The Development of Accuracy Maintenance Method for Mobile Mapping System (MMS) Data at GPS Invisible Area

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Key words: Mobile Mapping System, Land Mark Update, GPS Invisible Area, Accuracy Maintenance

SUMMARY

The approach in the field of the maintenance of topographic map data has been improved significantly. The remarkable representative is three-dimensional measurement of road space using Mobile Mapping System (MMS). However, measurement accuracy of the MMS data is highly dependent on the GPS satellite constellation, the number and the signal acquisition situation.

In such situation, so called Land Mark Update (LMU) technique which corrects MMS vehicle position using control points is employed to maintain accuracy. The accuracy investigation of LMU and development of accuracy maintenance method for MMS measurement data at GPS invisible area were carried out.

From result of study at 3 test route where there are characteristic of horizontal and vertical alignment, we have established the accuracy maintenance method for MMS measurement data.

This method is very useful and valid for tunnel mapping and/or very busy main road mapping where re-observation is difficult and it is usable to create road management map quickly and precisely.

要約

近年,我が国における地形図データの整備手法は,著しく発展してきた.その代表といえるものが,モービルマッピングシステム(Mobile Mapping System)による道路空間 3 次元計測である.しかし,MMS 計測データの精度は,GPS 衛星の状態,数,信号の取得状況に大きく左右される.
そこで,調整用基準点を用いた MMS 車両位置の補正処理(ランドマークアップデート)の精度検証を行い,GPS 衛星不可視区間における MMS 計測データの高精度化手法について検討した.
我々は,路線形状に特徴がある 3 区間を対象に検討した結果をもとに, MMS 計測データの高精度化手法を確立した.
これらの成果は,トンネルや再計測が困難な交通量の多い幹線道路において有効であり,迅速かつ高精度な道路平面図作成に利用できる.

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1. INTRODUCTION

Roads are improved and maintained depending on the roles of which serve as transport routes, minelayers of lifelines and also refugee roads at disaster and also needs of users. To improve the roads safety and convenience, road authorities need the data to be used to comprehend 3D shape of the road space and its deformation quickly and accurately.

Recently, Approaches in the field of the maintenance of topographic map data have been improved significantly in Japan. The biggest one is three-dimensional measurement of road space using Mobile Mapping System (MMS). Measurement accuracy of the MMS data is highly dependent on GPS satellite constellation, the number of satellites and the signal acquisition situation. While enough GPS satellite signals are captured, the absolute accuracy of the position i.e. latitude, longitude and altitude is accomplished less than 10cm.

However there are so many GPS invisible area in the geospatial space such as urban and mountainous area in Japan. It is expected that maintenance of topographic map can be improved efficiently and secondly use of map data in various purpose is prospected if the MMS measurement data in such area can be improved. In this paper, from these perspectives, accuracy investigation of Land Mark Update (LMU) which corrects MMS vehicle position utilizing ground control point was carried out and depending on this result development of accuracy maintenance method in GPS invisible area was considered. Established accuracy maintenance method can be expected that it contributes to common use of MMS and the rapid and steady supply of national infrastructure data.

2. GENERAL DESCRIPTION OF MMS

MMS developed by MITSUBISHI ERECTRIC CORPORATION obtains its position and orientation accurately by 3 GPS antennas which allocated as triangle constellation, IMU and odometer. Each collected laser point is given geographical coordinates and superimposed onto imagery captured simultaneously. By using the MMS data, very accurate road 3D spatial information can be obtained. In Fig.1, the system configuration of MMS (Type-S) and in Fig2., collected MMS measurement data(laser point cloud and imagery) are displayed.

The key facility and technology to achieve precise positioning of MMS are Japanese GPS permanent ground control network (GEONET) and commercial real time kinematic GPS services which utilize 1sec interval real time data derived from GEONET. GEONET consists of approx.1,200 GPS continuous observation stations which are well distributed all over the country. The average distance between the stations is about 25km. VRS (Virtual Reference

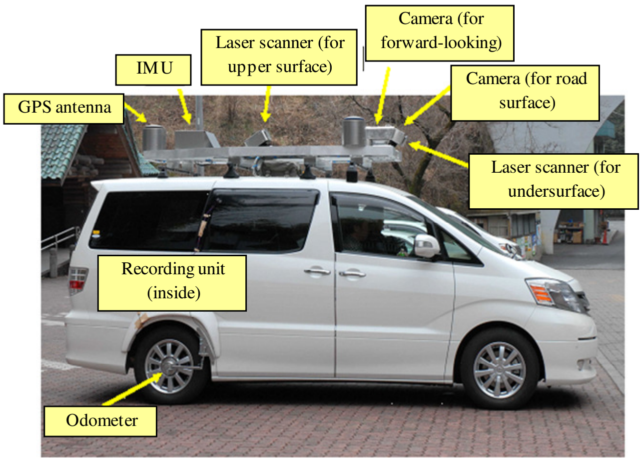


Fig.1 System configuration of MMS (TYPE-S)

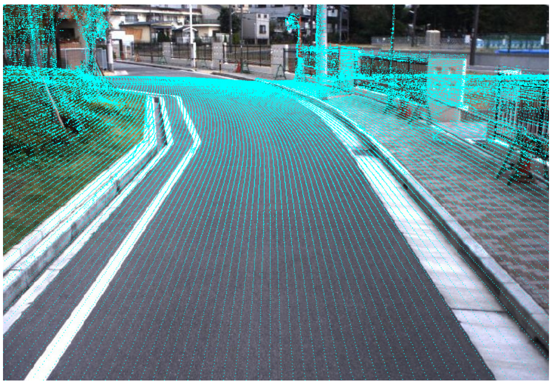


Fig.2 MMS measurement data

Station) and FKP(Flaechen Korrectur Parameter) services are available. For MMS, FKP method is adopted.

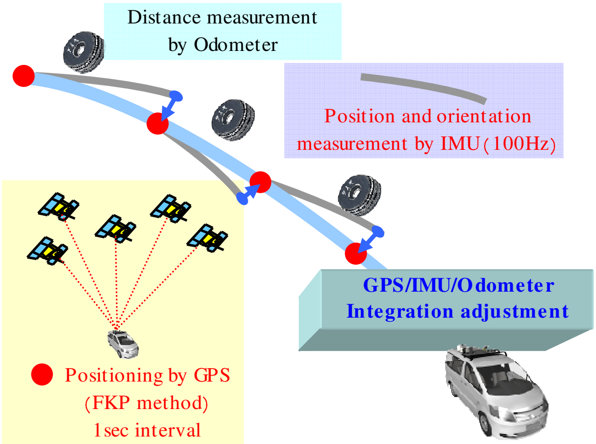


Fig.3 Concept of MMS data integration

By using 3 GPS receivers set as triangle configuration the position and also orientation of MMS are determined precisely. In addition, IMU observe acceleration and angler rate at 100Hz and calculates attitude and relative position of MMS. However the position error by IMU is accumulated over time. To avoid it and to determine the precise trajectory, integration of GPS precise positioning data which observed at satellite visible area and IMU data which interpolates during satellite invisible area is carried out. Furthermore distance measurement result by odometer is also integrated. Fig.3 is the concept of data integration. By this integration method, stable and precise vehicle position of the MMS can be kept even in GPS invisible areas and/or wide and long distance mission.

3. ESTABLISH OF MAPPING PROCEDURE USING MMS AND ITS PROBLEMS

3.1 Establish of mapping procedure using MMS

An effort of topographic mapping by using MMS was started in 2008 as an internal project in PASCO CORP. and since then, accuracy investigation of MMS measurement data and establishment of MMS operation manual have been carried out and its success has steadily increased. In 2010 MMS was employed in the first-ever public mapping project to update road administration map of TOYONAKA CITY in OSAKA prefecture. The result of this project was checked by the Japan Association of Surveyors and certified as public mapping result by GSI (Geospacial Information Authority of Japan) after its evaluation.

Through this project we confirmed that MMS can reduce field surveying task drastically and lead to approx.10% reduction of total cost and approx.30% reduction of total project period respectively.The reduction of field surveying task is also very effective in ensuring safety. At present, MMS is adopted by many local municipalities and is firmly fixed as a value-added and efficient method of topographic mapping.

3.2 Problem at satellite invisible area

In case of MMS, GPS, IMU and odometer data are integrated to process precise vehicle position and thus most important factor is to observe sufficient number of GPS satellites during MMS mission. However there are GPS-invisible areas where GPS signals are obstructed by buildings, overpass and trees along a road. The vehicle positioning at invisible areas is highly dependent on IMU and odometer data. Therefore longer invisible period results in lower accuracy of vehicle position since IMU positioning error is accumulated over time. In such situation, so called Land Mark Update (LMU) technique which corrects vehicle's position using control points is employed to maintain accuracy. The accuracy investigation of LMU and development of accuracy maintenance method for MMS measurement data at GPS invisible areas are carried out.

4. LAND MARK UPDATE

The LMU method developed by MITSUBISHI ERECTRIC CORP. consists of processes to correct MMS vehicle position by using coordinates of ground objects (land mark) observed by GPS and/or total station as ground control point(Kajiwara, et al, 2008). Fig.4 is its overview.

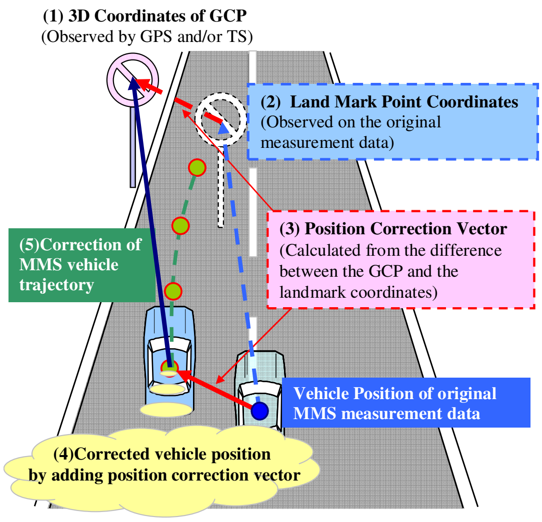


Fig.4 Overview of correction

4.1 Process of LMU

4.1.1 Ground coordinates observation of ground control point (GCP) Fig4. (1)

3D coordinates of GCPs for the LMU are observed by using network RTK-GPS method and/or total station. Ground objects which can be identified clearly e.g. street inlet, corner of the road marking, traffic sign are selected as GCP.

4.1.2 Land mark point coordinates observation Fig.4 (2)

Observe the position of land mark point selected at step1 in the original (uncorrected) measurement data using LMU tool.

4.1.3 Calculate position correction vector Fig.4 (3)

Calculate position correction vector depending on the discrepancy between the coordinates obtained in STEP1 and STEP2.

4.1.4 Correction of vehicle position Fig.4 (4)

Calculate corrected vehicle position by adding position correction vector calculated in STEP3 to vehicle position of original MMS measurement data. This vehicle position is treated as virtual GPS observation data.

4.1.5 Correction of MMS vehicle trajectory Fig.4 (5)

Correct MMS vehicle trajectory by re-adjusting of GPS/IMU/Odometer data with calculated virtual GPS observation data.

4.2 Updating MMS measurement data

Finally laser point cloud data are updated using corrected MMS vehicle trajectory data by LMU.

5. ACCURACY INVESTIGATION OF LMU

5.1 Objective of accuracy investigation

In this study, accuracy investigation of the corrected MMS measurement data by LMU and the mapping data derived from these corrected data were carried out to confirm the ability of MMS. The target mapping scale is 1/500 and required accuracy is 25cm RMS for both horizontal and vertical.

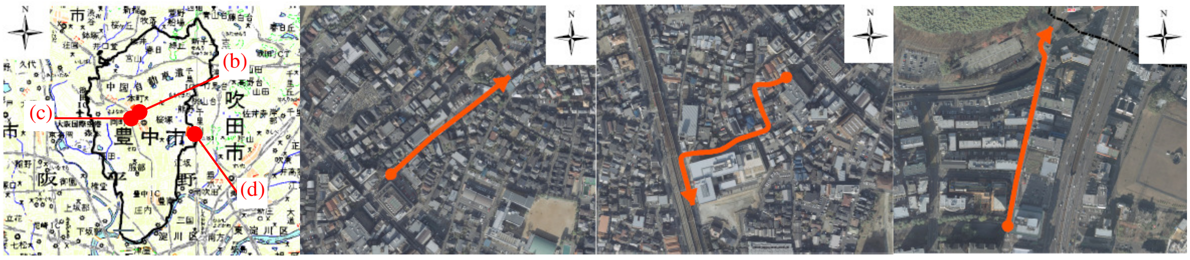
5.2 Overview of accuracy investigation

5.2.1 Test field

The accuracy investigation observation was carried out at TOYONAKA CITY in OSAKA prefecture.In Fig5. test route are displayed. One straight road is selected as standard test route. In addition, two other routes which includes ell-curve and inflection point of longitudinal slope were selected to check the influence of MMS vehicle motion (heading and pitching) in GPS invisible area.

5.2.2 Used MMS measurement data

The details of used MMS measurement data is shown in Table 1. All of the test data was captured on 18.Dec.2009. The observation was carried out during periods of sufficient GPS satellites were visible.



(a) Test Field (TOYONAKA CITY) (b) straight section (c)ell-curve section (d)longitudinal slope section

Fig.5 Accuracy investigation route

However due to influence of overpass, building and also traffic condition sufficient GPS could not be observed. Consequently the estimated posteriori error (EPE) value, index value for MMS vehicle position accuracy derived from position and orientation adjustment, exceeded limitation which defined in our operating manual.

Table.1 Details of MMS mission

Test Field	Measurement Date	Route	Measurement Time	Estimated Posteriori Error(EPE)
TOYONAKA CITY	18.Dec.2009	straight section	13:07:47～13:08:23	1.718m
		ell-curve section	12:50:02～12:51:15	1.710m
		longitudinal slope section	10:35:58～10:37:32	2.390m

5.3 Adoption of land mark

LMU corrects vehicle position using position correction vector which created from coordinates of land mark in the original MMS measurement data and its ground surveying data (true coordinate value).Therefore selected land marks must be able to identify clearly in the imagery captured by MMS and the objects must be represented by laser point cloud absolutely.
The objects selected as land mark are corner of the parcel line, manhole and corner of the gutter.

5.4 Ground coordinates observation of land mark

Ground coordinates of land mark was observed by network RTK-GPS (FKP method) and TS. 3D coordinates were observed. The accuracy level of land mark coordinates refer to the 4th order control point survey standard of Japan. In addition, some extra objects were also observed as check point to confirm accuracy of corrected MMS measurement data by LMU and mapping data derived from it.

5.5 Accuracy investigation of LMU

5.5.1 <u>LMU processing</u>

MMS vehicle position is calculated by GPS/IMU/Odometer data integrated adjustment. In this process interpolation between GPS observed point is carried out and precise vehicle position is calculated. Vehicle position correction by LMU is needed due to lack of GPS satellite during MMS mission. Therefore interval distance between virtual GPS observation points derived from LMU should be considered to keep precise vehicle position comparable to state when sufficient GPS satellites are available. To confirm it vehicle position correction by LMU with 4 different setting where interval distance of 150m, 100m, 50m and 25m was carried out. Original data set without correction was also processed to provide data for comparison. MMS data were captured at standard mission velocity of 40km/h therefore 150m corresponds to 14sec and 100m corresponds to 9sec respectively.

5.5.2 Investigation of vehicle position

Depending on the result of vehicle position correction by LMU confirmation and investigation of EPE was carried out. The results of vehicle position correction by LMU with each interval distance are shown in Fig.6. It is confirmed that MMS vehicle position correctionis activated by LMU and its accuracy is improved. Especially improvement of vehicle position at neighborhood area of land mark position is prominent. It means that the GPS/IMU/Odometer data integrated adjustment was carried out depending on the virtual GPS observation data and observation data close to the land mark points was corrected. In case of long interval distance, however, vehicle position correction could not be completed due to the error accumulated over time.

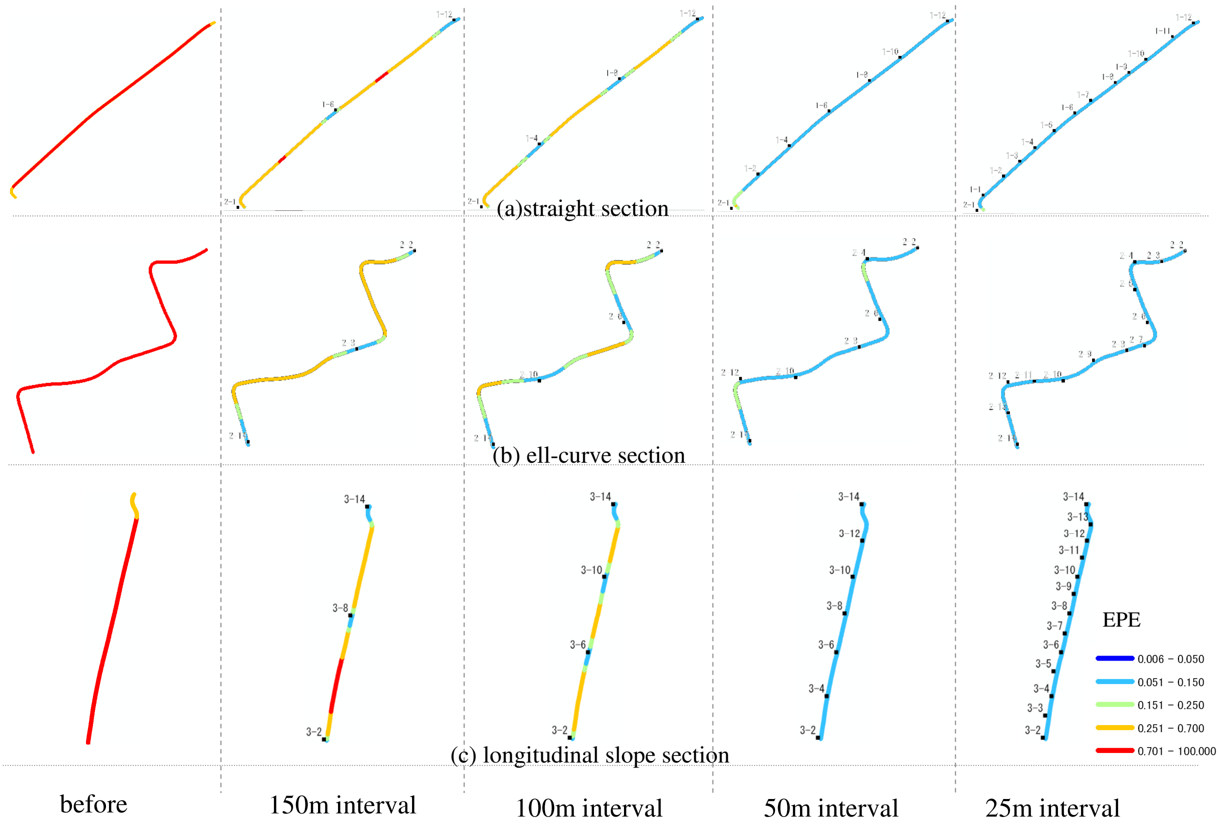
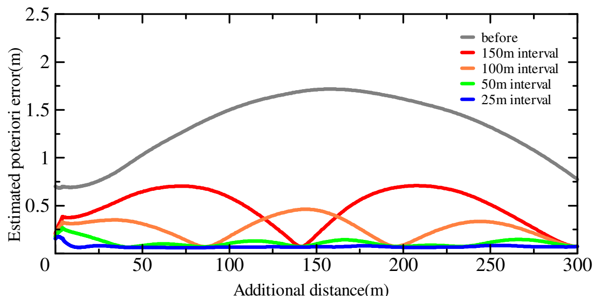


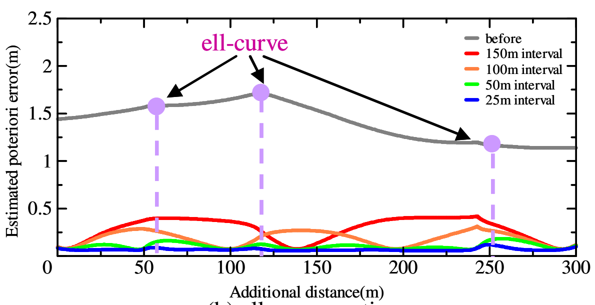
Fig.6 Distribution of EPE for each interval distance

Fig.7 shows transition of EPE for each land mark interval setting. Vertical axis is EPE and horizontal axis is additional distance respectively. AS shown in fig7. each EPE undergo a transition nearly constant intervals. The position where EPE is converged is the point where land mark is placed. The maximum EPE appears at midpoint of each land mark point. This is why that interpolation and correction of GPS/IMU/Odometer integration adjustment were done from both forward and reverse direction. Therefore most effective land mark point location is the point where EPE shows maximum value.

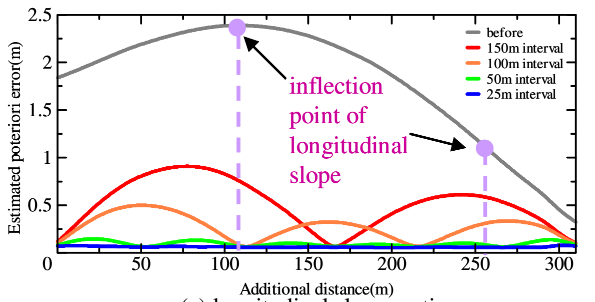
The influence of vehicle motion (heading and pitching) to the vehicle position estimation was also analyzed. In Fig6.(b) distribution of EPE at ell-curve is displayed. The ell-curves are correspond to the position at additional distance of 50m, 120m and 250m points. In case of 100m interval distance of land mark accuracy of vehicle position is degraded. In the mean time in case of 50m interval degradation happens only at ell-curves section. Fig7.(b) shows transition of EPE at ell-curve section. 50m interval case (plotted green line) also shows drastic change of transition at ell-curve. Thus motion of vehicle (heading) have much effect on the



(a) straight section

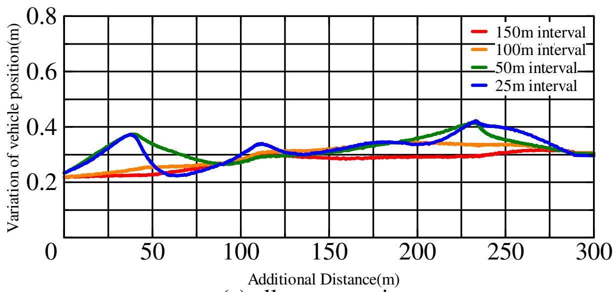


(b) ell-curve section

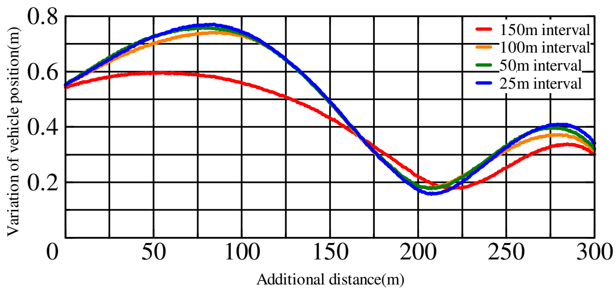


(c) longitudinal slope section

Fig.7 Transition of EPE for each interval distance



(a) ell-curve section



(b) longitudinal slope section

Fig.8 Variation of vehicle position

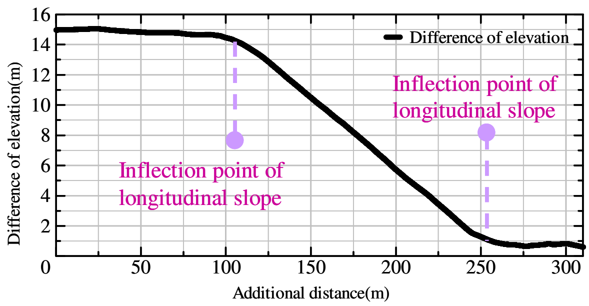


Fig.9 vertical profile based on the minimum height vehicle position accuracy. Additionally the relative vehicle position variation was also checked. Fig.8(a) shows variation of vehicle position at ell-curve section. Vertical axis is variation of vehicle position based on the original uncorrected position and horizontal axis is additional distance respectively. In case of 50m and 25m interval distance where land mark point was located around ell-curve the variation of position is significantly increased. Thus it supposed that land mark which located near ell-curve also has effect on the vehicle position correction.

Fig6.(c) and Fig7.(c) shows EPE and transition of EPE at inflection point of longitudinal slope respectively. In Fig9.vertical profile based on the minimum height around inflection point of longitudinal slope section is displayed. As shown the inflection point of longitudinal slope is position at 100m of additional distance. From this point it goes down about 15m and then inflection point appears again at 250m of additional distance. It is expected that this change also have some influence to the position accuracy. However there are influences of land mark point interval but any clear influence of vehicle vertical motion (pitch). Same as before the relative vehicle position variation was also checked. Fig.8(b) shows variation of vehicle position at inflection point of longitudinal slope. Vertical axis is variation of vehicle position based on the original uncorrected position and horizontal axis is additional distance respectively. In case of 100m, 50m and 25m interval distance where land mark point was located around inflection point the variation of position is significantly increased. Thus it supposed that land mark which located at inflection point also has effect on the vehicle position correction.

As mentioned before investigation of MMS vehicle position at each test route was carried out and it is confirmed that shorter interval of land mark improve vehicle position accuracy. It is also suspected that the vehicle motion at ell-curve (heading) also have influence to the vehicle position accuracy. Moreover it is expected that set up of land mark at inflection point of vehicle orientation (Heading,Pitch) has effect to the correction of vehicle position. However the effect of vehicle position correction is not yet confirmed at this stage. Therefore accuracy investigation of laser point cloud data which corrected by LMU was carried out by comparing to the ground survey data (check point).

5.5.3 Accuracy investigation of laser point cloud

Following the investigation of vehicle position accuracy of laser point cloud corrected by LMU was also evaluated. The check point residuals for each rand mark interval are shown in Table2.The check point residual is discrepancy between check point coordinate observed by network RTK-GPS and TS and the coordinate observed on the point cloud. Fig10. shows distribution of residuals for each check point depending on the Table2. Each check point was located at midpoint between land mark point where EPE indicated maximum value. The example of check point is displayed in Fig11.

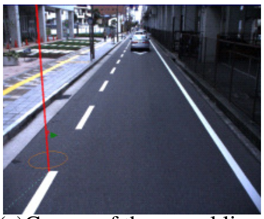
Fig10.(a) is distribution of check point residuals at straight road. Almost uniform effect of LMU is confirmed on all check point residuals after correction (150m to 25m). Check point 1-1 is close to intersection and expected that vehicle motion (heading) had some influence.

There for it was excluded and rest check point 1-2 to 1-11 was evaluated as standard straight road data. To evaluate accuracy of laser point cloud reference value is needed. In this study value of 0.15m was selected as this reference value depending on the Japanese mapping standard.

In case of 150m interval residuals of check point 1-2 and 1-3 exceeded 0.1m. Therefore 150m of land mark interval is not sufficient to keep stable accuracy level of 0.15m which required for laser point cloud accuracy. On the other hand in case of 100m, 50m and 25m interval all of the check point residuals achieved better than 0.1m (maximum 0.077m). Even there are 2-3 cm deviations between each interval setting it can be evaluated as keeping a similar accuracy level. Thus at straight road 100m interval should be considered as standard.

Table.2 3D residuals of laser point

Route	Check Point	Before	150m interval	100m interval	50m interval	25m interval
straight section	1-1	0.391m	0.197m	0.167m	0.099m	0.030m
	1-2	0.300m	0.129m	0.077m	0.018m	0.003m
	1-3	0.243m	0.109m	0.057m	0.029m	0.007m
	1-5	0.215m	0.070m	0.029m	0.028m	0.024m
	1-6	0.209m	0.015m	0.064m	0.005m	0.008m
	1-7	0.308m	0.046m	0.073m	0.032m	0.032m
	1-9	0.577m	0.067m	0.003m	0.010m	0.006m
	1-10	0.679m	0.074m	0.006m	0.013m	0.025m
	1-11	0.656m	0.075m	0.044m	0.055m	0.042m
ell-curve section	2-3	0.297m	0.113m	0.097m	0.113m	0.012m
	2-4	0.241m	0.189m	0.179m	0.046m	0.021m
	2-5	0.061m	0.115m	0.079m	0.097m	0.074m
	2-7	0.178m	0.094m	0.056m	0.077m	0.023m
	2-8	0.166m	0.082m	0.099m	0.071m	0.051m
	2-9	0.181m	0.095m	0.038m	0.040m	0.014m
	2-11	0.305m	0.054m	0.046m	0.050m	0.017m
	2-12	0.494m	0.168m	0.155m	0.007m	0.059m
	2-13	0.518m	0.073m	0.079m	0.040m	0.022m
longitudinal slope section	3-3	0.628m	0.054m	0.014m	0.030m	0.031m
	3-4	0.756m	0.162m	0.041m	0.041m	0.007m
	3-5	0.787m	0.209m	0.039m	0.026m	0.030m
	3-7	0.568m	0.101m	0.025m	0.027m	0.020m
	3-8	0.363m	0.077m	0.038m	0.027m	0.047m
	3-9	0.189m	0.070m	0.041m	0.031m	0.076m
	3-11	0.289m	0.176m	0.124m	0.075m	0.040m
	3-12	0.390m	0.140m	0.087m	0.036m	0.025m
	3-13	0.395m	0.066m	0.039m	0.057m	0.048m

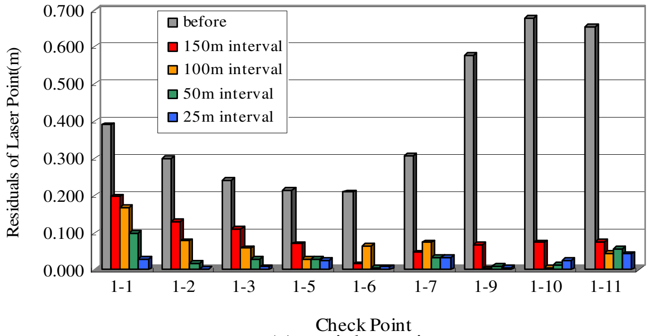

(a)Corner of the parcel line


(b) Corner of the gutter

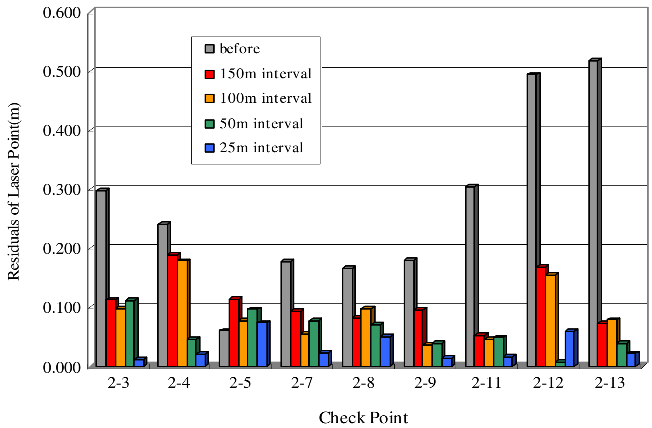

(c)Eedge of the gutter


(d) Manhole

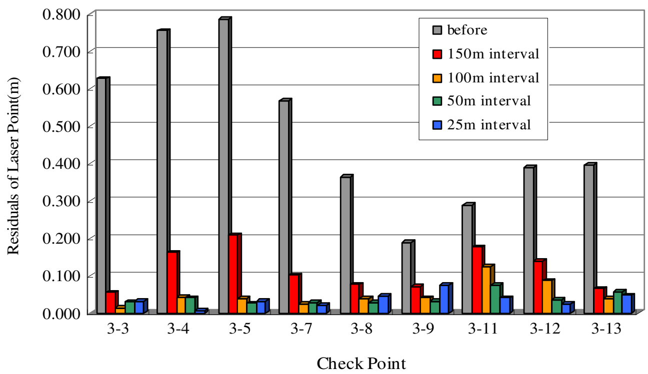
Fig.11 Check point for laser point checking



(a) straight section



(b) ell-curve section



(c) longitudinal slope section

Fig.10 Distribution of 3D residuals of laser point

Fig10.(b) is distribution of check point residuals at ell-curve section. In case of 150m interval residuals of check point 2-3, 2-4, 2-5 and 2-12 exceeded 0.1m. In especial check point residuals of 2-4 and 2-12 exceeded 0.15m. Therefore as same as before 150m of land mark interval is not sufficient to keep stable accuracy level of 0.15m. In case of 100m interval check point residuals of 2-4 and 2-12 still exceeded 0.15m while rest points achieved better result of less than 0.1m (maximum 0.099m). Check point 2-4 and 2-12 is close to ell-curve. It is confirmed that vehicle motion (heading) has a influence to the position accuracy and it is one of the factor of accuracy degradation.

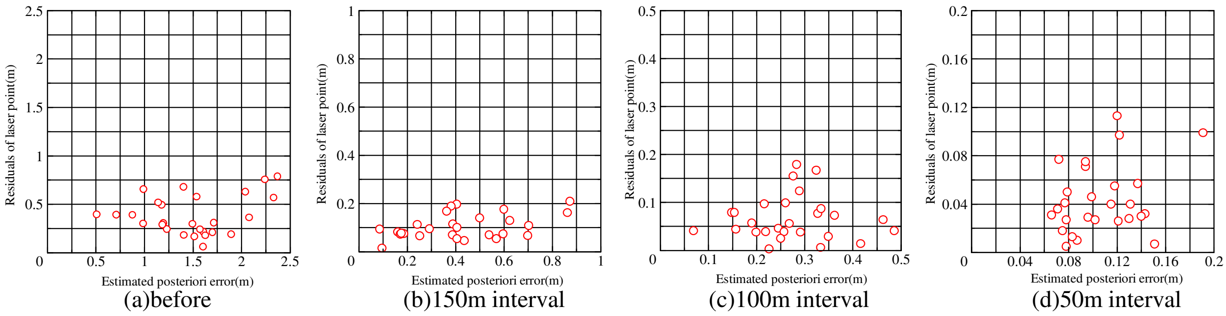
Continuously 50m and 25m interval cases were also evaluated. In this case it is confirmed that the check point residuals of 2-4 and 2-12 were highly improved. As shown in Fig.6(b) land mark points were located near ell-curve. It is expected that these point assignment effected on the accuracy improvement.

Fig10.(c) is distribution of check point residuals at inflection point of longitudinal slope. In case of 150m interval residuals of check point 3-4, 3-5, 3-7, 3-11 and 3-12 exceeded 0.1m. 150m interval is again not sufficient. In case of 100m interval check point residuals form 3-3 to 3-9 indicated keeping stable accuracy. However 3-11 and 3-12 indicated large residuals comparing to the other points. Check point 3-11 and 3-12 is located at 250m additional distance point and here is inflection point of longitudinal slope where it is changed from down slope to flat. From this result it is also confirmed that vehicle motion (pitch) has a influence to the position accuracy and it is one of the factor of accuracy degradation.

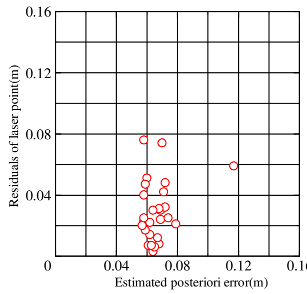
In case of 50m and 25m interval check point residuals of both 3-11 and 3-12 was improved about 5cm. In this case land mark point is located near inflection point of as shown in Fig.9. It is also expected that these point assignment effected on the accuracy improvement at inflection point.

In conclusion it is confirmed that LMU has effective correction capability by selecting appropriate location. In the area where vehicle motion is relatively small 0.15m of criteria can be achieved by adopting 100m land mark interval. Based on this result and taking into account of efficiency of production work 100m is defined as standard land mark interval. On the other hand the area where some vehicle motion is supposed 100m interval is not sufficient. In this case additional land mark point should be located at these points. The result of empirical accuracy investigation under defined land mark point assignment is mentioned in the next chapter.

Furthermore from result of this study there were a quite number of sections where laser point cloud had a precise accuracy even EPE indicated lower accuracy. Fig.12 shows the relationship between EPE and check point residuals of laser point cloud for each case i.e. uncorrected original, LMU with 150m, 100m, 50m and 25m interval distance. As shown in Fig.12 EPE always tends to indicate a value greater than the actual error. The relationship and correlation should be clarified though more research projects in the future.



(a)before (b)150m interval (c)100m interval (d)50m interval



(e)25m interval

Fig.12 The relationship between EPE and check point residuals of laser point cloud

6. OPTIMAL ASSIGNMENT OF LAND MARK POINT

To establish optimal land mark point assignment method empirical accuracy investigation under defined land mark point assignment was carried out.

6.1 Result of accuracy investigation at ell-curve section

Land mark point was assigned with 100m interval and also added at near ell-curve (check point2-12, at 250m of additional distance.) In Fig13.(a) the result of correction by LMU, EPE and its transition are displayed. As shown in Fig13.(a) the accuracy of vehicle position around check point 2-12 where land mark point was added was improved.

Consecutively accuracy investigation of laser point cloud corrected by LMU was carried out. In Fig13.(b) distribution of Check point residuals are displayed. Check point 2-4 which is laid near ell-curve shows large residuals. However this point was eliminated from evaluation of this study since there was no land mark points added around it. As shown in Fig13.(b) the accuracy of laser point cloud near check point 2-12 where land mark point was added is improved and it is confirmed that it fully fulfils criteria of check point residuals (equal less than 0.15m). From these result defined optimal land mark point assignment method is effective and then accuracy maintenance method at ell-curve section was established.

6.2 Result of accuracy investigation at inflection point of longitudinal slope

Land mark point was assigned with 100m interval and also added at near inflection point of longitudinal slope (check point3-12, at 250m of additional distance.) In Fig14.(a) the result of correction by LMU, EPE and its transition are displayed. As shown in Fig14.(a) the accuracy of vehicle position around check point 3-12 where land mark point was added was improved.

As same as before accuracy investigation of laser point cloud corrected by LMU was carried out. In Fig14 .(b) distribution of check point residuals are displayed. As shown in Fig14.(b) the accuracy of laser point cloud near check point 3-12 where land mark point was added is improved and it is confirmed that it fully fulfils criteria of check point residuals (equal less than 0.15m). From these result defined optimal land mark point assignment method is

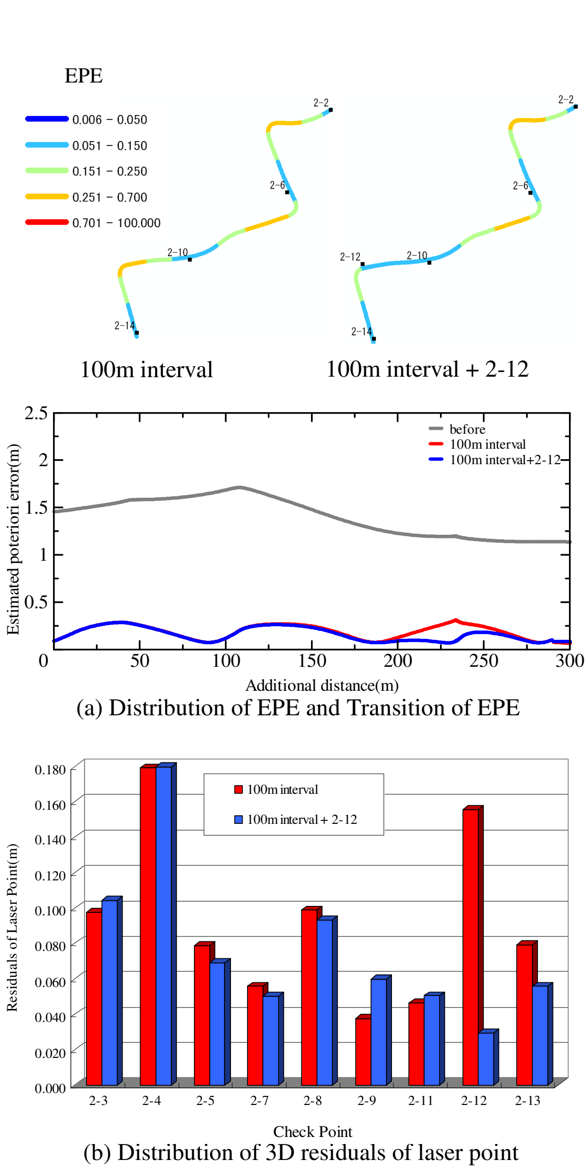


Fig.13 Result at ell-curve section

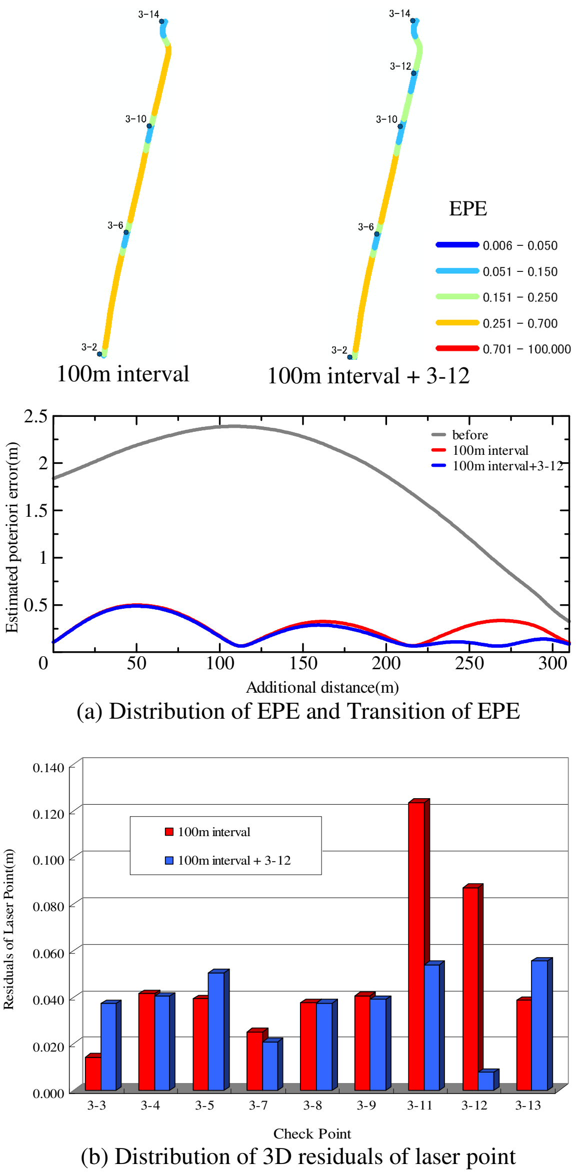


Fig.14 Result at inflection point of longitudinal slope

effective and then accuracy maintenance method at inflection point of longitudinal slope was established as well.

6.3 Optimal assignment method of land mark point

Depending on the previous investigation result optimal assignment method of land mark point was established. The definitions are shown in table.3. The

Table.3 Optimal assignment

Route	Optimal Assignment Method of Land Mark Point
straight section	100m interval
ell-curve section	100m interval and additional point at inflection point
longitudinal slope section	100m interval and additional point at inflection point

standard interval distance of land mark point is 100m and additional point is allocated at inflection point.

7. ACCURACY INVESTIGATION OF MAPPING DATA

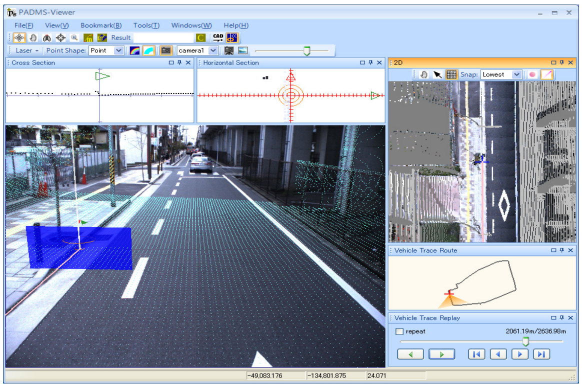


Fig.15 PADMS-Solid

Table.4 residuals of mapping point

	Res_X	Res_Y	Planimetric
RMS	0.074m	0.070m	0.102m
MAX	0.217m	-0.242m	0.242m
Reference Value			0.250m

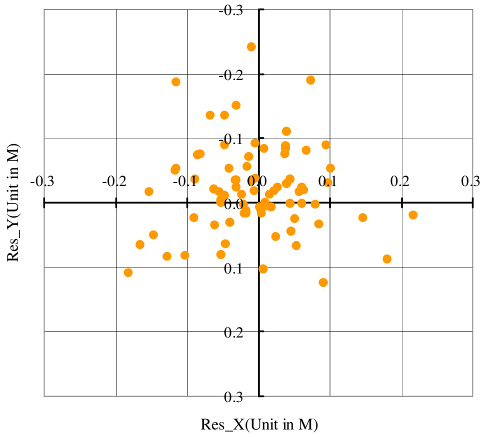


Fig.16 Distribution of mapping point residuals

Depending on our MMS operation manual, in which operational procedure, quality control and also some accuracy criteria is defined, mapping was carried out by using MMS measurement data (laser point cloud and imagery) after quality control process. In-house software [PADMS-Solid (PAsco Digital Mapping System-Solid Model)] was used for mapping process. (Fig.15) This accuracy investigation also has done by comparing coordinates observed by ground surveying using network RTK-GPS and TS and digital mapping data. The accuracy of mapping data was evaluated using these coordinate residuals. The result is listed in Table.4 and distribution of residuals is also shown in Fig16. As shown in this table and figure it is confirmed that the mapping point accuracy efficient to meet the requirement for 1/500 map i.e. position RMS equal less than 25cm defined in Japanese mapping standard. Therefore MMS measurement data which is corrected and updated by LMU can be used for official mapping project (1/500).

8. CONCLUSION AND FURTHER WORK

In this paper accuracy investigation of MMS vehicle position correction process using GCP and development of accuracy maintenance method for MMS data at GPS Invisible Area were discussed,

From result of study at 3 test routes where there are characteristic of horizontal and vertical alignment, we confirmed two things as follows.

— In case of standard data capture speed of 40km/h, 100m interval of land marks is sufficient.

— Additional land mark at inflection point (horizontal curve and vertical point) is very effective to improve laser point cloud accuracy.

By verifying these results it is confirmed that scale of 1/500 mapping by MMS is available even under GPS invisible area. This method is very useful and valid for tunnel mapping and/or very busy main road mapping where re-observation is difficult and it is usable to create road management map quickly and precisely.
PASCO has established [MMS operation manual] and now updating [MMS LMU manual].
In this paper optimal assignment method of land mark point based on the horizontal and vertical road profile is discussed. In order to examine more effective methods of assignment it is considered necessary to take into account of vehicle velocity and it is our future work.

REFERENCES

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BIOGRAPHICAL NOTES

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Akihisa Imanishi has been involved with Mobile Mapping System since 2008 and belongs to PASCO CORP. MMS High Accuracy Information Center at present. His experience is primarily based around advanced surveying technology for field and aerial survey. Akihisa holds a Surveyor of the national qualifications.

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