

# Performance Analysis of Single Point Positioning (SPP) and MADOCA-Precise Point Positioning (MADOCA-PPP) in Road/Lane Identification

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**ABSTRACT**— *The advancement in GNSS technology introduced many possible applications that involve its basic functions, namely Positioning, Navigation and Timing. Single Point Positioning (SPP) is the most common positioning technique that is instantaneous, however less accurate. Relative positioning was introduced to improve the point positional accuracy. However, this necessitates connection to a single GNSS receiver or network of GNSS receivers. Latest innovation in relative positioning is the Precise Point Positioning (PPP) that requires augmentation from satellite. This study explores the use of PPP utilizing the Quasi-Zenith Satellite System (QZSS). The QZSS is a satellite system operated by the Japanese Aerospace Exploration Agency (JAXA). It is also a satellite-based augmentation system (SBAS) complementing the Global Positioning System (GPS) whose signal can be received in Japan, some countries in East and Southeast Asia and in the Oceania region.*

*This study aims to evaluate the performance of QZSS, Multi-GNSS Advanced Demonstration of Orbit and Clock Analysis – Precise Point Positioning (MADOCA-PPP) in car navigation and road/lane identification. This will be compared with the current car navigation positioning using SPP (GPS-only). The data used was obtained from a probe experiment conducted on October 10-12, 2016 along the Skyway and non-Skyway routes between Buendia, Makati City and Bicutan, Parañaque City. The RTKLib software was used during data acquisition and also for processing the ground control points (GCPs). The GCPs were used to geo-reference the orthophoto map provided by NAMRIA to the WGS84 reference system. Digitization and comparative analysis were done using ArcGIS software. The road/lane identification was done by taking the distance from the centerline of the road/lane identified to be the route traveled by the car based on the experiment instruction. The vertical accuracy was assessed by comparing the point distances from the digitized line with heights extracted from Digital Surface Model (DSM).*

*The preliminary assessment using estimates of points per 100 m segment showed that MADOCA-PPP gave 74.59% of the estimates falling in the inner lane against the 32.21% of SPP (GPS-only) in the northbound Skyway run. In the southbound it is 52.06% and 9.58% for MADOCA-PPP and SPP respectively. The percentage of points going out of the road boundaries is at most 2.47% for MADOCA-PPP while SPP had a maximum of 40.7%. On the non-Skyway run, MADOCA-PPP still dominates the SPP on partially obstructed roads such as East Service Road, West Service Road and Pason Tamo. However, in Osmeña Highway where the road is located underneath the Skyway, PPP logged intermittently while SPP continuously logged data indicating continuous car movement albeit inaccurate. In the Skyway lane identification, the results showed that MADOCA-PPP gave a 0.92 m average distance from the lane centerline against 3.66 m average for SPP. This proves that MADOCA-PPP can better delineate the lane traveled by car as it is within 1.75 m (½ of the standard lane width of 3.5 m). On average, the vertical accuracy of MADOCA-PPP is 1.64 m against 10.67 m using SPP. The resulting average height from SPP is more than the minimum 4.9 m standard vertical clearance for roads hence; it could not provide clear vertical separation between roads compared to PPP.*

**Keywords**— Single Point Positioning, Precise Point Positioning, GNSS, QZSS, MADOCA

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## **1. INTRODUCTION**

At present, most car navigation systems rely on Single Point Positioning (SPP) using GPS for location and route determination. As of 2016 the global horizontal and vertical positional accuracy of said system were reported at around 2 m and 4 m respectively [1] but maybe more depending on the surrounding environment. The SPP, also known as absolute positioning or navigation solution, is a positioning technique characterized by a single receiver getting signals from at least 4 different satellites [2]. It does not use any post-processing techniques, and its position is not relative to any point with known position. This is usually done for instantaneous positioning, especially when only one receiver is available, or one cannot connect to any nearby base station. The main weakness of SPP is it relies on the data received from the satellites alone; however, the data also have significant errors which make the accuracy of SPP questionable [3]. Other options in getting more accurate positions for car navigation were investigated after SPP, such as Differential GPS/GNSS (DGPS/DGNSS), Real-time Kinematic (RTK) [4] and Network Real-Time Kinematic (NRTK) technologies [5]. DGPS/DGNSS basically works with a network of ground-based reference stations via pseudo ranging or code measurement unlike RTK that has centimeter level performance and operates around a base station, with known position, via carrier measurements and corrections coming from the base station [6]. However, these positioning techniques have not been fully exploited in most car navigation in the Philippines. Although the GNSS infrastructure is already available i.e. Active Geodetic Network Stations (AGNS) [7] from the National Mapping and Resource Information Authority (NAMRIA), such application in car navigation have not been tested.

Another technology emerged which could lead to more accurate car navigation: the Precise Point Positioning (PPP) technique [8]. It requires only one receiver like SPP, but it relies on satellite position and clock data which can be obtained from agencies providing GNSS service, instead of the satellites themselves in SPP [9]. The PPP also does not rely on simultaneous observations or connecting to previously establish base stations unlike DGPS, RTK or NRTK. It is very useful in remote areas, places beyond coastlines, or those areas where there are no Continuous Operating Reference Stations (CORS). The main disadvantage of PPP is the long convergence time taken before accurate measurements can be taken [10]. It usually takes 30 minutes to achieve centimeter- to decimeter-level accuracy [11]. For static PPP, 20 minutes are required for the accuracy to reach 20 cm or better, and 1 hour is recommended for an accuracy of 5 cm [12]. The better the accuracy required for a project or application, the longer the time one takes before measurements can be done. In urban areas such as Metro Manila, SPP accuracy is also degraded due to signal obstructions due to tall buildings and the dominance of multipath. The QZSS was designed to orbit in high elevations thus providing satellite availability in urban canyons [13]. The augmentation coming from the QZSS satellite is the core of the PPP. Despite the obvious technical advantage of PPP based on several literatures, it is not safe to assume that PPP will perform better than SPP since QZSS satellite reception in the Philippines is not yet tested and no study/studies in the local setting was carried out.

This study was viewed to test the Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) PPP [14] in the Philippines. As a way of evaluating its performance, a joint experiment between the University of the Philippines Department of Geodetic Engineering (UPDGE), Japan Aerospace and Exploration Agency (JAXA) and Honda Motor Inc. was conducted with focus on car navigation application. With latest technological innovations gearing towards “driverless” car navigation, the results of this study will provide assessments and inputs in how to improve this technology. The capability to precisely delineate one lane from the other will make car navigation system more detailed and hence more effective. From its present road-based direction guidance, car navigation can be stepped up to having specific lane-based instructions. Currently, SPP vertical accuracy based on 2016 data from International GNSS Service (IGS) is around 14 m [15] hence, road outlining between upper and lower road is practically not possible considering a standard road vertical clearance of 4.88 m [16]. This study analyzed further if MADOCA-PPP JAXA is capable of recognizing vertical separations of roads. This will further enhance the effectiveness of car navigation using satellite based system.

One of the limitations of this study is the non-availability of reference data to which the MADOCA-PPP and SPP could be validated. This reference data could be from RTK observation done simultaneously during the experiment. The accuracy assessment was based only on the data spread and relied on pre-experiment instructions on the road traveled by the car i.e. to travel in the inner lane for the Skyway run, and on the outer lane for the non-Skyway run. These were used as the reference lines for assessing the performance of MADOCA-PPP against SPP.

## **2. STUDY AREA AND DATA USED**

The joint experiment was conducted between Buendia, Makati City (14° 33' 27.79''N, 121° 00'26.84''E) and Bicutan, Parañaque City (14° 29' 13.03''N, 121° 2' 42.19''E) (Figure 1), covering a total road length of 7.3 km. It traversed Metro

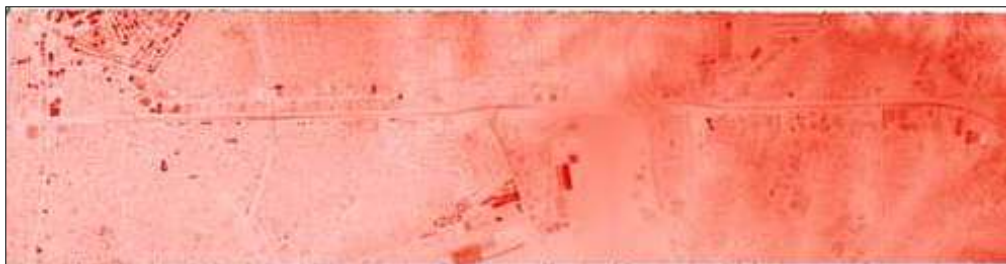
Manila Skyway, Osmeña Highway, West Service Road, East Service Road and Pasong Tamo. The Skyway run was an experiment on open or unobstructed area. Underneath the Skyway is Osmeña Highway where it is mostly obstructed. The rest of the roads traveled by the car were partially obstructed. Travel runs were classified as Skyway run (car traveling Metro Manila Skyway) and Non-Skyway run (rest of the roads). Both runs are classified as southbound (Buendia to Bicutan) and northbound (Bicutan to Buendia).



**Figure 1:** The study area (Source: Google Map)

The following data as described below were used to assess the performance of the SPP and MADOCA-PPP in road/lane identification:

1. *SPP (GPS-only) and MADOCA-PPP data.* These data were collected simultaneously by the receiver during the joint experiment on October 10 to 12, 2016. The SPP data is the instantaneous solution based on codes modulated on L1 frequency signal. The MADOCA-PPP data is the corrected data resulting from incorporations of global and local correction data. The global corrections coming from analysis of real-time data from Multi-GNSS Network (MGM-Net) such as clock and orbit corrections are generated by JAXA and uploaded to the QZSS satellite. The local correction data such as ionosphere and troposphere corrections are generated from local GNSS monitoring station, analyzed by JAXA and sent via internet to the user.
2. *Digital Surface Model (DSM) (Figure 2).* The DSM was obtained through a LiDAR (Light Detection and Ranging) aerial survey conducted last 2011. The high-resolution dataset has a 1 meter spatial resolution with an assessed vertical accuracy of 11 cm [17].



**Figure 2:** Digital Surface Model at 1 meter resolution

3. *Orthophoto map (Figure 3).* The map was provided by NAMRIA from an aerial photography taken during the conduct of the LiDAR survey. The spatial resolution is 25 cm and given in the local datum (PRS92). This was used as

reference during the digitization of the roads and lanes.

4. *Ground Control Points (GCPs)* (Figure 3). There were four (4) GCPs that were collected through 30-minute static observation using Trimble SPS855. This was done for the purpose of geo-referencing the map in PRS 92 to WGS 84. The GNSS observations were conducted on February 13, 2017 at four different locations (Figure 3) namely: 1) Gil Puyat Avenue corner Marconi Street, Pasay City; 2) Ayala Avenue corner Gil Puyat Avenue, Makati City; 3) DOST-Bicutan, Paranaque City; and 4.) Western Bicutan, Paranaque City. These four (4) points were chosen because they are easily distinguishable and are located near the edges of the orthophoto map. The observation data were post-processed using RTKLIB with PTAG on NAMRIA building as base station.



Figure 3: Orthophoto map and locations of 4 GCPs

### 3. METHODOLOGY

The general methodology of the study is shown in the flowchart (Figure 4) below:

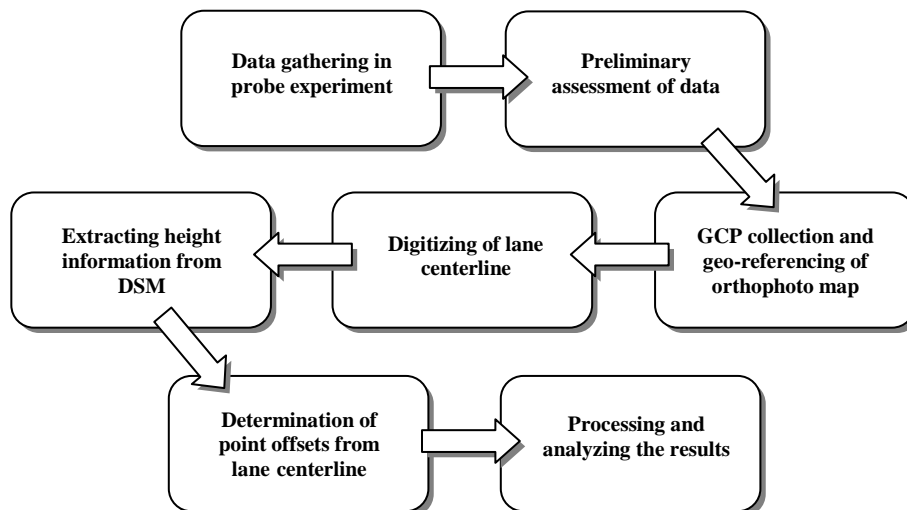


Figure 4: General methodology

### 3.1 Data gathering in probe experiment

In the probe experiment conducted last October 10-12, 2016, SPP data and data with augmentation i.e. MADOCA-PPP were simultaneously collected by GNSS receivers inside three (3) cars traversing the study area. The data collection of GPS data started in the patch antenna attached on top of the car. This inexpensive antenna with size about 56 mm can receive L1 signal from different navigation satellites. The signals then go to the U-Blox EVK-M8T receiver for processing of received C/A codes from L1. The U-Blox EVK-M8T receiver used in the probe experiment supports not only GPS but also QZSS, Galileo, GLONASS, and BeiDou satellite systems [18]. It can achieve high precision positioning through the combination of GNSS and Real-time Kinematic (RTK) technology. The MADOCA-PPP processor then incorporates correction received from the QZSS satellite and from Master Control Station in Japan via internet to further refine the data positions. The processed data goes to the Ethernet convertor and converts them into usable National Marine Electronics Association (NMEA) data. The data were sent to the server through internet which, can be downloaded after, thus continuous internet connection was necessary during the experiment. Figure 5 shows the data flow in the MADOCA-PPP system.

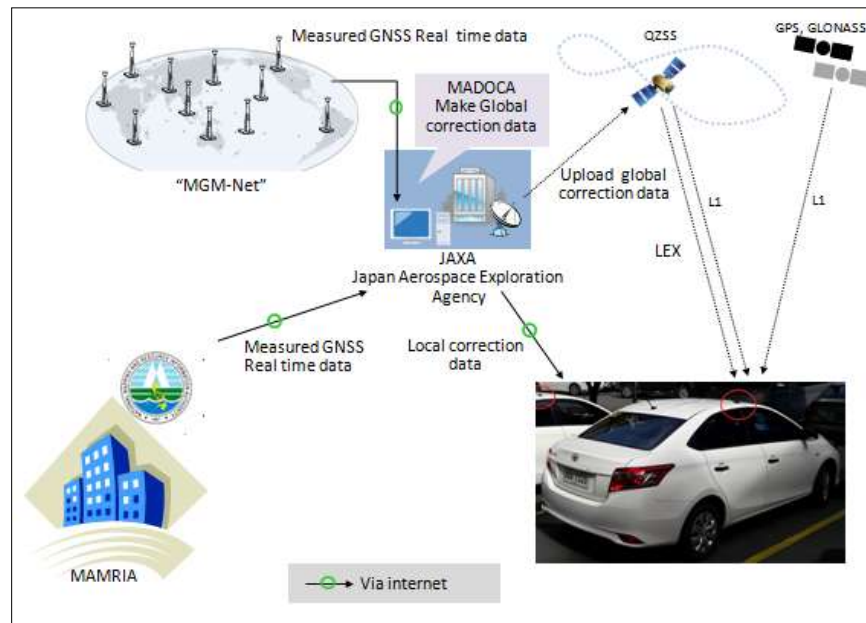


Figure 5: MADOCA-PPP system

### 3.2 Preliminary assessment of data from probe experiment

Preliminary assessment of the data from experiment was done to see in general how the SPP data compares with MADOCA-PPP especially in open areas. The assessment is done so as not to pre-judge that PPP is better than SPP. The MADOCA-PPP has not been tested in the Philippines and no assessment as to the quality of the signal received from QZSS satellite was done. Although, pre-experiment instruction was to travel on the specified lane but this was not 100% realized due to actual traffic conditions during the experiment.

### 3.3 Geo-referencing of orthophoto map to WGS84 datum

The orthophoto map was geo-referenced to the WGS-84 datum using the GCPs collected during the GNSS observations. The transformation parameters from PRS 92 to WGS 84 [19] were not used since these were not updated to the new version of WGS 84 in which the experiment data are referenced.

### 3.4 Measuring lane width and digitizing lane centerline

Traffic lane minimum width is typically 3.35 m [20]. To validate the lane width, measure tool of ArcMap was utilized in the geo-referenced map. The measured lane width from the image was 3.5 m. The digitizing of centerline to be used as reference for measuring offset of points from SPP and PPP methods was done in ArcMap. This was based on the pre-experiment instructions to drivers to drive in the inner lane in the skyway run and outer lane in the non-skyway run.

### 3.5 Extracting height information from DSM

From the digitized centerline the Interpolate Shape tool was used to give Z-values to every point on the centerline. The digitized centerline was provided with height attributes extracted from the DSM. The result was the centerline Z-value (reference line) attributes at every point so that the vertical offsets of the points from the experiment could be measured.

### 3.6 Measuring offsets from centerline

Using Near 3D tool of ArcScene, output distances of the points from the centerline were acquired. Output tables from SPP points and MADOCA-PPP points were then tabulated, compared and analyzed. The NEAR\_DIST column of the data points attribute table was used for the analysis in the horizontal direction.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Preliminary assessment of data from probe experiment

Initially, the data from the probe experiment was analyzed and counted for every 100-meter segment. The number of estimates is counts of road segments where points are located based on the lane traveled by car. High estimates indicate the probability of the road/lane traveled by the car. The result showed that in the skyway run northbound, MADOCA-PPP had 74.59% of the estimates falling in the inner lane against the 32.21% of SPP. In the southbound it is 52.06% and 9.58% for MADOCA-PPP and SPP respectively. The percentage of points going out of the road boundaries is 2.47% for MADOCA-PPP while SPP had a maximum of 40.7 %. Since pre-experiment instructions were to travel as much as possible in the inner lane, the results showed high percentage of estimates falling in the inner lane.

The car is running mostly on ground level for the non-skyway run. Osmena Highway is underneath the Skyway and mostly obstructed. Although it consists of several lanes but the car was instructed to run in the outer lane so that reception of GPS signal is still possible. However, due to traffic this was not 100% realized. The service roads were located besides the skyway and also obstructed by buildings on the sides. In the non-skyway run, the roads that are partly obstructed are East Service Road, West Service Road and Pasong Tamo. Based on the results MADOCA-PPP is still better than SPP. However, during the Osmena Highway run MADOCA-PPP is logging intermittently since no corrections are being received while SPP continuous to log points that indicates continuous car movement although very large offsets were observed. Some of the points also fell within the Philippine National Railway during this run, which is improbable. Outliers are also dominant in SPP with 23.20% in northbound and 29.6 % in southbound.

### 4.2 Lane identification (horizontal assessment)

The lane identification was made for the Skyway run where several lanes are distinguishable. From the digitized centerline, point offsets were determined using the Near 3D tool in ArcScene. The statistics of the results are indicated in Table 1 for Skyway run.

**Table 1:** Horizontal assessment results

Distance from centerline (m)	MADOCA-PPP	SPP
Average	0.92	3.66
Standard Deviation	0.68	3.04
Minimum	0.0004	0.0007
Maximum	8.01	27.59

On average the MADOCA-PPP gave a 0.92 m offset from the centerline with a standard deviation of 0.68 m. The SPP offset average from centerline is 3.66 m with standard deviation of 3.04 m. The half width of the lane is 1.75 m and judging from the resulting average, MADOCA-PPP is clearly within the specified lane. It could not be said for the SPP data wherein the average is twice the half lane width that could indicate the car is traveling on the adjacent lane or on the opposite road. Clearly, MADOCA-PPP can identify lane traveled than SPP. Figure 6 below shows the deviations of the points from the reference line for the MADOCA-PPP and SPP. The green line represents the centerline of the target lane, the white dots symbolize the MADOCA-PPP points while the blue dots represent the SPP points.

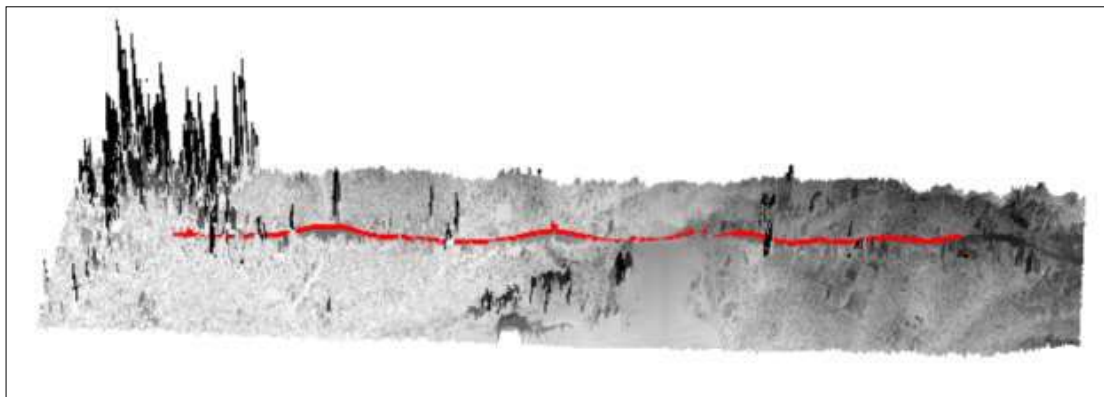
### 4.3 Road identification (vertical assessment)

Since the run was experimented on both skyway and non-skyway (ground level), the data was assessed on how clearly it could identify the car traveled based on the vertical offsets. Shown in Figure 7 is the digitized line in 3D overlaid on the DSM. Table 4.6 shows an average offset of 1.64 m respectively with standard deviation of 0.86 m for the MADOCA-PPP. The average offset 10.67 m with standard deviation of 11.58 m for the SPP. Usually the minimum vertical clearance of roadway from ground based on Philippine standards is around 4.88 m [16]. Therefore, MADOCA-PPP can identify road traveled by the car based on the vertical offset from the reference road. In this case using the height of the road as reference level, MADOCA-PPP showed that it has not yet went beyond the minimum vertical clearance while SPP is already more than twice the same clearance. Table 2 summarizes the results in the vertical component.

**Table 2:** Vertical assessment results

Height (m)	MADOCA-PPP	SPP
Average	1.64	10.67
Standard Deviation	0.86	11.58
Minimum	0.005	0.002
Maximum	16.88	43.36

**Figure 6:** Deviations of points from the centerline (green line). White dots are data from MADOCA-PPP and blue dots are data from SPP. Here, the car is traveling northbound but the blue dots are already located on the southbound lane (beyond the center island).



**Figure 7:** Overlay of road centerline on DSM

## **5. CONCLUSIONS**

Preliminary assessment of the data based on segment (every 100 m) analysis shows that MADOCA-PPP performs better than SPP (GPS-only) even in open-sky conditions. In the Northbound direction, 74.59% of estimates were in the target inner lane for MADOCA-PPP while only 32.21% of estimates were in the same lane for GPS-only. Likewise, in the Southbound direction, 52.06% and 9.58 % of estimates were in the inner lane for MADOCA-PPP and SPP respectively. MADOCA-PPP is also more consistent in road identification since only a maximum of 2.47% of these points fell outside the Skyway road while 40.7% of SPP points fell outside of the Skyway. This can be an indication of the dispersion of SPP points. The non-Skyway roads are on at-grade level, and these roads were either partially or completely obstructed. The Osmeña Highway is completely obstructed by the Skyway, so the vehicle was instructed to stay at the outer lane in order for the signals to still be received. East Service Road, West Service Road and Pasong Tamo were partially obstructed roads. Results showed that MADOCA-PPP generally performed better than SPP, except for Osmeña Highway Northbound. SPP continuously logged positions that indicate continuous car movement while MADOCA-PPP logged points intermittently. MADOCA-PPP does not generate any measurement when there are no corrections received.

Assessing the performance of SPP versus MADOCA-PPP in lane identification through the analysis of the horizontal measurements, the latter was able to give the best estimate than the former. On average GPS-SPP lane centerline compared to the 0.92 m average offset by MADOCA-PPP. With half the lane width equal to 1.75 m, the MADOCA-PPP technique can identify clearly the lane traveled by the car. On the other hand, SPP average offset showed that the car was traveling on the adjacent lane or opposite lane of the target lane that was improbable.

For the vertical component of road identification, results showed that the SPP vertical accuracy is about 10.67 m. The minimum vertical clearance of roadway above ground is 4.88 m with an additional 0.15 allowance for road improvements based on road standards. This means that based on the result, SPP had overshoot the maximum vertical clearance. The MADOCA-PPP gave an average of 1.64 m vertical offset. Therefore, it can identify road traveled by the car based on the vertical offset from the reference road. In this case using the height of the road as reference level, MADOCA-PPP showed that it has not yet went beyond the minimum vertical clearance while SPP is already more than twice the same clearance.

In conclusion, this research was able to assess the performance of MADOCA-PPP for car navigation application. The results showed that in the Philippines the use of MADOCA-PPP is feasible. Future car navigation can adopt this technique to improve the accuracy of positioning both in the horizontal and vertical directions. Based on the results road/lane identification is probable using MADOCA-PPP.

## **6. ACKNOWLEDGMENT**

The authors would like to thank Honda Motors Inc. Ltd. Japan for funding the joint experiment, JAXA for the real time data access and software used and NAMRIA for the GNSS data, orthophoto map and DSM provided.



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