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STUDYING THE MULTIPATH EFFECTS OF GPS OBSERVATIONS USING DIFFERENT ANTENNA HEIGHT

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الملخص العربي
تعدد المسارات يعد مصدراً رئيسياً للخطأ في شفرة نظام تحديد المواقع العالمي(GPS) وقياسات طول الموجة الحاملة في اثناء التشغيل، مما يمكن أن يمنع تحقيق أعلى مستويات الدقة. هوائي GPS هو المكون المتصل بين القمر الصناعي GPS وحدة المستخدم لل GPS. سيناقش هذا البحث دراسة عن أخطاء المسارات المتعددة عن طريق أربعة اختبارات أجريت عند أربعة ارتفاعات مختلفة للهوائي (1.88m , 1.48m, 1.02m, 0.67m). تم فحص تأثيرات مواضع الارتفاع المختلفة لهوائي GPS على الأخطاء الناتجة من تعدد المسار. النتائج التي تم الحصول عليها في هذا البحث تثبت أن تحديد موقع ارتفاع هوائي GPS لا تعطي نفس الخطأ متعدد المسارات في بعض الاختبارات الأربعة. كما تم تقديم الطريقة الإحصائية للمقارنة والاختبار باستخدام اختبار F- الإحصائية. كما يمكن تحقيق التخفيف من أخطاء المسارات المتعددة من خلال تحسين معالجة الإشارة وتصميم ارتفاع هوائي أفضل. ويوصى بإجراء المزيد من الدراسات لمعرفة تأثير أنواع المواد المختلفة الموجودة بمنطقة الرصد على أخطاء متعددة المسارات.

ABSTRACT
Multipath is a major source of error in GPS code and carrier phase measurements in the differential mode of operation, which can prevent the achievement of the highest levels of accuracy. GPS antenna is the connecting component between the GPS satellite and the GPS receiver. This paper will discuss the detection of the multipath errors from four tests carried out by set up at different antenna heights. The effects of different height positioning of the GPS antenna on the pseudorange multipath are examined. The results obtained in this research proves that the for positioning the GPS antenna height do not give the same multipath error performance in all four tests. The statistical method of comparison and the test are also presented using F-statistical test. Mitigation of multipath errors can be achieved by improving signal processing and a better antenna design. Further studies are recommended to know the effect of different materials types on multipath errors.

Key Words: GPS observations, antenna height, multipath error

1- INTRODUCTION
The use of satellite based Global Positioning System (GPS) is normal in engineering and surveying for a wide range of applications as the accuracy capability increases. The GPS satellites transmit signals that are received by the receivers on the earth's surface to determine the position. However, many GPS users are still not fully aware of the vulnerabilities of GPS systems to various error parameters, such as ionospheric and tropospheric delays, satellite clock and ephemeris errors, satellites positioning and geometry, radio frequency interference (RFI) and spoofing, and obstructions and multipath. These errors can severely affect the accuracy of readings and in a number of cases, even disrupt GPS signals [Schue, 2012]. However, the ground and other objects easily reflect GPS signals, often resulting in one or more secondary paths, which are superimposed on the direct-path signals at the antenna causing longer propagation time

and can significantly distort the signals waveform's amplitude and phase. For precise GPS positioning multipath is one of major source of error. Multipath is a very localised effect, which depends only on the local environment surrounding the antenna. As illustrated in Fig. 1, the receiver may receive both the direct transmitted signal and the reflected (indirect) signal. The indirect path is obviously dependent on the reflecting surface and the satellite position. The reflecting surface is usually a static one related to the receiver; however, the satellite moves with time. Therefore, the multipath effect is also a variable of time [Xu, 2007].

Therefore, it is important to get information about the possible multipath signals in a complex scenario such as urban or suburban man-made environments [Chen et al., 2009]. Magnitude from the multipaths depends on three factors [Kamarudin and Amin, 2004]. First, position and types of reflected surface that located near the antenna. Next, the height of antenna from earth surface. Finally, GPS wave distance signals.

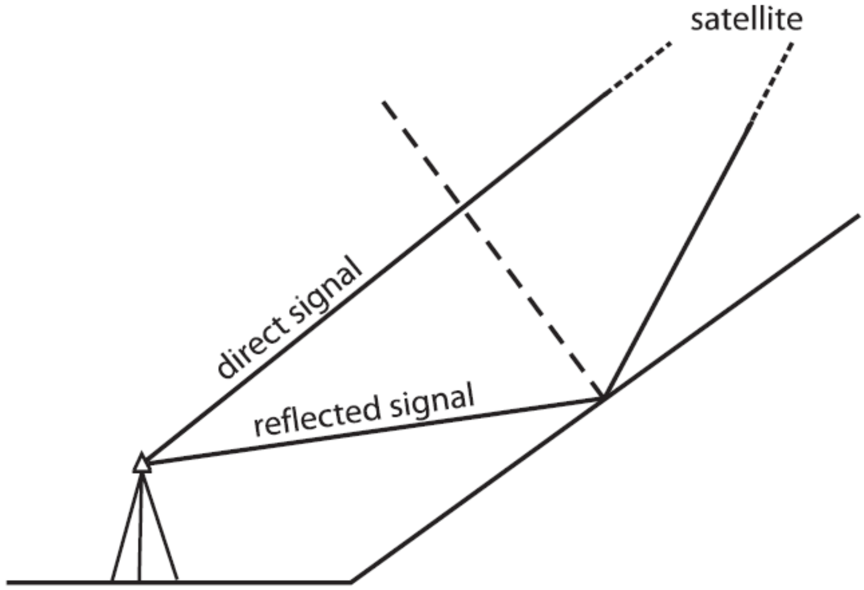

Fig. 1. Geometry of multipath effects [Xu, 2007].

There is ample research in the field of carrier phase multipath. For example, Lau and Cross (2007) describe the basis of a model for the GPS carrier phase multipath process using raytracing and identifies the key factors that can contribute to carrier-phase multipath errors. Satirapod and Rizos (2005) apply a wavelet decomposition technique to extract carrier phase multipath from GPS observations. The extracted multipath signature is then applied directly to the GPS observations to correct the multipath effects.

Further work in the field of pseudorange multipath includes Hilla and Cline (2004), who evaluated the amount of pseudorange multipath at hundreds of sites in the CORS network in order to identify the most affected and least affected sites in the network. Even-Tzur (2007) examined the effects of the pseudo-range multipath in a variety of GPS antenna types and compared the ability of different antenna types in mitigating multipath. Park et al. (2004) designed and constructed a prototype antenna and multipath calibration system to determine site dependent errors such as antenna phase-center variations and multipath.

2- MULTIPATH ESTIMATION

To estimate multipath, it is not possible to simply compare the measured pseudo-range (P_1 and P_2) or carrier phase (ϕ_1 and ϕ_2) to the true geometric range since the error is a combination of several factors in addition to multipath. Therefore, multipath isolation or the formation of a multipath 'data combination' is essential. The following pseudo-range combination is achieved through judicious combination of pseudo-range and carrier phase measurements, taking advantage of the fact that the noise and multipath effects on the carrier phase are negligible compared to those of the pseudo-range, although most other error sources are the same. So, $MP1$ and $MP2$ are the pseudo-range multipath effects on L1 and L2 can be given by equation 1 and 2 as follows [Ge et al, 2002].

$$MP1 = P_1 - \frac{9529}{2329}.\phi_1 + \frac{7200}{2329}.\phi_2 + K_1 \quad (1)$$

$$MP2 = P_2 - \frac{11858}{2329}.\phi_1 + \frac{9529}{2329}.\phi_2 + K_2 \quad (2)$$

where

P_1 and P_2 are pseudo-range data on L1 and L2; ϕ_1 and ϕ_2 are carrier phase data on L1 and L2; and K_1 and K_2 are functions of the receiver noise, the multipath on carrier phase and include the unknown integer ambiguities (which can be assumed constant if there is no cycle slip in the carrier phase data). All terms are expressed in meters. After the combination, the result is the pseudo-range multipath mixed with the receiver noise, which is referred to as the 'pseudo-range multipath residual series.

3- DATA COLLECTION

The data collection for this study involving the comparison of the observation results from four different height (1.88, 1.48, 1.02, and 0.67m) in four days (15,16, 17, and 18 February 2017) respectively. The survey station is located at the roof of Civil Engineering building, Al-Azhar university, Cairo, Egypt (N30°03'22" and E31°18'54"), Fig. 2.

Fig. 2. GPS receiver set up on test site.

The GPS observations conducted from 08:55 to 09:55 am. The observations were done at the same time period have the same satellite geometry. The data were collected using Trimble R4 GPS receiver, the PDOP (Position Dilution of Precision) value is less than 3.0 and 5 minutes interval for 1-hour observation.

4- RESULTS

When the geometry between the GPS satellite and the receiver (positioned at the same place) remains unchanged, the pseudorange multipath pattern is repeated every sidereal day (Ge et al, 2002). On average, the offset Δt of the time of two complete satellite revolutions from one mean solar day equals approximately 240 seconds (Wanninger and May, 2000). This enables checking the effect of the pseudorange multipath on different heights. The analysis was carried out on RINEX files using TEQC software. The TEQC output is types of pseudorange multipath (MPP1 and MPP2). TEQC is a freeware program allows the user to translate from the binary receiver format to the standard Receiver Independent Exchange (RINEX) format, to edit existing RINEX files, and to quality-check the data before postprocessing. It has a command line interface modeled after common UNIX commands. This combined with TEQC's extensive documentation makes it simple to use for new and experienced users and in automated processing scripts. TEQC is a Toolkit for GPS/GLONASS/SBAS data used to solve many pre-processing problems with GPS, GLONASS, and SBAS data. It stands for Translation, Editing, and Quality Check. It was developed and is maintained by the UNAVCO (University Navstar Consortium) scientists in Boulder, CO, USA. A detailed description of the toolkit is given in the article (Estey and Meertens,1999).

Table. 1. The recorded multipath errors (MP1 and MP2) in four days using different antenna height.

15-Feb			16-Feb			17-Feb			18-Feb		
1st day			2nd day			3rd day			4th day		
1.88 m			1.48 m			1.02 m			0.67		
Time	MP1 (m)	MP2 (m)	Time	MP1 (m)	MP2 (m)	Time	MP1 (m)	MP2 (m)	Time	MP1 (m)	MP2 (m)
08:55 to 09:00	0.276	0.252	08:51 to 08:56	0.271	0.261	08:47 to 08:52	0.261	0.250	08:43 to 08:48	0.271	0.252
09:00 to 09:05	0.284	0.288	8:56 to 09:01	0.273	0.288	08:52 to 08:57	0.225	0.219	08:48 to 08:53	0.266	0.276
09:05 to 09:10	0.270	0.270	09:01 to 09:06	0.264	0.282	08:57 to 09:02	0.282	0.267	08:53 to 08:58	0.276	0.269
09:10 to 09:15	0.264	0.234	09:06 to 09:11	0.257	0.235	09:02 to 09:07	0.279	0.240	08:58 to 09:03	0.269	0.240
09:15 to 09:20	0.271	0.274	09:11 to 09:16	0.275	0.281	09:07 to 09:12	0.273	0.276	09:03 to 09:08	0.276	0.261
09:20 to 09:25	0.277	0.255	09:16 to 09:21	0.273	0.267	09:12 to 09:17	0.274	0.292	09:08 to 09:13	0.267	0.296
09:25 to 09:30	0.277	0.270	09:21 to 09:26	0.272	0.272	09:17 to 09:22	0.281	0.265	09:13 to 09:18	0.271	0.255
09:30 to 09:35	0.277	0.255	09:26 to 09:31	0.298	0.278	09:22 to 09:27	0.304	0.262	09:18 to 09:23	0.304	0.268
09:35 to 09:40	0.277	0.270	09:31 to 09:36	0.273	0.278	09:27 to 09:32	0.268	0.253	09:23 to 09:28	0.272	0.264
09:40 to 09:45	0.295	0.277	09:36 to 09:41	0.261	0.260	09:32 to 09:37	0.262	0.254	09:28 to 09:33	0.259	0.254
09:45 to 09:50	0.276	0.273	09:41 to 09:46	0.284	0.258	09:37 to 09:42	0.270	0.255	09:33 to 09:38	0.268	0.270
09:50 to 09:55	0.267	0.260	09:46 to 09:51	0.241	0.238	09:42 to 09:47	0.232	0.232	09:38to 09:43	0.235	0.247
Mean (m)	0.276	0.265		0.270	0.266		0.268	0.255		0.269	0.263
St. Div(m)	0.0078	0.0138		0.01335	0.016312		0.0205	0.0185		0.0147	0.01416
Variance	6.1E-05	0.0002		0.00018	0.000266		0.0004	0.0003		0.00022	0.0002

A sample of multipath effects with time is given in Table 1. One can see that MP1 is equal to about 0.27m using the four different antenna heights. However, the MP2 values ranges between 0.255m and 0.266m for antenna heights 1,02m and 1.48m respectively. The standard deviations and variances of the 12 samples were calculated for the four tests. The smaller standard deviations were obtained using 1.88m height (0.78cm and 1.38cm for MP1 and MP2 respectively). On other hand, the largest values of standard deviations were result from 1.02m height with 2.05cm and 1.85cm for MP1 and MP2 respectively.

To see if there are significant difference of multipath using different antenna heights, F-test were applied. Table. 2 shows the results of F-calculated values for the four tests in MP1. From the results shown in the table and by applying F-statistical test, for 11 degree of freedom and confidence level 90 % the Fcrit = 2.23. So, it can be concluded that the three-different height 1.48m, 1.02m, and 0.67m have a significant difference in their performances compared with 1.88m height. Change. The same performance results from using antenna 1.02m height with 1.48m. While the other test does not give significant difference.

Table. 2. F-calculated values results from 4 testes for MP1.

Height(m)	1.88	1.48	1.02	0.67
1.88	1	**2.93**	**6.93**	**3.56**
1.48	**2.93**	1	**2.36**	**1.21**
1.02	**6.93**	**2.36**	1	1.08
0.67	**3.56**	**1.21**	1.08	1

Table. 3 shows the results of F-calculated values for the four tests in MP2. From this table results and by applying F-statistical test, for 11 degree of freedom and confidence level 90 % the Fcrit = 2.23. From that, it can be concluded that, there are no significant difference for all different heights.

Table. 3. F-calculated values results from 4 testes for MP1.

Height(m)	1.88	1.48	1.02	0.67
1.88	1	**1.40**	**1.81**	**1.05**
1.48	**1.40**	1	**1.29**	**1.33**
1.02	**1.81**	**1.29**	1	**1.71**
0.67	**1.05**	**1.33**	**1.71**	1

5- CONCLUSION

Based on the results of this study, it was found that the multipath signals from the panels increase probable error values, due to errors in the GPS receiver’s pseudorange measurements. The GPS antenna is mounted on roofs. So, no obstructions or reflectors exist above the antenna horizons. Hence, only the roof and height of antenna need be considered potential reflectors. The F-statistical tests used to show if the differences between any two tests are significant. The main conclusions can be given as:

- Using antenna height with 1.88m height gave significant change with other three different heights for MP1.
- Using antenna height with 1.48m height gave significant change with 1.02m heights for MP1.
- Using antenna height with 1.02m height did not gave significant change with 0.67m heights for MP1.
- From the above three points, it means that, the results multipath errors gave better accuracies for 1.02m and 0.67m heights than using other two antenna heights for MP1. So, the data obtained in this research proves that the optimal height for positioning the GPS antenna in order to reduce pseudorange multipath is at lowest level.

- There is no significant change by using the four antenna heights for MP2. It means that. The results multipath errors are the same in performance in all four tests.
- Finally, it is recommended to study the effect of different materials found in test site on multipath errors.

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