Construction of Tidal Datums Based on Ellipsoid Using Spatial Interpolation

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Key words: Spatial Interpolation, Tidal bench Mark, Ellipsoid, Tidal Datums, Spline with Barrier

SUMMARY

In this paper, conversion of vertical based information provision system through tidal bench mark which is currently implemented to area based information provision system was studied. When analyzing a range that allows area modelling using tidal bench mark by calculating the height from ellipsoid to mean sea level based on tidal bench mark performance in 2016. For spatial interpolation, IDW interpolation, Spline interpolation, Kriging interpolation and Spline with Barrier interpolation were used. Parameter for each interpolation was selected through cross validation. An experiment for obtaining optimum spatial interpolation was conducted by comparing and analyzing external verification and performance. The experiment showed that for RMSE of IDW was 14.5cm, for RMSE of Spline was 9.47cm, for RMSE of Kriging was 8.49cm and for RMSE of Spline with Barrier 8.60cm.

It was found that Spline with Barrier interpolation is the most suitable in constructing ellipsoid based tidal datums because Spline with Barrier interpolation using Minimum Curvature technique meets allowable error based on first class of hydrographic survey provided by International Hydrographic Organization (IHO) and allows us to interpolate considering coastline. Ellipsoid based area shaped mean sea level was constructed by using Spline with Barrier interpolation obtained from the experiment and it was converted into approximately highest high water and datum level by obtaining the sum of four Largeness tide value in tide from tide grid mesh model and adding and subtracting it. When comparing a result of conversion with observed value, it was found that for approximately highest high water, RMSE was 3.235cm and for tidal bench mark, RMSE was 3.529cm.

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1. INTRODUCTION

Recently, owing to development of GNSS (Global Navigation Satellite System) based global navigation satellite system technology, ellipsoidal height could be determined precisely and rapidly and one of the most important topics in marine survey today is to use ellipsoidal height as vertical standard of survey. In 2014, FIG announced to use ellipsoidal height as vertical standard system as an official guideline in order to integrate dualized two data types of inland, marine survey and in order to produce data continuously, IHO TWCWG (Tides, Water Level and currents Working Group) have decided to use ellipsoidal height as observation standard of tide and sea level.

In addition, tidal datum is provided by burying tidal bench mark after surveying sea level at a place like coast, island and as its height also shows regional difference due to tide or marine features, it is hard to know height of other area. And as tidal bench mark is buried with concrete mainly at natural bedrock of coastal area or near to quayside, a problem may be taken place when using tidal information as loss or damage by typhoon or corrosion is more frequently taken place than inland benchmark in view of costal features.

Therefore, in this thesis, a research of converting to area form through spatial interpolation in tidal datum information provision system of point form through current tidal bench mark was performed. By using tidal bench mark outcome, height from ellipsoid to average sea water surface was estimated and by using optimal spatial interpolation, ellipsoid based tidal datums was constructed and then semirange sum of four largeness tide value was extracted from tide model and by converting it to app. lowest low water and app. highest high water, ellipsoid based tidal datum was constructed.

2. PRECEDING RESEARCH AND EXPERIMENT METHOD

2.1 Preceding research

2.1.1 Research trend of ellipsoid based tidal datum system

Today, in hydrographic surveying field, a research on application and utilization for channel area by using high precision GNSS is under progress and in particular, a research on using ellipsoid as tidal datum has been emerged as a topic.

As its research, Dodd (2012) suggested SEP model that defined a relation between ellipsoid and chart datum by using ellipsoid, geoid, tide model in order to integrate inland and marine spatial information. SEP model is the one being constructed by using models of geoid, tide and fluid dynamics after estimating ellipsoid height through GNSS observation in tidal bench mark.

And advanced off-shore countries developed relation model of tidal datum based on global ellipsoid in order to rapidly convert, utilize GPS outcome. United States provides conversion to chart datum from ellipsoid by developing tidal datum conversion service.

As tidal datum system that could be commonly applied when applying sustained development of GNSS and surveying technique like LiDAR, Multibeam is required, U.K. provides information by developing VORF system and rapidly converting values of tidal datum.

Australia developed AUSGeoid (that data-based a height from WGS84 ellipsoid to Australian height datum and AUSHydroid (that data-based a height from WGS84 to chart datum).

2.1.2 Research trend of spatial interpolation

In order to express spatial data distribution having continuous features, it is expressed by area shaped information by applying diversified spatial interpolation basaed on observe3d point data.

As a research for this subject, Marcelo Curtarelli et al., (2014) performed a mapping research of water depth of Amazon hydraulic reservoir by using diversified spatial interpolations and through its cross validation, deduced a research result that interpolation of Ordinary Kriging was the most suitable. Nickitas Georgas et al., (2013) deduced a research result that Spline with barrier interpolation was the most suitable by comparatively analyzing actual observed value with V-Datum after applying interpolation for vertical tidal datum of Hudson river and constructing its tide level model. Kim, Dae-Hyeon (2016) progressed a research of constructing tide model showing relation between approximate lowest low water and regional average sea level by using spatial interpolation after extracting semirange sum of four largeness tide value in tidal bench mark performance. And through cross validation, a research result that Spline interpolation was the most suitable was deduced through cross validation. Jung, Se-Han (2015) performed a research of constructing submarine topography model through spatial interpolation by using water depth data of Jeju area and deduced a research result that Kriging interpolation was most suitable and considered that point density features of collected data affected its accuracy.

2.2 Experiment outline

In this study, through surface modeling of spatial interpolation by using height value from ellipsoid of each tidal bench mark to average sea water level, spatial distribution aspect of average sea water surface was intended to be expressed. For this objective, height from ellipsoid to average sea water surface was estimated by using 67 tidal bench marks of 2016 by selecting around Gyeonggi Bay among the Western coast as experiment target. And parameter by each interpolation was selected through cross validation after performing parameter selection test for each spatial interpolation (IDW, Spline, Kriging, Spline with barrier) after entering attribute data using ArcGIS Tool. Surface modeling was performed by applying parameter and external verification and comparative validation with actual observed value were performed. External verification is to verify accuracy by points not utilized in modeling.

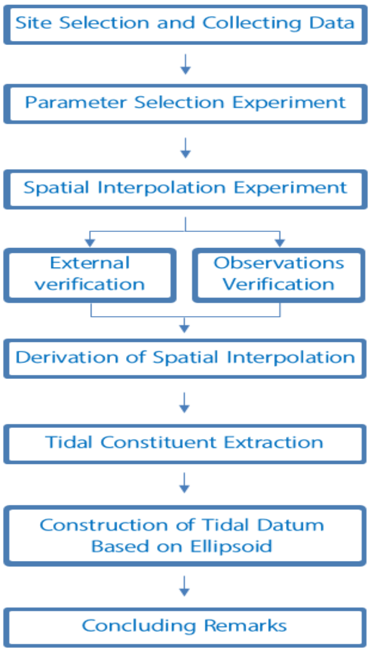

Figure 1. Experimental procedure

3. PRECEDING RESEARCH AND EXPERIMENT METHOD

3.1 Experiment area

In this study, in order to construct ellipsoid based new tidal datum, Gyeong-gi Bay area of western coast was selected as experiment target region on the ground that in view of western coast features, as tidal difference is big, coastal line is complicated due to presence of small/large bay and several islands and features of tidal, oceanic current is diversified, if spatial interpolation satisfying western coast should be deduced, it was considered that southern coast and eastern coast that are not comparatively complicated could be also satisfied. In addition, Korea Hydrographic and Oceanographic Agency performed tidal bench mark survey for western coast in 2016 and new burial of such mark and performance renewal. As spatial interpolation that estimates unknown point was used, accuracy of observation point is important more than anything else and so, western coast area that may reflect latest outcome of tidal bench mark was selected as experiment target region.

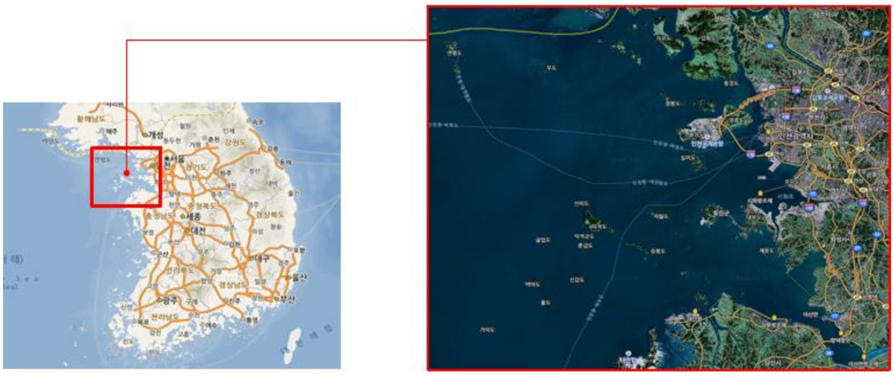

Figure 2. Experiment target area (Around western coast Gyeong-gi Bay)

3.2 Experiment area

As spatial interpolation generates discontinuous point data as continuous area data, parameter shall be established differently based on distribution and condition of point data in order to convert to more accurate area data. Therefore, before starting this experiment, an experiment for selecting optimal parameter by each spatial interpolation (IDW, Spline, Kriging, Spline with barrier) was performed. In case of parameter by each spatial interpolation, RMSE was deduced and optimal parameter was selected by comparing a difference between forecasted value and observed value for every point through cross-validation approach. Cross-validation is a method of verifying accuracy through difference with actually observed value after obtaining forecasted value for total target point while excluding experiment target point present in a certain area one by one.

3.2.1 IDW(Inverse Distance Weighted) Interpolation

Parameter of IDW(Inverse Distance Weighted) is Power index(distance index) and by dividing it into total 8(0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0), parameter selection test was performed. Test result is as shown on following <Table 1> and 3.0 was selected as final parameter.

Table 1. Result of IDW Parameter selection experiment (Unit : cm)

Power	RMSE
0.5	24.7245871
1.0	20.1379911
1.5	18.1539135
2.0	14.9404941
2.5	13.5309015
3.0	12.2002601
3.5	12.2959557

3.2.2 Spline Interpolation

Parameter of Spline type is mainly divided into regulized type and tension type abd by dividing parameter into 4 (0.1, 0.2, 0.3, 0.4), its selection test was performed. Test result is as shown on <Table 2> and as final parameter, 0.4 was selected from regulized type.

Table 2. Spline parameter selection experiment (Unit : cm)

Parameter		RMSE
Regulized	0.1	20.137991
	0.2	14.940494
	0.3	12.200260
	0.4	12.026612
Tension	0.1	24.724587
	0.2	18.153913
	0.3	13.530901
	0.4	12.295955

3.2.3 Kriging Interpolation

In case of Kriging, parameter is mainly divided into ordinary (5), universal (2) and each is divided into Spherical, Circular, Exponential, Gaussian, Linear and Linear with Linear drift, Linear with Quadratic drift. Test result is as shown on following <Table 3> and as parameter, Linear with linear drift was selected from universal.

Table 3. Kriging parameter selection experiment (Unit : cm)

Parameter		RMSE
Ordinary	Spherical	20.137991
	Circular	14.940494
	Exponential	12.200260
	Gaussian	12.026612
	Linear	24.724587
Universal	Linear with Linear drift	18.153913
	Linear wih Quadratic drift	13.530901

3.2.4 Spline with Barrier(Minimum Curvature) Interpolation

In case of Spline with Barrier, its parameter is Smoothing factor(that is established as valuer between 0~1. Smoothing factor is a factor of determining how much smoothly spatial interpolation is performed and by dividing variable into 5(0.6, 0.7, 0.8, 0.9, 1.0), parameter selection test was performed. Test result is as shown on following <Table 4>and 1.0 was selected as Smoothing factor.

Table 4. Spline with Barrier parameter selection experiment (Unit : cm)

Power	RMSE
0.6	11.3238128
0.7	11.3848056
0.8	11.4484401
0.9	11.5143191
1.0	8.6727854

3.3 Spatial interpolation experiment

In this study, spatial distribution aspect of regional average sea surface was intended to be expressed through surface modeling of spatial interpolation by using height from ellipsoid of tidal bench mark to average sea water surface.

As test procedure first, height value (ellipsoid height - sea level of average sea water surface) was estimated by using ellipsoid height and sea level of average sea water surface that are information provided by each tidal bench mark performance table of test target region. Based on this result, parameter selection test of each spatial interpolation (IDW, Spline, Kriging, Spline with Barrier) was performed after generating polygon file by extracting basic data such as coastal line from coastal map of electronic navigation chart after entering attribute data of tidal bench mark including height value of average sea water surface from altitude/longitude coordinate, ellipsoid by using ArcGIS and Suffer. Afterwards, spatial interpolation test was performed and test validation was performed by comparing validation with its performance and by deducing optimal spatial interpolation after verifying accuracy, ellipsoid based tidal datum (average sea water surface) was constructed.

3.3.1 Spatial interpolation experiment and comparative validation

Optimal spatial interpolation deduction test for constructing ellipsoid height based tidal datum was performed by each spatial interpolation (IDW, Spline, Kriging, Spline with Barrier) through ArcGIS Tool by estimating height from ellipsoid to average sea water surface based on information provided by performance table of 67 tidal bench marks for this test target region.

By using 60 places excepting 7 places (Joomoon port, Incheon, Deokjeok-do Buk-ri, Poongdo port, Gungpyeong-ri, Eoeundol port, Palmi-do) among 67tidal bench marks, spatial interpolation was performed and external validation was carried out. Where, external validation is to verify model accuracy by point not being utilized at the time of modeling.

For validation, Gungpyeonghang, Deokjeokdo bukri, Eoeundol hang, Incheon hang, Jumun hang, Palmido, Pungdo hang were selected and the reason of it is that as these places are heavily affected by oceanic, tidal current, if there is little difference between forecasted value and observed one, reliability of spatial interpolation could be secured and as there are a few tidal bench marks in its surrounding, it was considered to be adequate for deducing forecasted value by minimizing an effect of surroundings.

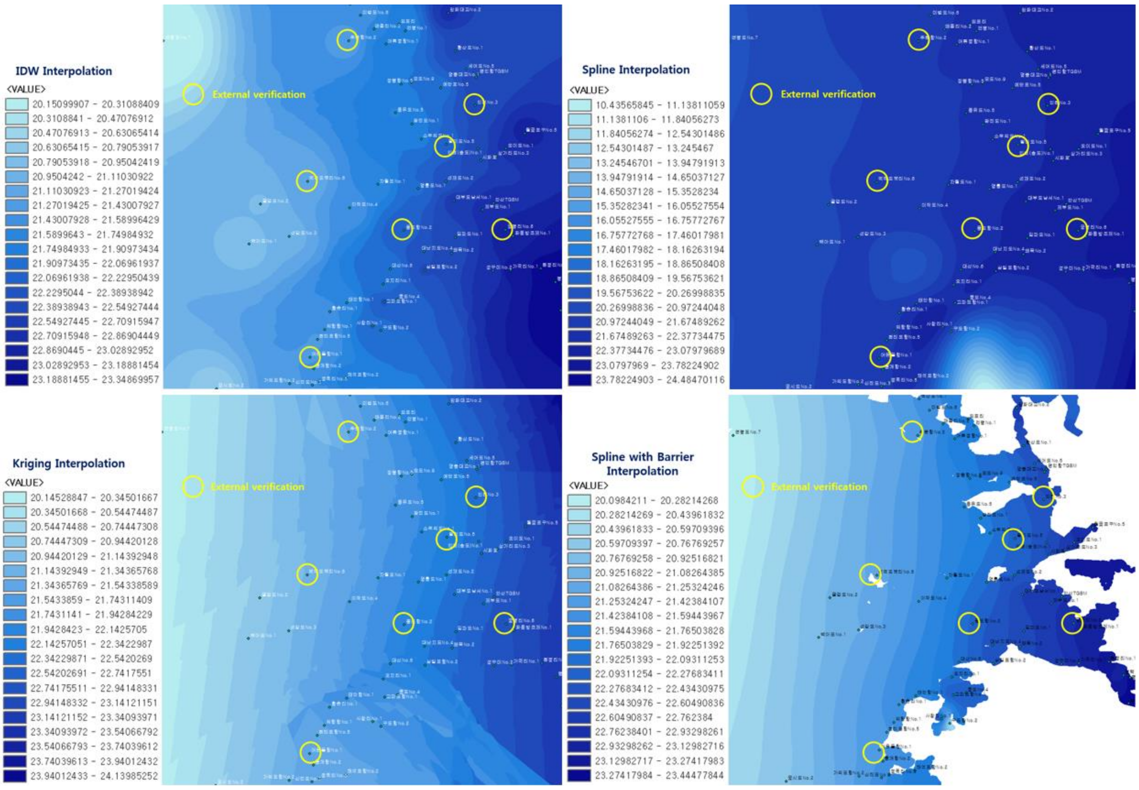

Figure 3. Result of each interpolation (Interpolation of 60 tidal bench marks)

Table 5. Oberved value and Forecasted one by each place (Unit : m)

		Observed Value	IDW	Spline	Kriging	Spline with Barrier
1	Gungpyeong hang	22.8912	22.9944	22.9260	22.8823	22.9370
2	Deokjeokdo bukri	21.1823	21.3342	21.1747	21.1734	21.2201
3	Eoeundol hang	21.3962	21.4765	21.3919	21.4184	21.3810
4	Incheon hang	22.4185	22.4271	22.4156	22.4659	22.4340
5	Jumun hang	21.3311	21.6121	21.5213	21.5072	21.5274
6	Palmido	22.1469	22.1642	22.0922	22.2237	22.1552
7	Pungdo hang	22.1385	21.9490	21.9848	22.0514	22.0710

Following <Table 6> is summary table of obtaining difference between observed value and forecasted one for each place by each spatial interpolation and deducing RMSE. In case of IDW interpolation, difference between 0.86cm (min.) and 28.11cm (max.) was represented total RMSE showed 14.90cm. In case of Spline interpolation, difference between 0.29cm (min.) and 19.02cm (max.) was represented and total RMSE showed 9.57cm. In case of Kriging interpolation, difference between 0.89cm (min.) and 17.60cm (max.) was represented total RMSE showed 8.22cm.In case of Spline with Barrier interpolation, difference between 0.83cm (min.) and 19.63cm (max.) was represented total RMSE showed 8.21cm.

Table 6. Difference between observed value and forecasted one by each place – External validation(Unit : cm)

		IDW	Spline	Kriging	Spline with Barrier
1	Gungpyeong hang	-10.32	-3.48	0.89	-4.58
2	Deokjeokdo bukri	-15.19	0.76	0.89	-3.78
3	Eoeundol hang	-8.03	0.43	-2.22	1.52
4	Incheon hang	-0.86	0.29	-4.74	-1.56
5	Jumun hang	-28.11	-19.02	17.60	-19.63
6	Palmido	-1.73	5.47	-7.68	-0.83
7	Pungdo hang	18.95	15.37	8.71	6.75
RMSE		14.90	9.57	8.22	8.21

3.3.2 Comparison, validation with observed value

Spatial interpolation was performed and forecasted value was deduced through spatial interpolation having each different features by using 67 tidal bench marks in order to perform comparison, validation test of observed value and forecasted one by obtaining validation performance. Validation performance was estimated through actual tide observation and GNSS surveying at southern part of Incheon Grand Bridge and northern part of Pungdo where tidal bench mark is not available. The reason why such part was selected as validation point was based on a judgment that if difference between forecasted value and observed one is minimal as such place was heavily affected by oceanic, tidal current, reliability of spatial interpolation could be secured and such place was suitable for validation point as tidal bench marks are evenly distributed around that place. Tidal value of these two points was annually revised by using yearly data of standard port (Incheon, Yeongheungdo) after observing it 30 day and night.

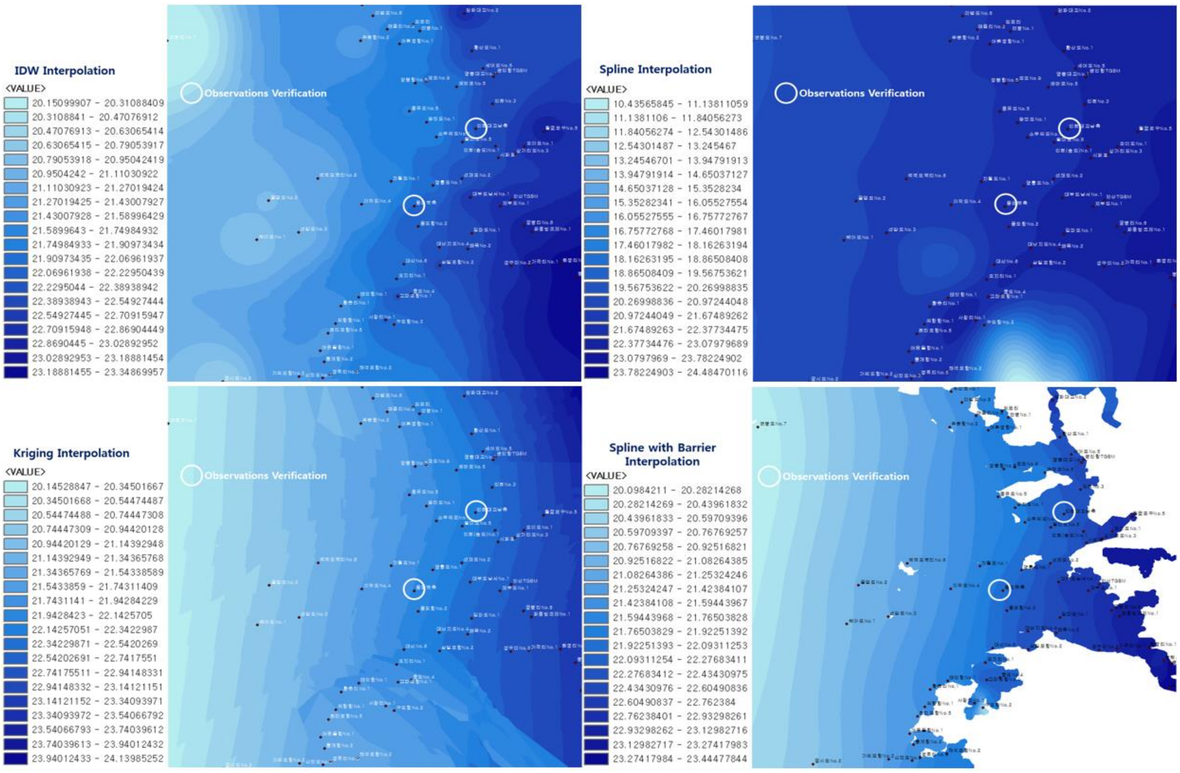

Figure 4. Result of each interpolation (Interpolation of 67 tidal bench marks)

Table 7. Validation performance and forecasted value by each place (Unit : m)

		Observed value	IDW	Spline	Kriging	Spline with Barrier
1	North of Pungdo	22.8912	22.7628	22.7671	22.9860	23.0163
2	South of Incheon Grand bridge	22.0543	22.1860	22.0192	22.1466	22.1155

Following <Table 8> is summary table after obtaining difference between observed value and forecasted one and deducing RMSE. In case of interpolation of IDW, Spline, Kriging, Spline with Barrier, total RMSE showed 13.90cm, 9.12cm, 9.36cm and 9.85cm, respectively.

Table 8. Difference between validation performance and forecasted one by each point(Unit : cm)

		IDW	Spline	Kriging	Spline with Barrier
1	North of Pungdo	12.84	12.41	-9.48	-12.51
2	South of Incheon Grand bridge	-13.17	3.51	-9.23	-6.12
RMSE		13.01	9.12	9.36	9.85

3.3.3 Analysis of validation result

Comparatively validate external validation and validation performance by applying 4 types of spatial interpolations for the test target area. Previously analyzed result was summarized in the following <Table 9> and RMSE was deduced.

Table 9. General analysis of difference between observed value and forecasted one by point (Unit : cm)

		IDW	Spline	Kriging	Spline with Barrier
1	Gungpyeong hang	-10.32	-3.48	0.89	-4.58
2	Deokjeokdo bukri	-15.19	0.76	0.89	-3.78
3	Eoeundol hang	-8.03	0.43	-2.22	1.52
4	Incheon hang	-0.86	0.29	-4.74	-1.56
5	Jumun hang	-28.11	-19.02	17.60	-19.63
6	Palmido	-1.73	5.47	-7.68	-0.83
7	Pungdo hang	18.95	15.37	8.71	6.75
8	North of Pungdo	12.84	12.41	-9.48	-12.51
9	South of Incheon Grand bridge	-13.17	3.51	-9.23	-6.12
RMSE		14.503	9.470	8.490	8.599

As a result of analyzing general result, in case of IDW interpolation, its total RMSE showed 14.503cm, Spline interpolation 9.470cm, Kriging 8.490cm and Spline with Barrier 8.599cm, respectively.

As a result of deducing total RMSE, as Kriging interpolation showed smaller RMSE than Spline with Barrier by 0.109cm and it may be considered to be more suitable but problem of Kriging interpolation is that if barrier like coastal line impeding physical flow is present in a space to be interpolated, interpolation is unable to be performed. If coastal line is not considered, as interpolation is performed to inland and it may affect forecasted value and so, barrier like coastal line shall be considered and applied definitely. Considering this features, it was considered that Spline with barrier interpolation using minimum curvature technique was most suitable spatial interpolation in terms of the fact that spatial interpolation considering barrier like coastal line could be performed.

In addition, <Table 10> is a partial extraction of minimum standard of channel surveying specified by IHO. Maximum allowable total vertical uncertainty (TVU) in confidence level of 95% satisfies minimum 26cm in special grade that is the highest grade and interpolation that may perform spatial interpolation considering barrier like coastal line was considered to be Spline with barrier interpolation using curvature technique.

Table 10. Allowable TVU by each water depth in special grade(Source : IHO)

Depth of water	Order	Total Vertical Uncertainty
10m	Special	0.26m

20m		0.29m
30m		0.33m
40m		0.39m

4. CONSTRUNCTION OF ELLIPSOID BASED TIDAL DATUM

4.1 Conversion to each tidal datum

Through previous test, ellipsoid based average sea water surface height from ellipsoid of each tidal bench mark to average sea water surface was constructed by using spline with barrier interpolation. In tide model, when adding and abstracting as much as semirange of four largeness tide value, it could be converted to approximate highest high water, tidal datum of approximate lowest low water. Among diversified tide models, tidebed system of Korea Hydrographic and Oceanographic Agency that is applicable to overall waters of our country was utilized and by extracting range identical with that of test target region, conversion to app. lowest low water and app. highest high water was performed.[Fig. 5] is a fig. of extracting semirange sum of four largeness tide value of test target region by using tide model applied to this study. In [Fig.5] is Fig. that constructed tidal datum of app. highest high water, app. lowest low water by adjusting height from ellipsoid height to mean sea level as much as semirange sum of four largeness tide value from ellipsoid based mean sea level data by using spatial interpolation.

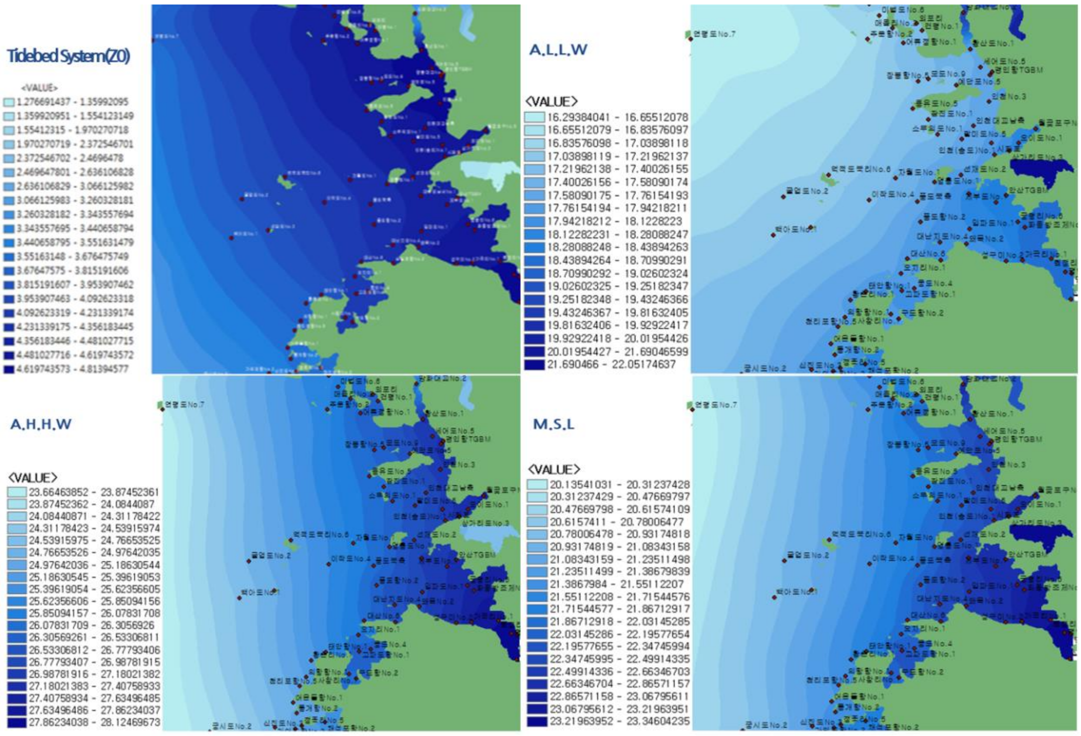

Figure 5. Construction of ellipsoid based tidal datum

4.2 Analysis of ellipsoid based tidal datum

After constructing ellipsoid based mean sea level by using Spline with barrier interpolation, as a result of comparative analysis with actual observed value as to whether conversion to app. highest high water and app. lowest low water was well performed, following <Table 4-1. could be obtained.

Table 11. Observed value and forecasted one by each tidal datum (Unit : m)

		Observed value(D.L)	Forecasted Value(D.L)	Observed Value(A.H.H.W)	Forecasted value(A.H.H.W)
1	Gungpyeong hang	18.3842	18.3992	27.3982	27.4054
2	Deokjeokdo bukri	17.0583	17.1125	25.3063	25.2649
3	Eoeundol hang	17.8332	17.8283	24.9592	24.9691
4	Incheon hang	17.7835	17.7147	27.0535	27.1265
5	Jumun hang	16.8761	16.8872	25.7861	25.7802
6	Palmido	17.6079	17.6136	26.6859	26.6905
7	Pungdo hang	17.8375	17.8493	26.4395	26.4404
8	North of Pungdo	17.5720	17.6211	26.8000	26.7631
9	South of Incheon Grand bridge	17.6430	17.6188	26.1310	26.1594
RMSE			0.03529		0.03235

In case of app. highest high water and app. lowest low water, as RMSE was represented as 3.235cm, 3.529cm, respectively, it satisfied allowable error specified by IHO. Therefore, it could be confirmed that conversion to app. highest high water and app. lowest low water was performed well.

5. CONCLUSION

At present, it is global tendency to unify vertical standard as standard ellipsoid and as tidal correction is performed after water depth surveying, heavy loss of time and economy is taken place. However, as water depth could be determined without tide observation through construction of ellipsoid based tidal datum, business efficiency and budget reduction effect could be obtained and if combining water depth data with vessel draft in real time, it is considered to be useful for safe vessel voyage by implementing dynamic electronic navigation chart. However, in case of open sea where tidal bench mark information is insufficient, as it interprets oceanic physical information being obtained through satellite altimeter data or GNSS buoy, it would be required to perform a research on constructing ellipsoid based tidal datum for offshore and open sea.

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BIOGRAPHICAL NOTES

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