Tropical Forest Tree Positioning Accuracy: A Comparison of Low Cost GNSS-Enabled Devices

Fauzi, M. F.,[1] Idris, N. H.,[1]* Yahya, M. H.,[1] Din, A. H. M.,[1] Idris, N. H.,[1] Lau, A. M. S.[1] and Ishak, M. H. I.[2]

[1]Department of Geoinformation, Faculty of Geoinformation and Real Estate, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia, E-mail: mfarid85@live.utm.my, hawani@utm.my,* hafizyahya@utm.my, amihassan@utm.my, nurulhazrina@utm.my, alvinlau@utm.my

[2] Department of Control and Mechatronic, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai 81310, Johor, Malaysia, E-mail: hafis@utm.my

**Corresponding Author*

Abstract

Today, faster than any previous communication technology, mobile technology such as smartphones, tablet phone and notebook has made a huge difference to the lives of a great number of people. Although one can collect data through a number of traditional channels, e.g. pen and paper and more advanced survey equipment, low cost smartphone and tablet phone are emerging as a good choice. To investigate the potential and performance of Global Navigation Satellite System (GNSS)-enabled smartphone and tablet phone in data collection, a study has been conducted at Forest Research Institute Malaysia (FRIM) Kepong, Kuala Lumpur. Geotrees mobile collector using a Sony Xperia C3 smartphone and Samsung Galaxy Tab 3 were used to geo-locate the attributes of tree species within the area of interest. Comparison was then made using a handheld GPS and a Total Station. The findings indicate that the horizontal positioning accuracy detected by the instruments used in this study were mostly accurate within 5 to 15m. The root mean square (RMS) errors were higher in the areas surrounded by larger canopy diameter trees. Based on the result, despite limited coverage of sky visibility, a GNSS-enabled smartphone and tablet phone was sufficiently adequate to augment the purpose of tree inventory for a certain area, and might suit to serve for low accuracy application.

1. Introduction

Citizen science is a concept that engages public citizens in environmental scientific studies. According to Cohn (2008), the practice was first introduced in 1900 during the National Audubon Society's annual Christmas bird count event. Also known as Volunteered Geographic Information (VGI) efforts, the term citizen scientist refers to volunteers who participate as field assistants in collecting scientific data. Citizens act as sensors in analyzing scientific data as well as generating location-based data (Goodchild, 2007). In the Web 2.0 era, there has been a significant increase in bi-directional collaboration whereby citizens are able to interact and provide local information, thereby augmenting the crowd sourcing approach in generating supporting data. Humans act as sensors in collecting data related to their community and environments. For example, citizens have been trained to detect and report invasive species (Gallo and Waitt, 2011), and insect monitoring in their local area (Braschler, 2009). The proliferation of low cost Global Navigation Satellite System (GNSS)-enabled smartphones available in the market has had a big impact on the rise of non-professional citizens in supplementing authority and scientific data with location-based data. Over the last few decades, various technologies have been used to locate and collect tree population information such as using aerial photograph interpretation, surveying, GPS technology and existing maps (Goodwin, 1996). For quick and high precision data collection, current advanced technology, namely airborne LiDAR and ground based LiDAR system are used. Nevertheless, integrated mobile application on a smartphone has been used for application that requires community based monitoring for quick tree inventory (Vastaranta et al., 2015 and Thompson, 2011). However, the quality of data generated by citizens, including the correctness of attributes and positional and geometric accuracies recorded, has been raised in Hess et al., (2012) and Foody et al., (2013). The use of a smartphone to provide user-generated location-based data has raised concerns about the accuracy of data recorded. Several studies have investigated the accuracy of positioning data derived by GNSS-enabled smartphones, such as in Kane and Ryan (1998) and Bauer (2013).

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This paper compares and discusses the horizontal positioning accuracy of location-based data using a low cost GNSS-enabled smartphone (i.e. Sony C3) and tablet phone (Samsung Galaxy Tab3) collected by citizen scientists to collect and map tree species.

2. Methodology

2.1 Research Framework

To investigate the potential and performance of mobile VGI, a study was conducted at Forest Research Institute Malaysia (FRIM) Kepong, Kuala Lumpur (3.2256°N, 101.6260°E) between 20th and 22nd January, 2015. Thirty respondents were involved in this study. The respondents collected tree species data via a GeoTrees mobile data collector using a Sony Xperia C3 smartphone. The respondents recorded the tree attributes and the positioning data (latitude and longitude) were detected and stored in the database automatically. A Samsung Galaxy Tab 3 was used for the same purpose, but operated only by a single user at a different time (22nd January, 2015). Figure 1 presents the framework of this study.

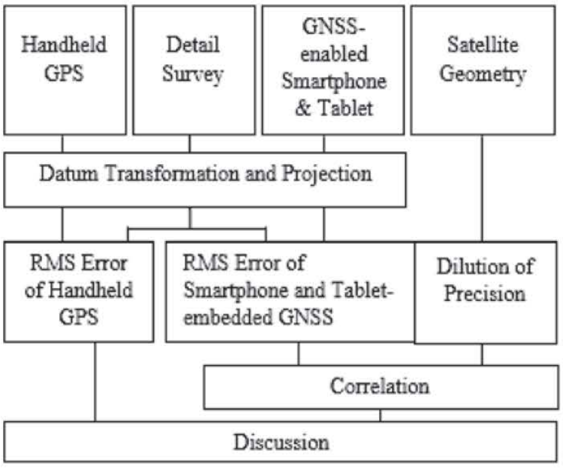


Figure 1: Research framework

3. Instruments

This study used data from four different instruments to collect tree positions. All tree position data were obtained in the same time period to maintain the same scenario and condition. Data were gathered by (1) total station using detailing survey, (2) handheld GPS and (3) a low cost GNSS-enabled smartphone. The data from the GNSS-enabled tablet (4) were obtained at a different time. All GNSS horizontal positioning data were obtained with a World Geodetic System 1984 (WGS84) coordinate system. Then, the data were transformed into Malayan Revised Triangulation 1948 (MRT48) and to Malayan Rectified Skew Orthomorphic (MRSO) Kertau map projection.

The final coordinate system used is MRSO using datum Kertau, which is comparable with the detailing data using Total Station. The procedures are as shown in Figure 2.

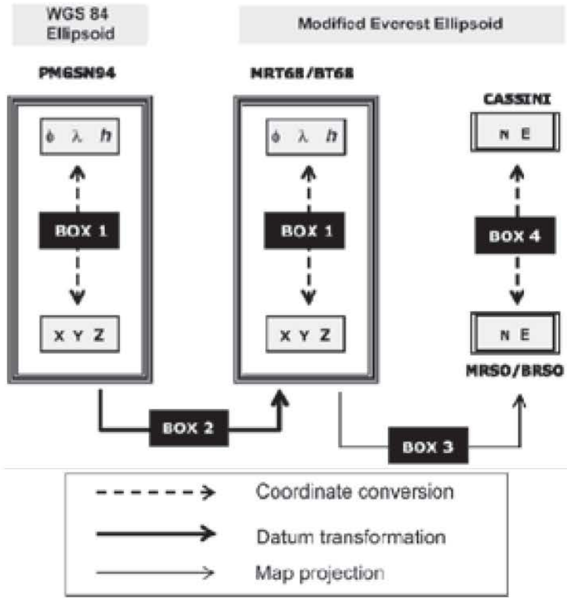


Figure 2: Relationship between various coordinate reference systems (JUPEM, 2009)

The process involves coordinate conversion and datum transformation, as represented by box 1 to 4. They are defined as follows:

Box 1: Coordinate conversion between geographical coordinate and cartesian coordinate.

Box 2: Transformation between various datums using Bursa-Wolf formulae.

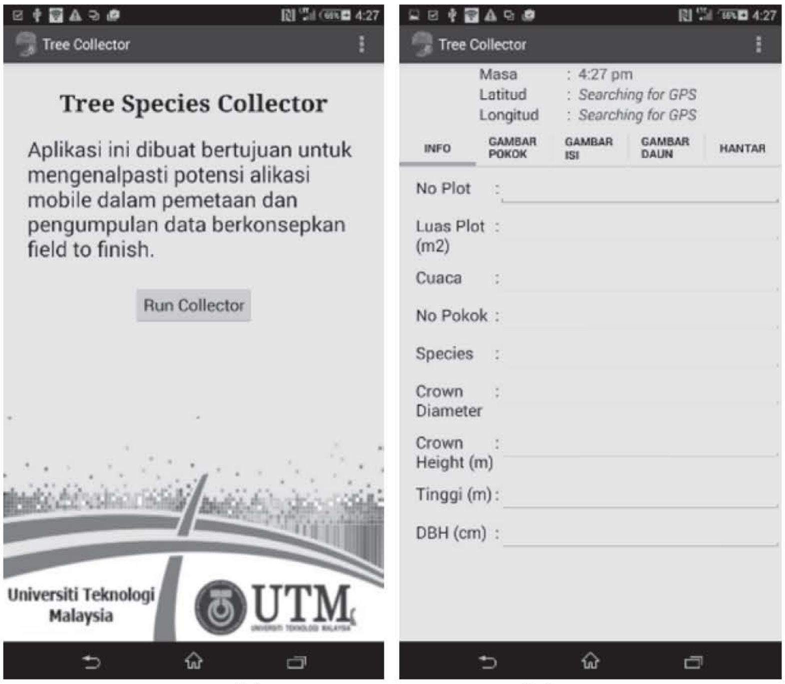
Box 3: Map projection of MRT48/68 geographical coordinate to RSO plane coordinates.

Box 4: Coordinate transformation from RSO to Cassini using polynomial function.

The following describe the instruments used in this study.

3.1 GeoTrees Mobile Application

A mobile tree species data collector, namely GeoTrees, was developed and used in this study. It was developed using Android Studio. Through this app, user can conduct tree inventory by collecting attributes such as tree identification number, location (latitude and longitude), species, height, diameter, diameter at breast height, crown base height, and crown diameter.



(a) (b)

Figure 3: User interface for GeoTrees application

Figure 4: Framework of GeoTrees mobile application

For detecting location, this collector uses a GNSS receiver embedded with a phone and retrieves coordinates without any post-processing. After recording a tree, users submit the data to database (Figure 3). The submitted data was sent to server as a JavaScript Object Notation (JSON) file. By using a PHP script, the data from JSON file is stored into MySQL database. User can views the submitted data on top of Google Map and on a tabular form. Figure 4 below shows the framework of GeoTrees.

3.2 GPS Static Receiver

Control points were obtained using static GPS. A static GPS receiver was set up at the control point for one hour to obtain more accurate and precise positioning data at centimeter level accuracy.

The ground control points (GCP) data were then used in detailing the study area.

3.3 Total Station ES Series

Total Station ES Series was used as a field survey technique to obtain the location of the trees. This instrument is an electronic theodolite which is integrated with an electronic distance meter. It uses a mini reflective prism and has long link rover communication utilizing bluetooth and a USB 2.0 slot. The horizontal accuracy is of 2mm + 2ppm and a range of 400m.

3.4 Handheld GPS

Tree location was collected using a commercial Trimble Handheld GPS Juno. This instrument uses 12 Channel, L1 frequency and can pinpoint a vertical position up to between 2m to 5m in real time in regions with SBAS coverage. In addition, accuracy can be further improved to 1 to 3m through simple post processing routines to meet company or regulatory standards (Trimble, 2015). This instrument was used to compare the accuracy of the smartphone used in this study.

3.5 Sony C3 Smartphone

This study used a Sony Xperia C3, a low cost GNSS-enabled smartphone. It has a GNSS-enabled chipset that is able to detect GPS and GLONASS receivers. This chipset uses L1 frequency and C/A code to obtain the location. Majority of receivers manufactured for mass consumer market use C/A code single frequency type that is designed for civilian locational purposes (Grejner-Brzezinska, 2005; p70). GeoTrees was installed in the smartphone to collect tree species data.

3.6 Samsung Galaxy Tab 3

Samsung Galaxy Tab 3 is another low cost GNSS-enabled tablet device which is able to detect GPS and GLONASS receivers. This chipset uses L1 frequency and C/A code to obtain the location. GeoTrees was installed in the tablet to collect tree species data study.

4. Discussion

4.1 Horizontal Positioning Error of the Devices

The main purpose of this study is to observe the performance of all three devices based on the field observation at the selected site. The forest at FRIM resembles virgin forest in a controlled environment grown with many dipterocarp and non-dipterocarp species. This kind of forest normally causes big errors in obtaining location-based information from positioning satellite system. Root mean square (RMS) error was used to determine the individual and overall positioning error of the collected points. The RMS error of the positions collected via the handheld GPS and the smartphone were compared to the reference GCP (obtained from the detailed survey data), accordingly, to check the significance differences and to investigate the reliability of both data. Table 1 compares the overall bias for each and every device based on easting and northing.

Table 1: Overall bias and RMS Errors for GNSS-enabled smartphone, tablet phone and handheld GPS

Device	EASTING		NORTHING	
	BIAS	RMSE	BIAS	RMSE
Samsung Tab 3	-1.556	7.139	-3.992	10.115
Sony C3	-2.903	13.230	-0.097	8.584
Hand held GNSS	-2.172	6.379	-0.775	8.865

This table shows the devices obtain around 6 – 13m RMS error for easting and 8 – 10m for northing. This error shows that handheld GPS obtained the lower positioning error value for both easting and northing. The error for northing position was slightly different for the Sony C3 smartphone compared to the easting position RMS error. The Samsung Tab 3, however, gave a higher error value on the northing part, whereas in the easting part, it gave 7.139m error compared to the Sony C3 smartphone with 13.230m. Figure 5 illustrates the errors that support the result in Table 1 where about 70% of the observed data indicates that handheld GPS accuracy is better than smartphone and tablet phone. The GNSS-enabled smartphone and tablet phone errors, as shown in Table 1, are higher when compared to the reference detailed survey data (GCPs). While, in Figure 5, it shows that 71% of the Sony C3 smartphone points have higher errors than the Samsung Tab 3 tablet. The result infers that the Samsung Tab 3 tablet has better positioning accuracy compared to the Sony C3 smartphone. RMS error lines shown in figure 5 illustrate the RMSE displacement for handheld GPS and GNSS-enabled smartphone and tablet phone versus survey data. It seems the errors obtained are not consistent. Table 1 and Figure 5 show the results of all three devices. This study identified the positional errors of trees observed by the low cost GPS Juno handheld were varying between 3.6 to 24.9m. This differs with a study by Rodríguez-Pérez et al., (2007) that identified horizontal accuracy of tree locations by using a low cost GPS receiver at West of León Province, Spain values ranges from 4.80 to 8.80m.

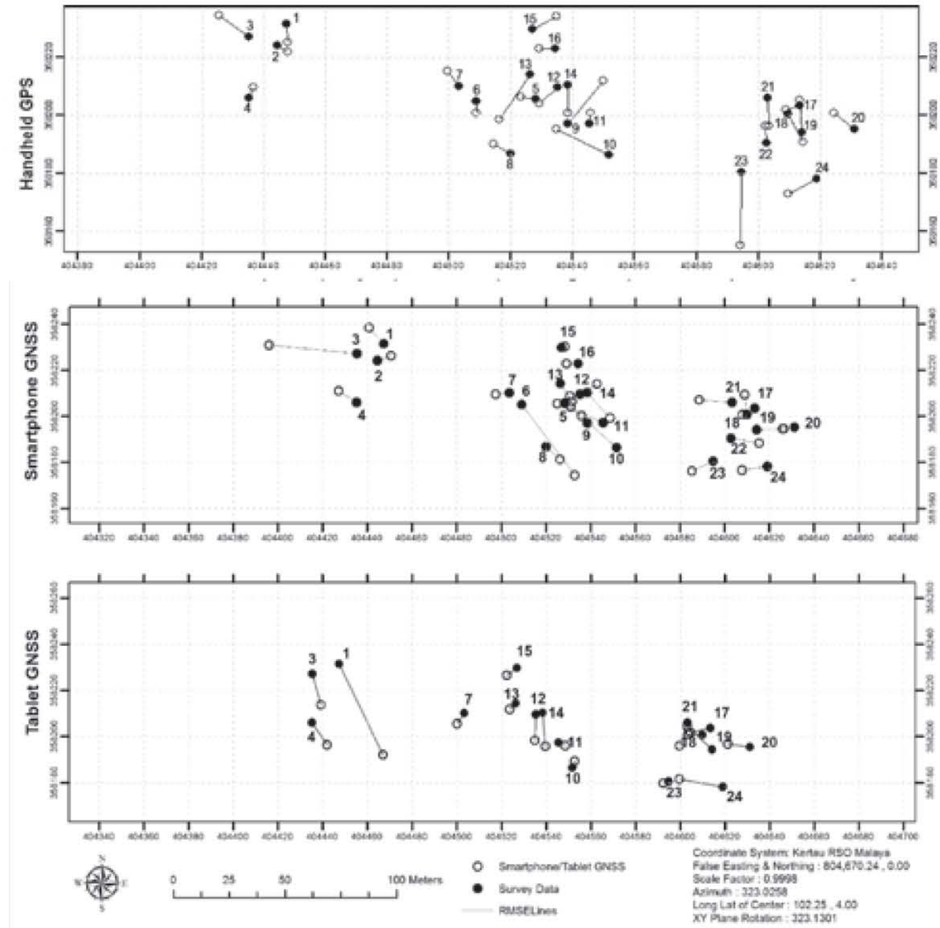


Figure 5: RMSE Map for handheld GPS, smartphone (Sony C3) and tablet (Samsung Tab 3) vs. survey data

The finding suggests that the horizontal positioning accuracy of the Sony Xperia C3 and Samsung Galaxy Tab 3 used in this study are in the range from 1.3 to 44m. This is in line with a study by Thompson (2011) that observed the reading of individual tree via Android mobile device is in between 2 to 42m accuracy. This is different with the accuracy of trees recorded by using typical GPS unit that can be within 2 to 5m or sub-meter with a high accuracy GPS unit (Goodwin, 1996). Wu et al., (2015) argued the actual positional accuracy of smartphones ranges from 1 m to up to 20m leaving room for various augmented technologies. From these results, this study indicates the errors recorded by all devices were varies, though most tree positional errors were within 5 to 15m. A question is raised whether such error is acceptable to use for tree inventory. As claimed by Rodríguez-Pérez et al., (2007) a low cost GPS receiver may provide valuable positional data under forest canopy for moderate to low accuracy context as long as careful GPS data acquisition protocols are conducted. Goodwin (1996) argued, the cost to locate the trees in their proper relative location would be expensive, especially if need to purchase or rental many of surveyor's grade GPS unit for conducting large area data collection. Due to this issue, many tree inventory studies using low cost handheld GPS units and currently use integrated mobile application on smartphone and tablet. For example, iNaturalist (Ruggles et al., 2015) has been developed by a non-profit nature-based organization to provide free mobile collectors for nature citizen observers to report their species observations on the platform; the USDA forestry service provides an iTree Eco mobile tool for communities in the United States to collectively gather tree inventory in their neighborhoods (Nicholas, 2011). The use of low cost GNSS-enabled devices might be sufficient for conducting inventory of trees that grow in a same group. In this case study, the forest area is a large area which divides into different types of tree group. Each area or plot has its own dominant tree with only a few mixed tree species. In community-based tree inventory, post quality control and assurance procedures that involve hot and cold check are commonly conducted (Gordon, 2016); As such, the usage of smartphones and tablet phone (or tablet

PC) in tree inventory still appears as relevant but it is suggested to act as supplementary data to other authoritative sources. Regression analysis was performed on the RMS of handheld GPS and smartphone as regards expected Horizontal DOP (HDOP). It seems that there is strong correlation between the two parameters, which have R^2 value of 0.7639 and 0.6235 for handheld and GNSS enabled smartphone, respectively. However, the expected HDOP for a best case scenario in a tropical rainforest with higher obstruction will give greater HDOP. It is right to mention that the handheld GPS gives the more likelihood of data with expected HDOP; in other words, the handheld GPS provides the best reading in this study. However, both R^2 values give high value, which means data observed are acceptable from both devices. The regression value does not present too many differences, which means the accuracy for both devices is nearly the same (Table 2).

Table 2: Regression statistics between overall RMSE and expected HDOP

Regression Statistics		
	Handheld GPS	GNSS-Smartphone
Multiple R	0.8740	0.7896
R Square	0.7639	0.6235
Adjusted R Square	0.7204	0.5800
Standard Error	0.3419	0.4318
Observations	24	24

4.2 Satellite Geometry

Satellite geometry is another possible factor in positioning error. Figure 6 shows the satellite availability and arrangement for study area during the time of the observation. These skyplots provide satellite location on the sky and also provide DOP value by calculating using specific equation (see Kaplan (1996)). Figure 6 (a) is the skyplot for tree No 16, which has HDOP of 0.6 with overall RMS error 5.376m (Sony C3) and 5.001m (handheld GPS). Figure 6 (b) shows tree no 23's skyplot with HDOP of 0.85, RMS error 10.389m (Sony C3) and 24.937m (handheld GPS). The above results show the relationship between satellite geometry, represented by the skyplots, HDOP and positioning error. Error is larger when the HDOP is large. The satellite geometry of Figure 6(a) gives a better arrangement because of the availability of satellites from all quarters of the sky. This kind of arrangement give a better fix and lower DOP, while, in Figure 6(b), the satellites are fewer in number and most are concentrated on top right quarter, which, in the end, gives higher DOP and leads to high positioning error.

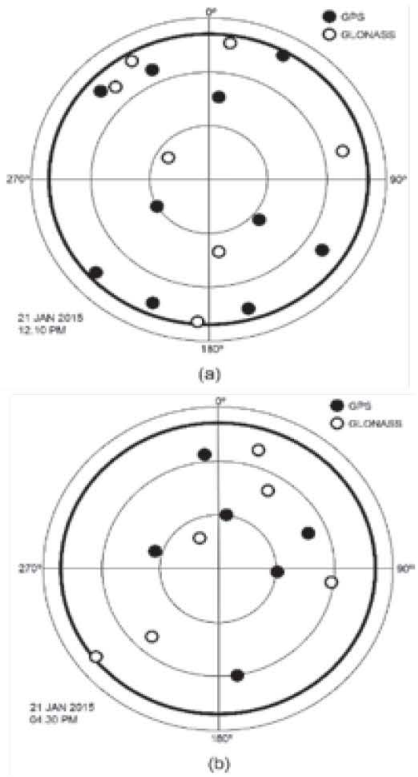


Figure 6: Skyplot of satellite positioning during observation of (a) Tree No 16 and (b) Tree No

Satellite-receiver geometry is important in achieving high quality results, especially for point positioning and kinematic surveying (Januszewski, 1999). Satellite geometry will change with time due to the motion of the satellites in orbit. Both devices use L1 frequency and C/A code to observe location based on GNSS. L1 frequency is used mostly for citizen purposes, which gives error of up to 5m. This is a consistent error for every device and can be reduced by placing a GNSS receiver at the known base station. In smartphone and tablet phone (or tablet PC) technology, there is an Assisted GNSS (A-GNSS), which helps to fix location information through external data. A GNSS receiver is solely dependent on the satellite reception, but, with an A-GNSS, data from the cell tower can be used to help improve precision. However, data used in this study were totally based on observed data solely from the GNSS receiver, without any correction or ambiguity-fixed via a differential approach from the reference station. This is to simulate the worst case scenario when there is absence of Internet or cellphone data coverage. Even without fixing with external data, it produced acceptable results, with most errors within 5 to 15m.

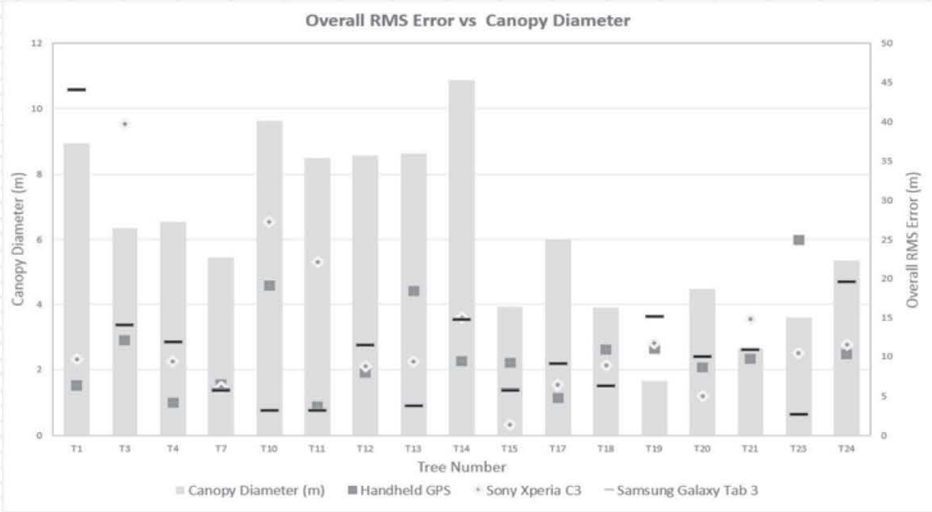


Figure 7: Overall Root Mean Square Error versus tree canopy diameter

4.3 The Influence of Tree Canopy on RMS Errors

The comparison of horizontal positional errors as shown in Figure 5 tells us that the area where trees no 1, 3 and 24 are located frequently returns high error when measuring with the all tested devices (i.e. handheld GPS, smartphone and tablet phone). One reason for this big discrepancy in those locations might due to signal shading by larger and dense tree canopy. Figure 7 shows the comparison of overall RMS Error for all three devices used and the tree canopy diameter information collected from the study. Most locations that give high positioning error are surrounded by larger canopy diameter trees. The location of tree no 1 and 3, for example, is surrounded with Angsana and Medang trees, which have 8.95m, 10.38m and 6.349m canopy diameter, while the location of tree no 24 is covered by 4.47m, 5.8m, 3.6m and 5.35m Cengal trees. Tree no 14, with 10.861m canopy diameter, also gives higher error for all devices. In other areas, the reading from handheld GPS did not give a very big error where the errors were still between the ranges of 3 to 15m. Referring to Figure 5, and Figure 7, the performances of handheld GPS versus GNSS-enabled devices (i.e. smartphones and tablet) used in this study does not show much difference. Only a few trees, which represent 20% of the data, show significant difference. Perhaps, the satellite signal is obstructed by the surrounding tree canopy (Yahya and Kamarudin, 2008) which possibly results in a high multipath due to signal reflection and deflection. It is also due to satellite availability, which differs from time to time.

5. Conclusion

This paper discusses the accuracy of a GNSS-enabled smartphone and tablet phone (or PC) to assist citizen scientists in collecting tree species data. The finding suggests that the horizontal positioning accuracy of the Sony Xperia C3 and Samsung Galaxy Tab 3 used in this study were mostly accurate within 5 to 15 m. Based on this study, at certain trees (points), the handheld GPS produced more accurate positions compared to readings from either GNSS-enabled smartphone or tablet phone (or PC). Most locations that produced high positioning error were surrounded by larger canopy diameter trees and due to satellite geometry arrangement. We conclude that low cost GNSS-enabled smartphone and tablet phone (or PC) are suitable for use in a moderate-low accuracy context and to act as supplementary data to other authoritative source. However, caution is required when interpreting the results presented in this study. Different devices and feature specification (model) and contexts (e.g. satellite geometry arrangement and sizes of canopy cover) may produce different results. Further study could be conducted to evaluate the performance of those instruments in different model specifications and contexts. Despite limited coverage of sky visibility – as expected in a tropical tree environment, a GNSS-enabled smartphone is sufficiently adequate to augment the purpose of tree species positioning and identification. In addition to the practicality and ease of use, smartphones and tablet phone (or tablet PCs) are expected to offer great potential for geospatial data collection and will only improve as the technology matures in the near future.

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