# CORRELATION CHARACTERISTIC OF GPS/DGPS MEASUREMENTS

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## ABSTRACT

**GPS signals are of time-spatial nature. And they should be modeled as such in the algorithms for establishing navigational measurements. Therefore, they should be treated as stochastic processes. This article presents the results of testing the correlation properties of GPS/DGPS signals. Several measurement series were carried out to obtain position co-ordinates at various times and in various points as well as synchronous measurements of two GPS/DGPS receivers. The tests aimed at identifying the function of auto-correlation between $\varphi$ and $\lambda$ co-ordinates and the function of intercorrelation between $\varphi$ and $\lambda$ coordinates. As it turns out, these measurements are significantly correlated, and the mean time of correlation is within the range of a couple or more minutes.**

## INTRODUCTION

**Navigation can be defined as a process of vessel conduct along a track (trajectory) pursuant to the passage planning and to the tasks being performed which are connevted with economical, time, geometrical, hydrometeorological and other constraints. The process can be further divided into certain sub-processes. These are as follows:**

- **gathering and processing information,**
- **navigational planning,**
- **determining ship's position and speed vector,**
- **monitoring ship location in relation to dangers to navigation,**
- **decision making,**
- **steering the ship.**

**Navigation is closely related to the measurements of the parameters which determine the location of the vessel (position coordinates), its speed vector (the components of that vector in relation to the course made good and making way), acceleration components, angles of hull orientation (inertial navigation systems) and other parameters. Those parameters have, in principle, a random character so they are to be modeled as random processes. And because navigation lends itself also to time parameters, it can be assumed that the results of parameter measurements are stochastic processes (in broader terms, a multidimensional stochastic process) [2], [3], [6]. It also concerns the measurement of position coordinates by means of GPS/DGPS receivers. The results of tests refer to the correlation functions of the coordinates determined by means of GPS/DGPS receivers in static conditions.**

## 1. COVARIANCE AND CORRELATION FUNCTIONS OF THE STOCHASTIC PROCESS

**The covariance function *X* of the stochastic (random) process is called the function *P* which, for each established pair of values $t_1$, $t_2 \in T$ (*T* – time), is expressed by the following formula:**

$$P(t_1,t_2) = E\left\{\left[X(t_1) - \overline{X}(t_1)\right] \cdot \left[X(t_2) - \overline{X}(t_2)\right]^T\right\}, \qquad (1)$$

**where: $\overline{X}$ – a mean value of the stochastic process.**
**The correlation function is called the standardized covariance function which is determined by this relation:**

$$R(t_1,t_2) = \frac{P(t_1,t_2)}{s(t_1)s(t_2)}, \qquad (2)$$

**where: *s* – standard deviation of the stochastic process.**
**Estimators of the correlation function for *n* of given values of the set $x_i$ ($i = 1, 2, ... , n$) of the stationary stochastic process *x* implementation is derived from the formula [2], [4]:**

$$R(rh) = \frac{1}{n-r}\sum_{i=1}^{n-r}(x_i - \overline{x}) \cdot (x_{i+r} - \overline{x}), \qquad (3)$$

**where $r = 0, 1, 2, ... , n - 1$ – number of delays; $\overline{x}$ – mean value of the stochastic process *x*.**
**The correlation function calculated for the same stochastic process is called the autocorrelation function, and the mutual correlation function (between various stochastic processes) is called the intercorrelation function [4] whose estimator is determined by the relation:**

$$R(rh) = \frac{1}{n-r}\sum_{i=1}^{n-r}(x_i - \overline{x}) \cdot (y_{i+r} - \overline{y}). \qquad (4)$$

## 2. PERFORMANCE OF THE TESTS

**In order to determine the correlation functions of the position coordinates measurements in GPS/DGPS system, a few sessions of measurement series was carried out. All the observations were carried out in a Maritime University of Szczecin laboratory (Fig.1), while the receiver antennas were placed on a special antenna platform wide apart from other sources of electromagnetic radiation. The tests were performed by means of two receivers of MiniMax CSI WIRELESS make. The measurements were carried out in two measurement points: on 22 November 2007 – GPS measurements (synchronous in both points); on 26 November 2007 DGPS measurements (also synchronous in both points). All the measurement series were recorded in one second intervals, at different times of the day. The data were recorded in the NMEA-0183 format.**

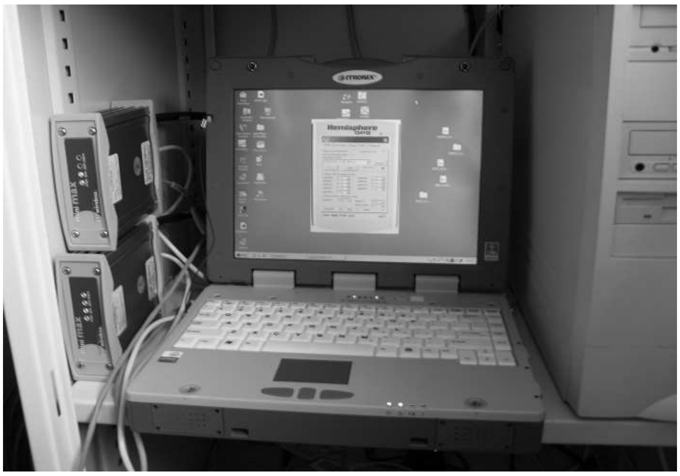

Fig. 1. Measurement station in the Maritime University of Szczecin

## 3. MEASUREMENT RESULTS ANALYSIS

**Measurement results are shown in Figures 2 – 7. They are graphs of the autocorrelation functions of the latitude ($\varphi$) and longitude ($\lambda$) and the intercorrelation functions between those coordinates as well as the intercorrelation functions between the antenna points 5 and 6 (for GPS and DGPS).**
**Figure 2 illustrates a pattern of the autocorrelation function of the latitude and longitude and the intercorrelations between the coordinates determined by means of the GPS. The measurement series shown in the graph were carried out in the antenna point number 5.**

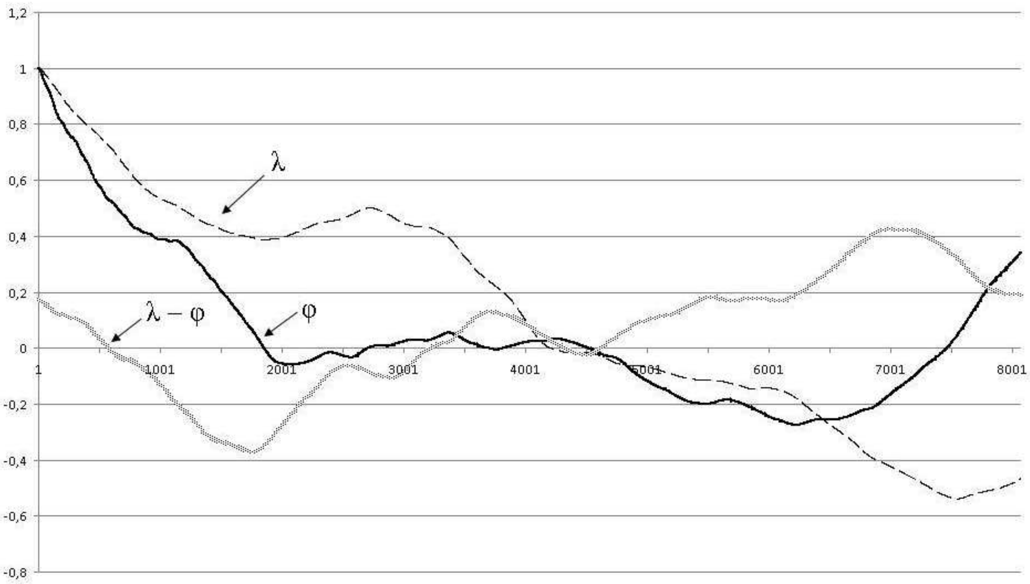


Fig. 2. GPS intercorrelation and autocorrelation functions – antenna point 5

**Figure 3 shows the same functions for the measurements in point 6. A prominent autocorrelation of the same coordinate can be seen in both diagrams, although in point 5 strong interferences of higher frequencies occur. In this case, the time of correlation is within the range of 15 – 25 minutes, whereas the correlation between the coordinates is much weaker, but significant.**

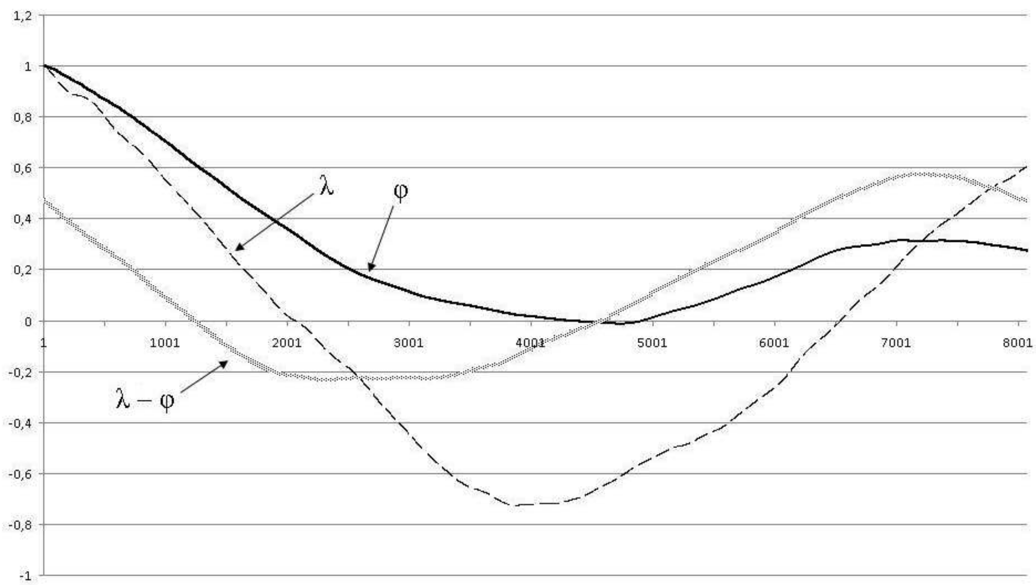


**Fig. 3. GPS intercorrelation and autocorrelation functions – antenna point 6**

**Figure 4 shows correlations between GPS coordinates in various points of measurement. The correlation between the longitudes determined by the GPS is weak (ca. 20 – 30%).**

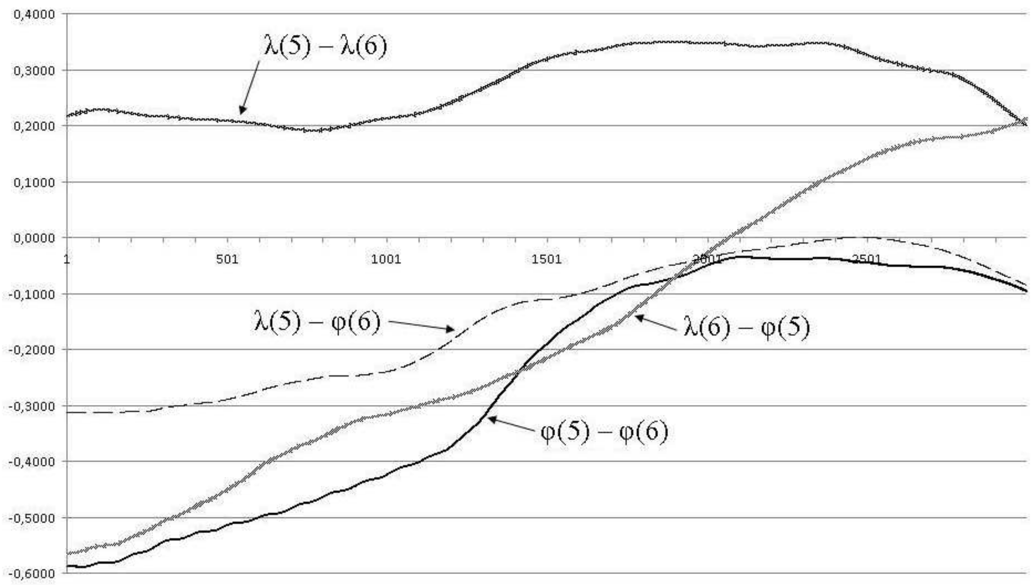


**Fig. 4. GPS intercorrelation functions between the antenna points 5 and 6**

**The latitudes show strong negative correlation, and the time of the correlation is within the range of 25 minutes. The longitude of the point 5 is weakly correlated with the latitude of point 6, whereas point 6 longitude is quite relevantly correlated with the point 5 latitude, in a short span of time.**

**Figures 5-7 show correlation functions determined for the DGPS (in identical measurement conditions). In Figure 5 the results referring to point 5 have been shown, and in Figure 6 – those referring to point 6. In comparison to the GPS, the signals are less correlated (time of correlation within the range of 5 – 10 minutes). Probably, the corrections of pseudo-ranges partly "de-correlate" the signals. Figure 7, in turn, shows that the coordinates of various points determined by DGPS are weakly correlated (correlation from – 20% to 30%).**

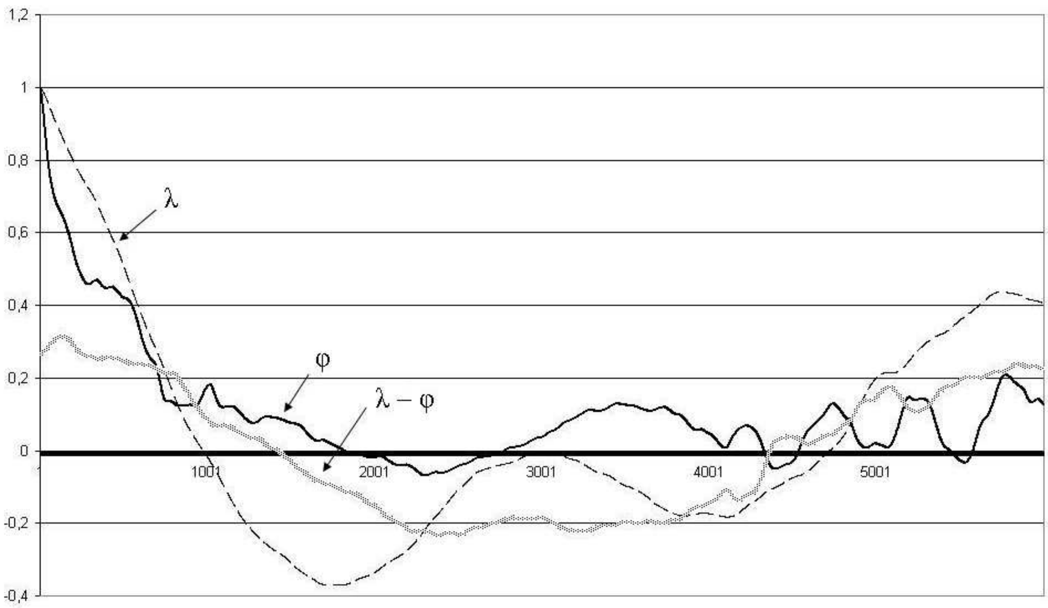


**Fig. 5. DGPS intercorrelation and autocorrelation functions – antenna point 5**

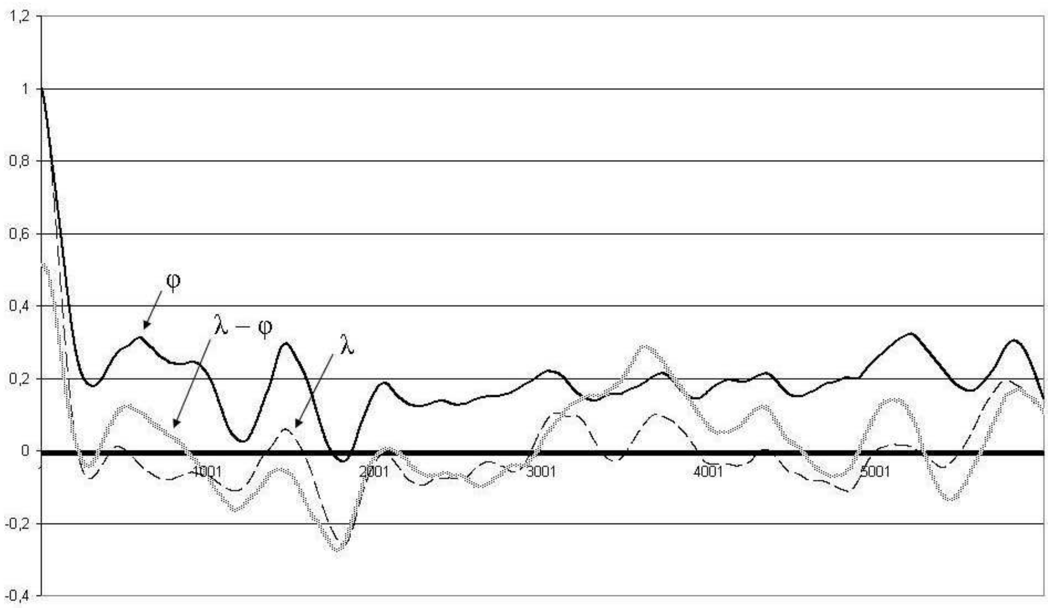


**Fig. 6. DGPS intercorrelation and autocorrelation functions – antenna point 6**

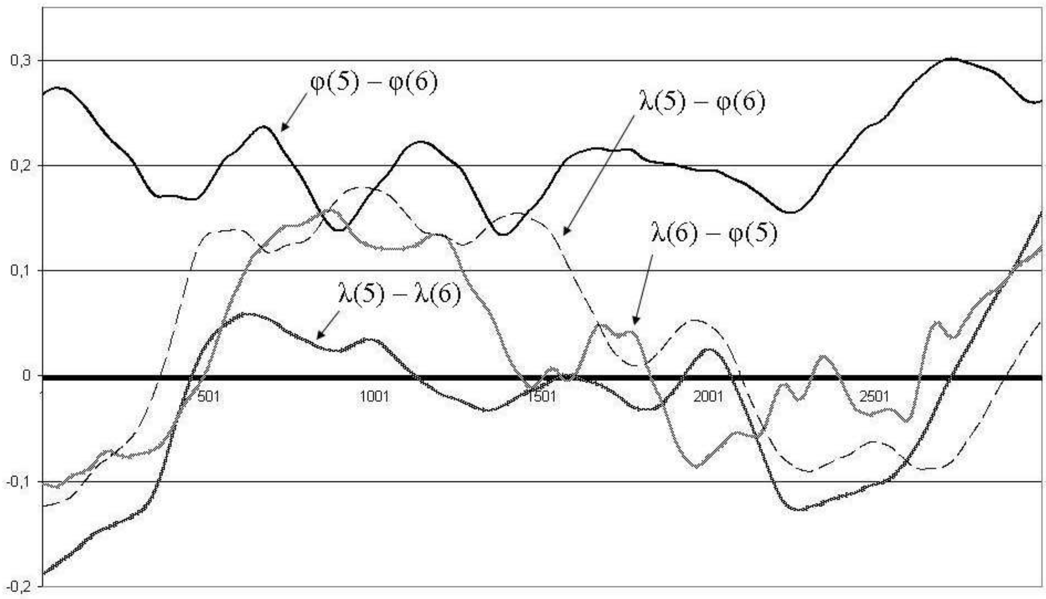


**Fig. 7. DGPS intercorrelation functions between antenna point 5 and 6**

## CONCLUSIONS

**The analysis measurements results, as illustrated in Figures 2-7, lead to the following conclusions:**

1. **The measurements of GPS position coordinates are strongly correlated – the time of correlation of a single coordinate is within the range of 25 minutes (a drop of correlation function value below 0.5), whereas among the coordinates, the values of the intercorrelation functions range from –0.4 to 0.4.**
2. **Between GPS synchronous measurements in two different points the correlation is much weaker, insignificant between some coordinates (e.g. between longitudes).**
3. **The coordinates correlation determined by means of DGPS is much weaker than by means of GPS (time of correlation is about 10 minutes).**
4. **In DGPS measurements a weaker correlation occurs between various points than in case of GPS. This fact should be accounted for when designing synchronous observations on the ship using two or more GPS/DGPS receivers (INS – Integrated Navigation System, ECDIS – Electronic Chart Display and Information System).**
5. **Considerable discrepancies have been noted in the values and the nature of autocorrelation and intercorrelation functions in various measurement points located within a small distance (of a few meters range). This refers to the measurements by both GPS and DGPS (the comparison of correlation functions of the same point for GPS and DGPS). It is only but a partial explanation of this fact that there exist differences in the configuration of the satellites received. It only proves that measurements of different receivers aboard the ship can have different static characteristics, and even more so, measurements from different ships and VTS centers (resulting in differences as to the coordinates received from AIS).**
6. **The correlation functions can be applied for measurement predictions in measurement filtration algorithms.**

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