distance, the BER is much worse than that of 1m. In the reduction of BER, the adaptive filter, decision feedback equalization (DFE), is effective[14].

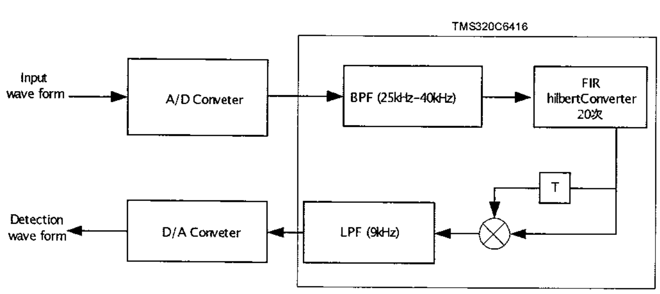

Figure 10. Block diagram of the demodulator

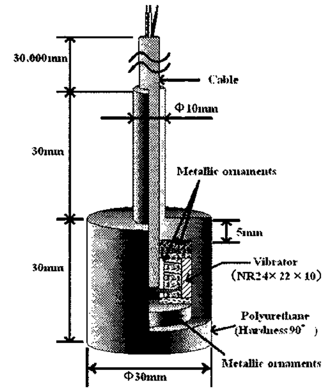

Figure 11. configuration of the transducer

Table 4 The result of the data transfer at Toyosu canal.

distance / bit length	1m / 4bit	1m / 8bit	5m / 4bit	5m / 8bit
Error bit number	0	5	5	14
BER(%)	0%	4.17	8.33	11.7

3.4.3 The advantage of positioning of the transducers by GPS

In this system, the transducers are anchored under the buoy of which position is measured by GPS. Figure 14 shows a typical block diagram of the DFE. T is the sampling time and $y(t)$ is the sampling value in the detection wave. $\bar{a}(t)$ is estimated digit by judging from the filter output $z(k)=\sum h_{fi} y(k+i) - \sum h_{bi} \bar{a}(k+j)$. h_{fi} and h_{bj} are the feed forward and feed back tap gains, respectively. N is the number of the feed forward tap and M is the number of the feed back tap. The optimum number M of the feedback filter tap is determined by the delay time of the reflection wave. If the position of the transducer is measured precisely, the number of the feed back filter is optimized. In the case of data transfer speed 8kbps, the propagating distance of the sound wave is 0.2 m in a symbol. Since more than two sampling values of the detection wave in a symbol are employed, in order to work the DEF effectively, the required precision of positioning is within 0.1 m. And, hence, the positioning of transducers by GPS is required

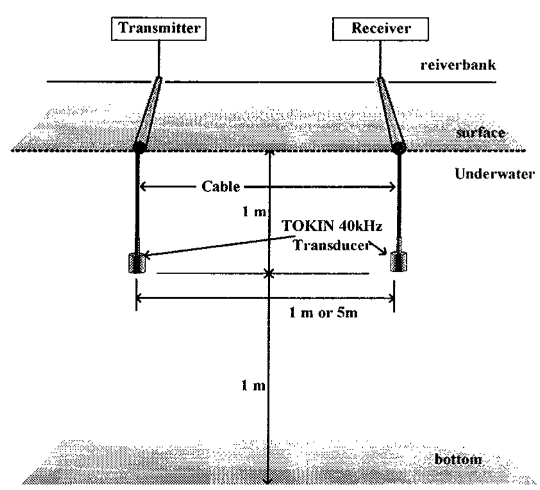

Figure 12. Arrangement of the transmitter and the receiver.

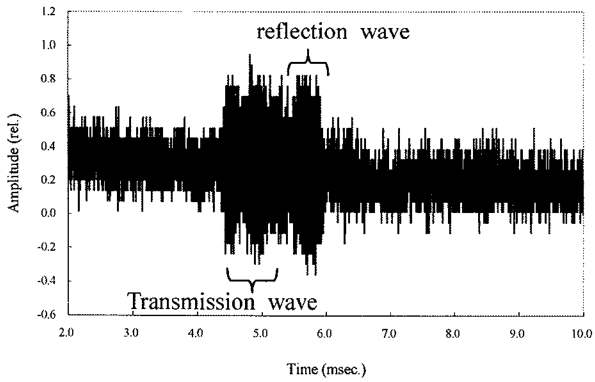

Figure 13. Example received wave form.

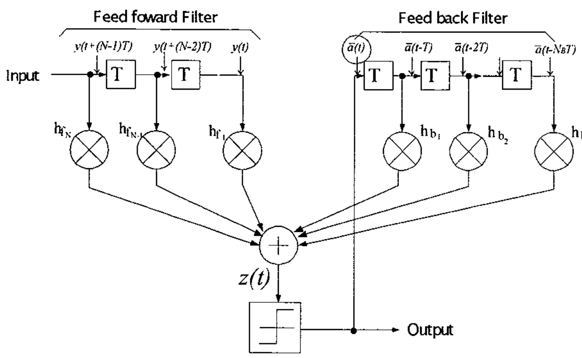

Figure 14. The block diagram of the typical DFE.

4. Conclusion and future study plan

In this paper the basic idea of a marine ubiquities sensor network was shown. The project is just at the beginning stages and many system parameters must be settled in future. In this stage, preliminary consideration of utilizing GNSS for network is described that was almost concerning wireless communication. This paper found wireless network standards adaptable to the systems above the sea surface. IEEE 802.11b is usable at node distances less than few hundreds meters, and IEEE 802.15.4 is also usable at maximum distance of 30-40 m. For these networks, location oriented routing may be used. Only the basic idea was shown in this paper. Underwater network study has just begun, and additional experiment is undergoing.

UWA communication using a small sized and low power system was also tested. In regards to the fading, MSK modulation is employed. Detection was confirmed when the transmitter transducer applied 12 Vp-p the input voltage, at a 5m distance between the transmitter and the receiver.

The project includes many research and study items. Sensors and sensor fusion area will be specified after the application field becomes clear. Long life power systems are also important for sensor network.

Acknowledgement

This work was supported by Grants-in-Aid for Scientific Research of JSPS. Thanks are also due to Mr. N. Aoto and Mr. T. Wakasa of Ebara Densan Co. Ltd. for WiFi evaluation traial.

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