GPS STRUCTURAL HEALTH MONITORING OF LONG-SPAN CABLE STAYED BRIDGES CONSIDERING ENVIRONMENTAL EFFECTS BASED ON TIME SERIES ANALYSIS

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1. INTRODUCTION

In general, interest in the ability to monitor a structure and detect damage at the earliest possible stage is commonly throughout the civil, engineering, mechanical, and aerospace communities. Otherwise, long-span bridges are flexible and low-damped and hence they are prone to vibrate under dynamic loadings. In addition, steel girders and towers, especially, are much lighter than those made of concrete and indeed many vibrations occur in real long-span bridges. Moreover, damage often relates closely with deformations and displacements of structures. Thus, the structural health monitoring (SHM) applied to many bridges has main purpose to determine the deformations or displacements of structures. Nowadays, there are only a limited researches which mentioned to apply GPS technology in SHMs of long-span bridges monitoring because of some reasons such as economic side, noise data process or difficulties of GPS system management under opertation. However, kinematic GPS technique can define the displacement of bridge directly with high accuracy in real time [1]. Therefore, application of GPS sensors in continuous monitoring is using in some long-span bridges in the world. Additionly, many previous studies addressed the effects of environment to the SHM data generally. In some cases of studies, the estimating stochastic regression models was one of the effective approaches to consider enviromental effects to analyze the structural conditions [2]. Another research, Omenzetter et al 2006, for example, proposed to use the seasonal ARIMA model coefficients to analyze the bridge conditions from the strain data acquired in continuous monitoring [3]. Thus, this study uses the time series analysis to apply for GPS data process to show the GPS data observations, comparison between the trend of data and environmental factors like temperature.

2. GPS SENSORS SYSTEM ON THE CABLE STAYED BRIDGE

The target bridge of this study is located in the South of Vietnam named Can Tho bridge that is over the Hau river. It is the long-span cable stayed bridge which is 2750 meters in total length of the main bridge with 550 meters of main span; 164.80 meters of tower high and opened to use in 2010. The target bridge uses the concrete girder box which is 26 meters of cross section. To reduce the loading capacity of main span, however, 210 meters at the middle of main span made by steel girder box to connect with the concrete girder box continuously. The SHMs of bridge includes many kinds of sensors such as temperature sensors, anemometers, accelerations etc. The GPS system in SHM of bridge includes 9 sensors as rover stations and 2 base station as shown in Fig 1. The rover stations are located on top of pylons, middle of bridge, a quater of main span and some piers such as pier 8, pier 24 and pier 31. The type of GPS data is coordinates in three directions: longitudinal (*x*), lateral (*y*), vertical (*z*).The frequency of GPS system is 20 Hz.

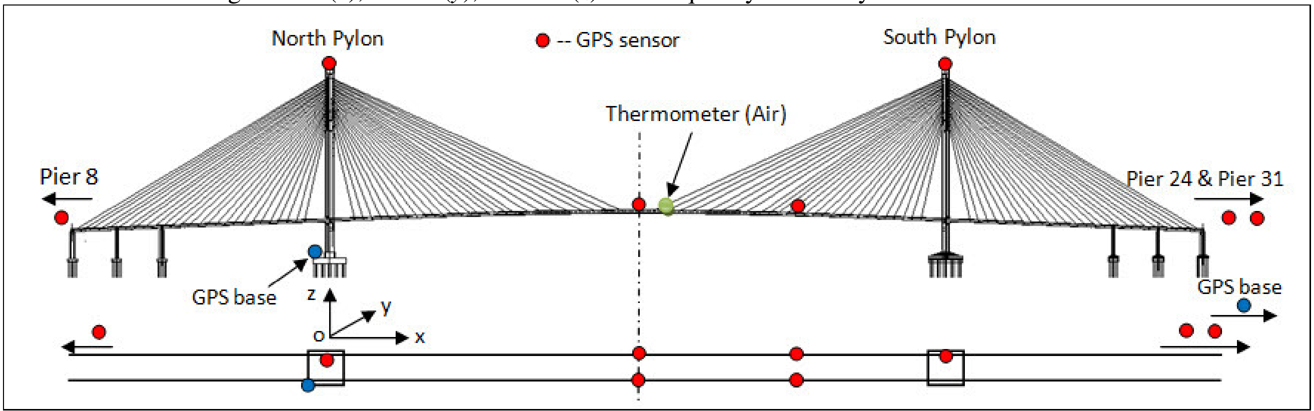

Fig. 1 GPS sensors on the Can Tho bridge

3. APPLICATION OF TIME SERIES ANALYSIS FOR GPS DATA

3.1 Observation data of GPS

The GPS observation data were acquired in 20 Hz and taking average each 10 minutes as plotted on the Fig. 2 which belong to the bridge direction called *x* corrdinate. Fig. 2 shows the *x* coordinate of three points: south peak pylon, middle deck and quater main span and the temperature data acquired. By Fig.2, actually, there are some missing data and extraordinary data. Therefore, how to process these data is very important in GPS data processing. Moreover, by study on another directions of coordinate system such as lateral direction or vertical direction, the displacements according to vertical direction is the largest displacement which are approximately double or triple of other directions. Otherwise, the displacements according to *x* direction and *y* direction are almost same values. For example, the maximum displacement of middle main span were 4.2, 4.0, 17.2 centimeters of *x, y, z* directions respectively

Keywords: GPS, ARIMA, Long-span bridge, SHM.
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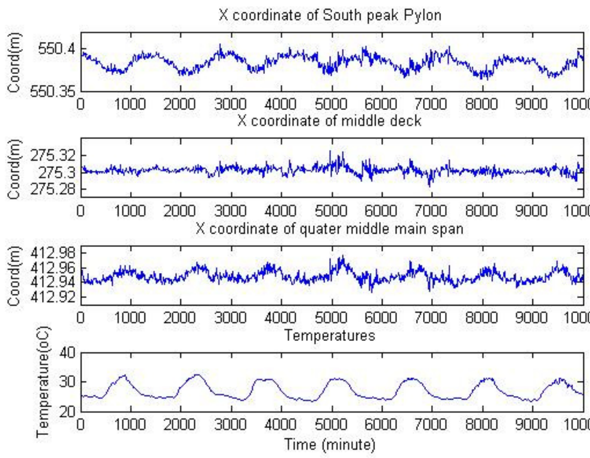

Fig.2 Observation data of Bridge

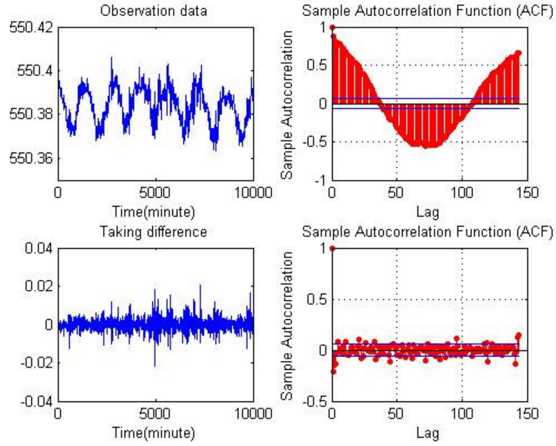

Fig.3 Autocorrelation step

3.2 Correlation between observation data and environmetal effects

The outside temperature is also shown on the Fig 2 that was acquired by temperature sensors set on bridge. The correlation coefficients between the outside temperature and GPS data can be recognized and its values are shown on Table 1. First of all, the correlation are distributed in all two side positive and negative. The correlation with middle main span points and quarter main span points during *z* direction is much higher than other all directions while the correlation with two pylon points have almost same values in all directions. This results shows that the thermal expansion and contraction of structure can occur due to the outside temperature change. Based on correlation coefficients, the global deformation of bridge can be recognized.

Table 1. Correlation coefficients

No	GPS points	Directions	Temperature
1	North Pylon	*x*	0.4571
		y	-0.4220
		z	0.4052
2	South Pylon	*x*	-0.6140
		y	-0.4935
		z	0.5567
3	Middle main span	*x*	0.1351
		y	0.0628
		z	-0.9131
4	Quarter of main span	*x*	0.6932
		y	-0.1055
		z	-0.8696

3.3 Autocorrelation step

The time-series model is popular method that is used as a forcasting model in many cases. In time-series model, the estimated model and the residual error can be used as the feature to investigate the change conditions of target systems. One of time-series models called the seasonal Autoregressive Intergrated Moving Average model (ARIMA) can be used for GPS data. Moreover, based on the intergration factor, the non-stationary time-series can be transferred to stationary by differencing. The period of difference can be defined by seasonal effects.

In this study, the *x* coordinate data of south peak pylon were extracted for using in autocorrelation step as shown in Fig 3. In the results of Fig 3, the autocorrelation function (ACF) shows the strong seasonal trend of data. The upper ACF fugure indicates clearly the 24 hours periodic behavior (144–Lags) and when the lag increases while the ACF decreases slowly to zero, that meas the observation data is non-stationary. However, the lower ACF figure shows the observation data after taking difference that means when the lag increases, the ACF decreases very fast to zero. These results can concludes that the observation data can be transferred stationary by taking difference. Therefore, stationary analysis can be used to define the fit ARIMA model for analyzing data.

4. CONCLUSIONS

This paper study on GPS structural health monitoring of long-span cable stayed bridges considering environmental effects based on time-series analysis. The GPS data in SHMs of Can Tho bridge was carried out. The observation data showed that GPS includes both missing data and extraordinary data which have to reduce in the processing data step to get higher accuracy. Furthermore, the outside temperature was also acquired to show that there is correlation between temperature and GPS data. In addition, GPS data transferred to stationary by taking difference . These results are important to extend study to define the applicability of GPS in SHMs of long-span cable stayed bridges.

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