Propagation Delay Modeling and Implementation of DGPS beacon signal over the Spherical Earth

Dong-Hui Yu and Sung-Hyun Weon, *Member, KIMICS*

***Abstract*—**This paper presents the ASF(Additional Secondary Factor) modeling of DGPS beacon signal. In addition to DGPS's original purpose, the feasibility to utilize DGPS system for timing and navigation has been studied. For timing and navigation, the positioning system must know the accurate time delay of signal traveling from the transmitter to receiver. Then the delay can be used to compute the user position. The DGPS beacon signal transmits the data using medium frequency, which travels through the surface and cause the additional delay rather than the speed of light according to conductivities and elevations of the irregular terrain. We introduce the modeling of additional delay(ASF) and present the results of implementation. The similar approach is Locan-C. Loran-C has been widely used as the maritime location system and was enhanced to E-Loran(Enhanced Loran). E-Loran system uses the ASF estimation method and is able to provide the more precise location service. However there was rarely research on this area in Korea. Hence, we introduce the ASF and its estimation model. With the comparison of the same condition and data from the original Monteath model and ASF estimation data of Loran system respectively, we guarantee that the implementation is absolutely perfect. For further works, we're going to apply the ASF estimation model to Korean DGPS beacon system with the Korean terrain data.

***Index Terms*—**ASF, Propagation delay modeling, Location, DGPS, Loran

I. INTRODUCTION

The signal coverage of DGPS beacon stations in South Korea may extend over the most of inland as well as the coast. From the view of the application of national infrastructure, DGPS system has the potential to be substituted for GPS backup system for time synchronization and satellite navigation system in an emergency.

To utilize the DGPS beacon signal for the use of timing and navigation, we analyze the propagation characteristics of DGPS signal and present the method to apply them to timing and navigation. Time synchronization is the infrastructure for the ubiquitous intelligent environment.

Location systems measure time delay or time delay differences in the signals they receive, compute the distance from the transmitter to receiver, and determine the user's position. The conversion from time to distance requires the knowledge of the signal's velocity. The signal velocities differ from seawater values when propagating over land. In case of land, they are different according to the surface's conductivities.

Especially for medium frequency, the characteristics of its propagation along the surface make the additional delay. This additional delay from different signal velocities and conductivities is called Additional Secondary Factor (ASF). Precise positioning requires the various delays to be accurately mapped [8].

This paper proposes an early stage on the ASF modeling of DGPS beacon signal or E-Loran system, illustrating the application of the modeling and influence of terrain data on the propagation delay.

A. DGPS overview

DGPS(Differential GPS) receives the signal from the navigation satellite in the well known position and compute the positioning error causing from the propagation and sends the compensation data using medium frequency, 283Khz ~ 325Khz. DGPS users determine their accurate position with DGPS data.

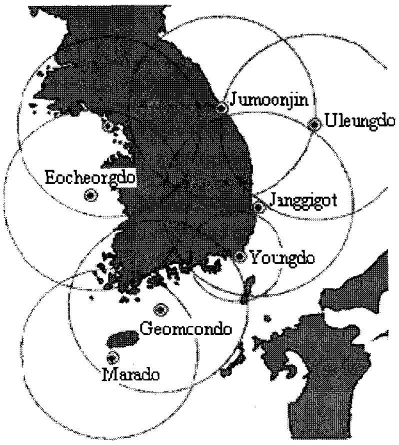

Fig. 1 Coverage of DGPS transmitter stations in South Korea

DGPS system in South Korea consists of 8 coastal transmitter stations. After 3 transmitter stations are supplemented, DGPS system is expected to provide the

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Dong-Hui Yu is with the Department of Multimedia Engineering, Catholic University of Pusan, Busan, 609-757, Korea (Tel: +82-51-510-0643, Fax: +82-51-510-0648, Email: dhyu@cup.ac.kr)

more accurate location information to users with dual service coverage. Fig. 1 shows the DGPS transmitter stations.

B. DGPS signal characteristics

DGPS signal is the groundwave signal. Groundwave signal propagates along the surface. The speed of the groundwave signals forming the components of each time varies according to the type of surface over which they travel. The key parameter is the electrical conductivity of the surface. signals travel most slowly over ice, deserts or mountains, a little more quickly over good farming land and most quickly of all over sea water. Further, velocity varies with distance from the transmitter in a complicated manner.

To utilize DGPS transmitter stations for navigation, it is necessary to study other navigation system with similar propagation characteristics. Loran-C system is the navigation system using 100 KHz medium frequency. Loran-C receivers have the ASF map for corresponding Loran-C transmitter and compensate the positioning error cased by additional delays.

The Salt Model is used to compute the positioning in Loran-C [5]. The Salt Model assumes that the velocity of a signal traveling over sea-water consists of two components.

The primary factor (PF) velocity is the velocity in the earth's atmosphere. This is the speed of light. It is 200, 792, 458 m/s.

The Secondary Factor (SF) versus Distance is the additional delay over sea-water. The USCG employs the curve from NBS 573 that corresponds to a conductivity of 5 S/m.

The Salt model doesn't consider the landmasses. In hence, Additional Secondary Factor (ASF) should be modeled, in order to compensate the delays from various conditions of terrain. Research on ASF of Loran-C has been conducted by University of Wales, Bangor [1], [6]. The research used the Monteath model for ASF estimation. Hence, we introduce the Monteath's ASF modeling. For reliability, we referred the progress reports of BALOR system of University of Wales, Bangor.

II. ASF MODELING

The subject of groundwave propagation over imperfectly-conducting paths has been studied. Much of early works concentrated on a smooth, plane, single conductivity earth. Extending these theories to a spherical earth was modeled by Norton. The complicating effects of mixed conductivities, ground and of terrain elevation variations have been studied by lots of researchers. The method most readily understood by engineers is that resulting from the application of the Compensation Theorem. Monteath used this method to formulate his solution to this difficult problem. The result of Monteath method is the complex attenuation factor of the surface of the earth over which the groundwave has traveled from transmitter to receiver. The method encompasses the effects of both conductivity and topography.

Monteath computed the effects of irregular earth by means of the Compensation Theorem, which provides a way of determining an unknown solution from a known solution by perturbation [2], [3], [4]. To clarify this point, consider Fig. 2. The transmitter is at A and the receiver at B. The bold line APB is the surface of the irregular earth over which we are to determine the unknown propagation parameters.

The known solution in this case is that of propagation over the dashed line AB, a path assumed to lie over perfectly-conducting plane earth.

The complex attenuation factor, that relates the amplitude and phase of the signal received at a point to that transmitted, is defined by G, where:

$$G = \frac{Z'_{AB}}{Z_{AB}} \tag{1}$$

In this equation, Z'_{AB} represents the complex mutual impedance between transmitter and receiver over the irregular and imperfectly-conducting path, while Z_{AB} is the equivalent impedance over the plane and perfectly-conducting earth. By means of the Compensation Theorem, Monteath shows that G at a receiver located a distance R from the transmitter may be represented by:

$$G(R) = 1 - \sqrt{\frac{j\beta_0}{2\pi}} \int_0^R (\psi + \frac{\eta}{\eta_0}) e^{-j\xi} \sqrt{\frac{R}{R-r}} G(r) dr \tag{2}$$

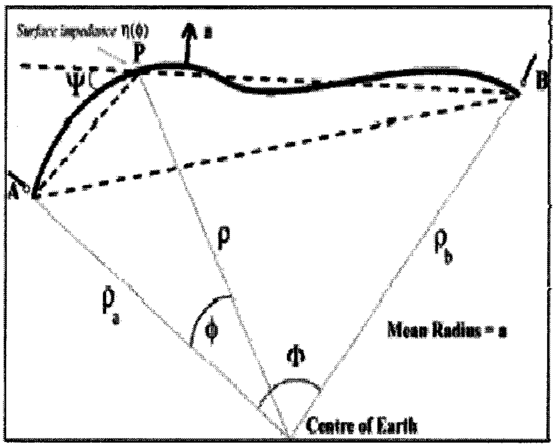

Fig. 2 Monteath's integral equation method.

This is a line integral along the path from transmitter A to receiver B with variable r, where r is the distance of point P from the transmitter.

Taking the other terms, β_0 is the free space wave number in radians/m and λ is the free space wavelength in m. The variable:

$$\xi = \beta_0[(AP) + (PB) - (AB)] \tag{3}$$

where AP, PB and AB are as shown in Fig. 4. The figure also shows that:

$$R = a\Phi, \quad r = a\phi. \tag{4}$$

The relative surface impedance of the Earth, $\frac{\eta}{\eta_0}$, is given by:

$$\frac{\eta}{\eta_0} \cong (\varepsilon_r + 1)^{-\frac{1}{2}} \tag{5}$$

In this equation, ε_r is the complex relative permittivity given by:

$$\varepsilon_r = k - j \times 1.8 \times 10^{10} \frac{\sigma}{F}, \tag{6}$$

where k is the dielectric constant, σ the ground conductivity in S/m, and F the frequency in Hz.

Monteath proposes an iterative numerical method for solving equation (2), suitable for implementation in software. This equation expresses the complex attenuation factor at a range R in terms of its value at all ranges between zero and R. Monteath divides the path into N equal sections, each of length D, the receiver thus being a distance ND from the transmitter.

The first step is to replace the integral by a sum, replacing R by ND and r by ID to give,

$$G(ND) = 1 - BD^{\frac{1}{2}} \sum_{I=0}^{N} E(ND, ID) C(N, I) G(ID) \tag{7}$$

where $B = \sqrt{\frac{j\beta_0}{2\pi}} = \sqrt{\frac{j}{\lambda}}$. D is the range interval and E, which will be termed the effective surface impedance, is given by

$$E(ND, ID) = (\psi + \frac{\eta}{\eta_0}) \exp(-j\xi), \tag{8}$$

where η has the value appropriate to range ID and ψ and ξ depend on both ND and ID. C(N,I) is a coefficient which takes into account the factor $\sqrt{\frac{R}{r(R-r)}}$ in the integrand.

Equation (6) may be written in the form

$$G(ND) = \frac{1 - BD^{\frac{1}{2}} \sum_{I=0}^{N-1} E(ND, ID) C(N, I) G(ID)}{1 + BD^{\frac{1}{2}} C(N, N) E(ND, ND)}, \tag{9}$$

He solves the equation in a progressive manner, starting the integral with G(0) set to unity, since there is no attenuation at the transmitter. Then, G(r) is derived at each of the series of equally-spaced values of r, i.e. r=0,d, 2d, id, (i+1)d,..., (N-2)d, (N-1)d, Nd. To compute G([i+1]d) , all previous values, G(0), G(d), G(2d), G(id) are employed in successive applications of equation (2). This process is repeated until one final application of the equation gives the value we require, G(Nd) at the receiver.

In applying equation (2) to the computation of a DGPS ASF at a range R from the transmitter, we set F to 300 kHz. ASF is then given by:

$$ASF(R) = G(R)_{Mixed-path} - G(R)_{Salt-water}$$

where G(R)Mixed-path represents G(R) over the actual path with its conductivity and topography variations and G(R)Salt-water represents a sea-water path over a smooth ellipsoidal earth with the Loran-C standard values of σ=5,000 mS/m, k=81.

III. IMPLEMENTATION & SIMULATION

Monteath devised a numerical algorithm for computing his integral. BALOR software is the LORAN-C ASF estimation software developed in University of Wales, Bangor. We have taken Monteath algorithm to estimate ASF of DGPS signal and implemented it in the C++ programming language. We have tested the resulting code by attempting to reproduce independently Monteath's own test results and Loran-C BALOR's results. CUP represents ASF estimation S/W by Catholic University of Pusan.

Table 1 Comparison of three implementations

Freq. (MHz)	Dielectric constant	Conductivity (S/m)	Range	Magnitude(9dB)			Phase(°)		
				Monteath	BALOR	CUP	Monteath	BALOR	CUP
0.2	4	0.003	780 810	-28 -29	-28 -30	-27.7 -28.7	-431 -452	-438 -459	-437.5 -460.4
			620 780 806 850	-22 -27 -29 -30	-22 -28 -28 -31	-22.2 -27.6 -28.1 -29.3	-329 -432 -453 -482	-327 -440 -456 -492	-327.6 -440.5 -455.9 -493.9
			300 640 820	-10 -23 -29	-11 -23 -28	-10.4 -23.3 -28.0	-173 -339 -472	-175 -338 -468	-174.5 -338.3 -483.8
0.7	4	0.01	350 380 490	-31 -34 -41	-31 -33 -41	-31.5 -33.8 -40.3	-318 -343 -435	-317 -342 -450	-317.2 -342.0 -453.5
1	4	0.003	144	-38	-38	-37.7	-211	-213	-213.7

The agreements were excellent. Table 1 shows the comparison results. The test model is smooth-earth model. The smooth-earth model ignored the topographical variations of irregular terrain.

A. Simulations

To figure out the effect of terrain on the signal propagation, we conducted some simulations. As mentioned before, since the propagation of medium frequency is affected by the conductivity and shape of the terrain, we simulated the case of conductivity variations and terrain variations.

To analyze the effect of conductivity, we simulate two cases. One is for the comparison between the mixed conducting path and perfectly-conducting path. The other is for the comparison between the different perfectly-conducting paths.

Fig 3 shows the first simulation result. The circled line is perfectly- conducting path, which means the surface has the same conductivity. The rectangle line represents two part conducting path. Frequency is 300 KHz, range is 60km, and interval distance is 2km. Conductivity and dielectric constant of perfectly-conducting path is 3 mS/m and 4, respectively [7]. Two part path has sea water from 8 km to 28 km and other area has the same condition as perfectly-conducting path. Conductivity and dielectric constant of sear water are 4.6 S/m and 81, respectively. There are very small delays about from 0.014° to 0.22° in the interval of sea water in two part conducting path from 8km to 28km. After sea water interval, additional phase delay is remarkable. The results show the propagation delay is smaller when the signal travels over seawater than land area.

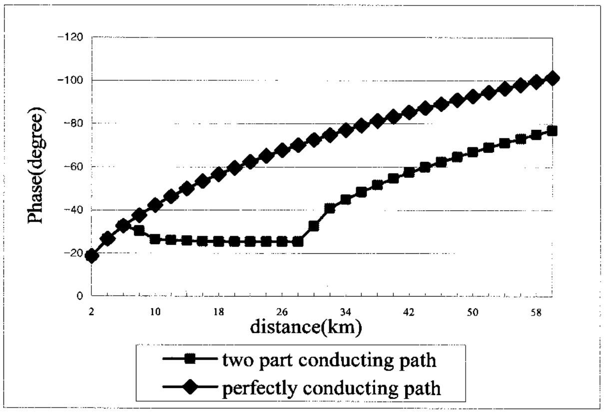

Fig. 3 Comparison of phase delay of perfectly Conducting path compared with two part conducting path.

The simulation of the shape of terrain, we compared between flat plane earth and spherical earth. In order to confirm the effect of shape of terrain, we set the same conditions such as conductivity, frequency, dielectric constant, etc. Intuitively, we can easily guess that spherical earth produces longer distance than plane earth. Them we can confirm the additional delay resulted from the shape of the terrain in Fig. 4. We simulated 4 cases. For each of spherical earth and plane earth, we make seawater condition and land condition. Seawater condition is that the dielectric constant is 80 and conductivity is 5 mS/m. Conditions of Land are dielectric constant of 4 and conductivity of 0.003 mS/m. As shown in the figure, the additional propagation delays results from the terrain types, the phase delays are different remarkably.

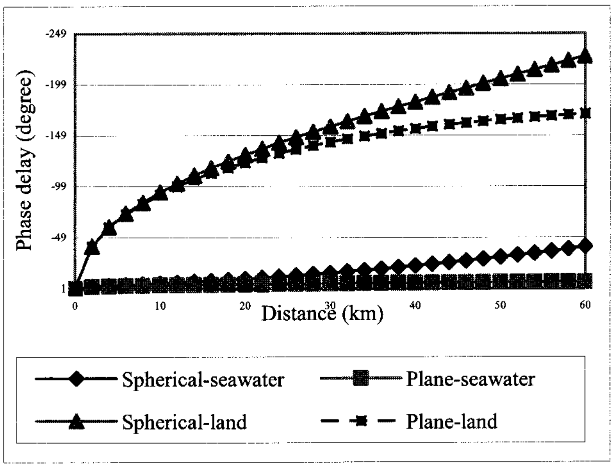

Fig. 4 Comparison of phase delays according to different types of terrains and conductivities.

We're simulating the effect of irregular surface, different elevation, and introducing the result in another paper. Fig. 5 shows comparison of phase delays when the different perfectly-conducting paths are applied. Smaller conductivity makes the signal propagate slowly. From the kinds of the land, there are various conductivities like the figure.

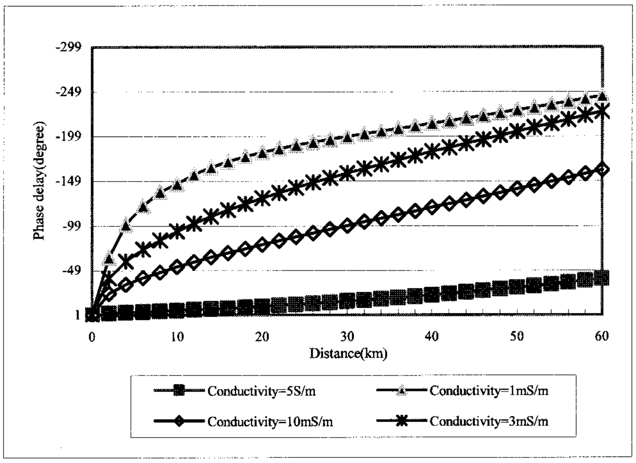

Fig. 5 Comparison of phase delays according to different conductivities.

B. Examples of estimated ASF for an path

We select Muju DGPS transmitter station and KRISS as a user position. We already know the accurate positions in the form of longitude, latitude, and elevation of them. After calculating the distance from Muju transmitter station to KRISS, we compute the estimated ASF value. The estimated ASF means the additional delay when the signal travels along the surface in comparison with when the signal travels straight.

Frequency is 300 KHz, conductivity is 3 mS/m in

ITU-R P.832-2, and dielectric constant is 4, and the used model is smooth-earth mode that is spherical earth.

The range from Muju transmitter station and KRISS is 57273.55m. The phase delay is calculated about -94.1926°. Converting it to range and time, about 260.913m and 871.28ns should be compensated for positioning, respectively.

IV. CONCLUSIONS

The simple and accurate way to determine the ASFs of DGPS is to measure on a land vehicle, the true position using surveying methods and the position given by a DGPS positioning receiver; the difference give the ASFs. But the method is slow and expensive. It would be more cost effective if estimated ASF values could be compensated by some measured accurate sample data.

Monteath's method of solution for modeling the propagation of groundwave radio signals has been adopted as an estimation model to calculate DGPS ASFs. The simulation results of our software closely match those of Monteath's own results and BALOR's result in Loran-C. To show the effects of the terrain on the propagation delay of DGPS signal, we present some simulation results.

As further works, we implement the process of irregular terrain and study the compensation method through the measurement of accurate propagation delay.

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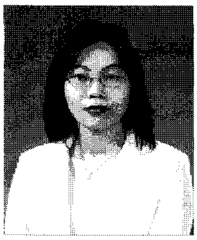
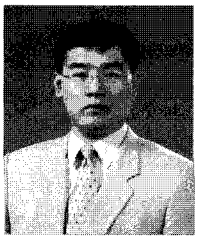


Dong-Hui Yu,
Member KIMICS Received the B.S., M.S., Ph.D. degrees in computer science from Pusan National University, Busan, Korea in 1992, 1994, 2001, respectively. From 1994 to 1997, she was a researcher in ETRI(Electronics and Telecommunications Research Institute). She developed ATM switch. From 2001 to 2002, she joined the Research Institute of Yhkim.Co., Ltd. She developed LBS(Location Based System), NTP time server and client S/W. From 2003, she has been the faculty of Dept. of multimedia engineering at Catholic University of Pusan, Busan, Korea. Her areas of interest are telematics service, GPS related applications, Internet time synchronization, precise time synchronization, ad-hoc network, and sensor network.



Sung-Hyun Weon,
He received his B.S. and M.S. degrees in the Department of Computer Science from Sogang University, Korea, in 1990 and 1992 respectively, and Ph.D. degree in the Department of Computer Science from Catholic University of Daegu, Korea, in 1998. He is currently an Associate Professor in Catholic University of Pusan, Korea. His research interests are intelligent system, cyber education system, E-commerce system etc. He is currently a member of KFIS, KACE, CALSEC.