Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2013, 36(108) z. 2 pp. 137–142
ISSN 1733-8670

2013, 36(108) z. 2 s. 137–142

Predict manoeuvring indices using AIS data by ridge regression

Jun-min Mou[1,3], Guang-hui Tang[1,2], Hao Rong[1,2], XuanYue[1,2]

[1] School of Navigation, Wuhan University of Technology, Wuhan, China
e-mail: ronghao1230@hotmail.com
[2] Hubei Key Laboratory of Inland Shipping Technology, Wuhan, China
[3] Key Laboratory of High Performance Ship Technology of Ministry of Education
(Wuhan University of Technology) , Wuhan, China, e-mail: moujm@whut.edu.cn

Key words: ridge regression, manoeuvring, AIS data, prediction, collision avoidance

Abstract
The ridge regression is presented for identify manoeuvring indices in Nomoto's model, and the result indicates that the method is robust and does not rely on initial estimation. For selecting appropriate AIS data for manoeuvring indices predicting, a frequency domain identification method is presented.

Introduction

The Automatic Identification System (AIS) for ships was introduced as a real-time system augmenting ship-borne radar to aid ship collision avoidance. It is compatible to the Vessel Traffic Services, so that it is a powerful tool for vessel traffic observation. Due to ship traffic with position and speed measurements from uniquely identified ship manoeuvring, the AIS data available from the system can then be used to predict manoeuvring indices by System Identification (SI) method.

Rate of turn and rudder angle are essential to predict manoeuvring indices in this research. However, rudder angle is not included in AIS data and some cases rate of turn only indicates positive or negative turn. Hasegawa [1] calculated rate of turn by the difference of two previous values of heading angle, and Quasi-Newton method is presented for optimize the *K–T* indices.

Inspired by Hasegawa's idea, the author apply ridge regression for identify manoeuvring indices in Nomoto's model. And in order to select appreciate data for study a frequency domain method is presented.

A frequency domain identification method for selecting appropriate ROT data

Because AIS message contain vessel's identity, position, course, speed and so on, the application of AIS data make it possible to investigate accurate and actual behaviors of ships during ship manoeuvring. Especially, rate of turn and rudder angle are essential data to predict manoenvring indices in this research, how to select appropriate data for system identification is also we concerned.

In this research, we obtain the *K–T* indices from analyzing the AIS data, and as known the Nomoto's model is the transfer function relating the heading angle ψ to the rudder angle δ. The power spectrum is a standard tool in periodicity investigations in nonlinear time series. For a periodic or quasi-periodic sequence, only peaks at certain frequencies exist; measurement noises are readily distinguished. Rate of turn series may also have sharp spectral lines, but even in the absence of the noise there will be a continuous part of the spectrum.

Power Spectrum Estimation

Suppose x_n, from $n = 0$ to $N - 1$ is a time series (discrete time) with zero mean. Suppose that it is a sum of a finite number of periodic components:

$$x_n = \sum_k \left[a_k \cos\left(2\pi v_k n\right) + b_k \sin\left(2\pi v_k n\right)\right] \quad (1)$$

The variance of x_n is, for a zero-mean function as above, given by $\frac{1}{N}\sum_{N=0}^{N-1} x_n^2$. If these data were samples taken from an electrical signal, this would be its average power.

Apply Fast Fourier Transform (FFT), estimate Fourier coefficient:

$$p_k = \sum_{i=1}^{N} C_j \exp\left[\frac{2\pi k_j \sqrt{-1}}{N}\right] \quad (2)$$

where p_k represent the effect that k component weight.

And the power spectrum is:

$$\bar{p}_k = a_k^2 + b_k^2$$

where:

$$a_k = \frac{1}{N}\sum_{i=1}^{N} x_i \cos\left[\frac{\pi i k}{N}\right], \text{ and } b_k = \frac{1}{N}\sum_{i=1}^{N} x_i \cos\left[\frac{\pi i k}{N}\right].$$

Estimation with AIS data

The rate of turn data which is very important for predicting manoeuvring indices in AIS message always indicates 0 or –128 (means not available). The first step is getting rid of the wrong rate of turn data. In this research we just analyze the situation that rate of turn is changing of the time.

We now attempt to empirically estimate the response frequency of the ROT data series of a vessel (MMSI number is 413433740). Figure 1 shows the ROT data observed at the Yangtze Estuary from 5:17:55PM on 4/18/2010 to 5:24:35 PM of this vessel. It is conveniently done by calculating the power spectrum. Figure 2 shows the power spectrum of the ROT time series of the ship.

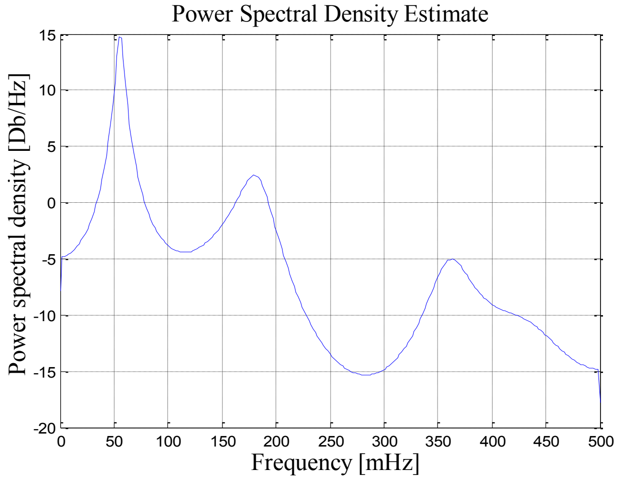

Fig. 2. Power spectrum for the ROT data of vessel “413433740”

The spectrum has been averaged over logarithmically spaced frequency intervals. The value of p_0, calculated from the FFT is approximately 53 mHz and, therefore, the base frequency may be sufficient related to the ship’s manoeuvrability. One should note that the vessel “413433740” is in the process of steering in the period of time of observation.

Figure 3 shows the ROT data observed at the Yangtze Estuary from 11:36:56 AM on 4/18/2010 to 11:43:36 AM of vessel “413352570”. It is conveniently done by calculating the power spectrum (in one dimension, the ensemble average of the square of the Fourier amplitudes as a function of the frequency f). Figure 4 shows the power spectrum of the ROT time series of the ship.

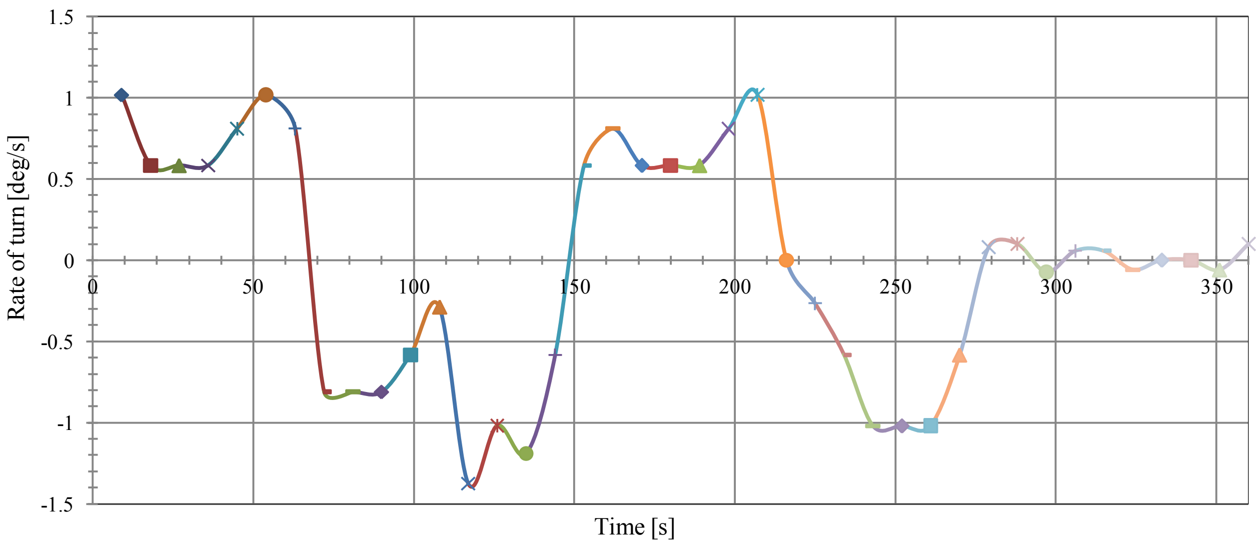

Fig. 1. Time series plot of the ROT data of “413433740”

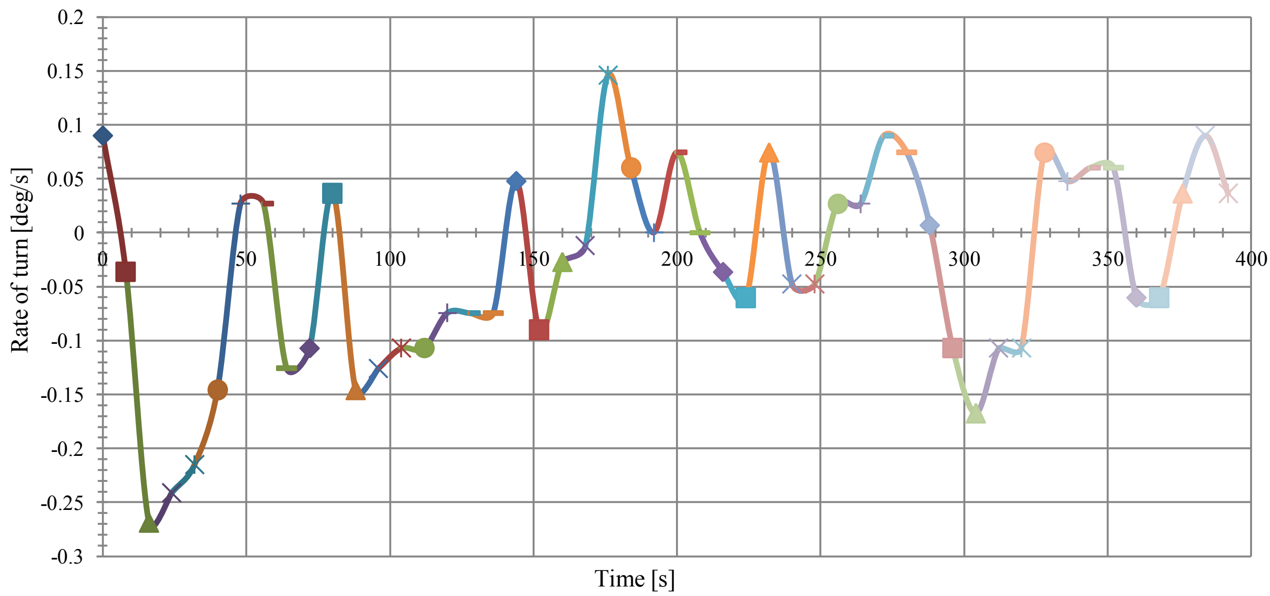

Fig. 3. Time series plot of the ROT data of "413352570"

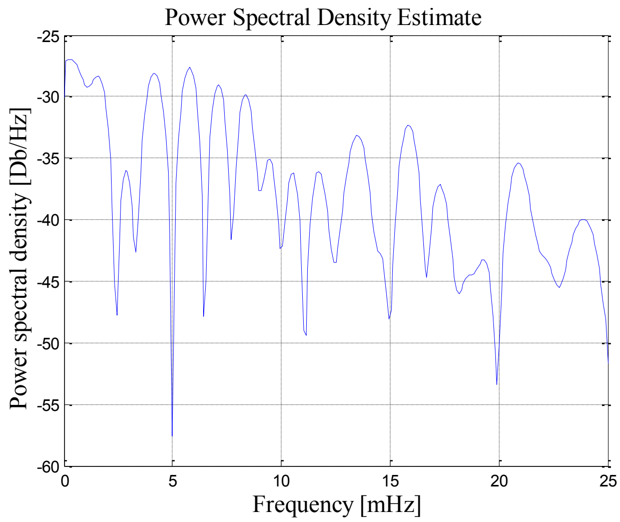

Fig. 4. Power spectrum for the ROT data of vessel "413352570"

As a result, power-laws are observed at multiple timescales in the ROT spectra. At low frequencies, ship steeling is in the highest flight, and the frequencies associated with ships' manoeuvrability. At higher frequencies, the power spectrum reflects the influence of external environment conditions. Furthermore, discrepancies and uncertainties are unavoidable, therefore, extreme caution is needed while using the power spectrum to identify the appreciate data for SI.

Predict manoeuvring indices by ridge regression

The identification study will be based on the Nomoto transfer function. Nomoto's first order model is the simplest mathematical model to describe ship manoeuvres, and the model is a compromise between the demand for a simple mathematical model and a fair approximation of the actual ship manoeuvring.

Ridge Regression

Ridge regression is the most commonly used method of regularization of ill-posed problems. It is related to the Levenberg-Marquardt algorithm for non-linear least squares problems [2]. Ridge regression is an improved least square estimation substantially.

Given the observed rate of turn data $r_i (i = 1,2,3,...n)$, and suppose observation error is Δr_i. Therefore, rate of turn can be defined as:

$$r_i = f(\theta, t_i) + \Delta r_i \tag{3}$$

The left side of Eq. 3 is the observed data and $f(\theta, t_i)$ is the calculated data. Ridge Regression starts at an initial guess $\theta = \{\alpha_1(0), \alpha_2(0), \alpha_3(0)\}$, and according to the Taylor expansion $f(\theta, t_i)$ can be expressed as Eq. 4:

$$r_i = f(\theta_0, t_i) + \left.\frac{\partial f(\theta, t_i)}{\partial \alpha_1}\right|_{\theta=\theta_0} \cdot \Delta\alpha_1 + \left.\frac{\partial f(\theta, t_i)}{\partial \alpha_2}\right|_{\theta=\theta_0} \cdot \Delta\alpha_2 + \left.\frac{\partial f(\theta, t_i)}{\partial \alpha_3}\right|_{\theta=\theta_0} \cdot \Delta\alpha_3 + \Delta\alpha_i \tag{4}$$

The matrix equation of Eq. 3 is:

$$\Delta R = J_r \cdot \Delta\theta + E_r \tag{5}$$

where:

$$E_r = \begin{bmatrix} \Delta r_1 \\ \Delta r_2 \\ \cdots \\ \Delta r_3 \end{bmatrix}, \quad \Delta R = \begin{bmatrix} r_1 - f(\theta_0, t_1) \\ r_2 - f(\theta_0, t_2) \\ \cdots \\ r_n - f(\theta_0, t_n) \end{bmatrix},$$

$$\Delta\theta = \begin{bmatrix} \Delta\alpha_1 = \alpha_1 - \alpha_1(0) \\ \Delta\alpha_2 = \alpha_2 - \alpha_2(0) \\ \Delta\alpha_3 = \alpha_3 - \alpha_3(0) \end{bmatrix},$$

$$J_r = \begin{bmatrix} \frac{\partial f(\theta,t_1)}{\partial\alpha_1} & \cdots & \frac{\partial f(\theta,t_1)}{\partial\alpha_3} \\ \cdots & & \cdots \\ \frac{\partial f(\theta,t_n)}{\partial\alpha_1} & \cdots & \frac{\partial f(\theta,t_n)}{\partial\alpha_3} \end{bmatrix}$$

Define quadratic objective function minimize the observation error:

$$\min\{J(\Delta\theta) = E_r^T E_r\} \tag{6}$$

Then:

$$\Delta\theta = \left(J_r^T J_r + \xi I\right)^{-1}\left(J_r^T \Delta R\right) \tag{7}$$

In the Eq. 7, ξ is damping factor, and if $\xi = 0$ the algorithm above is the classical least squares. Given any sufficiently small positive number ε, if:

$$\max\{|\Delta\alpha_1|, |\Delta\alpha_2|, |\Delta\alpha_3|\} \le \varepsilon \tag{8}$$

end of the algorithm. Otherwise assign each coefficient and iterate until conditions of satisfaction. The assignment of each coefficient:

$$\theta_{j+1} = \theta_j + \Delta\theta_j, \; j = 0,1,2,... \tag{9}$$

Compared with Gauss-Newton method, Ridge Regression is a biased estimate, but accuracy has been greatly improved.

Predict manoeuvring indices by AIS data

The data broadcasted from an AIS transponder is divided into static, semi-static, and dynamic ones:

- Static data: Ship identification number (MMSI number), length and breadth.
- Semi-static data: Ship destination, hazard level of cargo and ship draft.
- Dynamic data: Time of broadcast, ship speed, rate of turn, course over ground and position.

The rate of AIS data transmission is listed in table 1.

Meanwhile, static data is refreshed every 6 minutes or when information has changed.

Table 1. Rate of AIS transmission

Manoeuvring Situation	SampleRate
At Anchor	3 min
Speed 0–14 knots	12 s
Speed 0–14 knots and changing course	4 s
Speed 14–23 knots	6 s
Speed 14–23 knots and changing course	2 s
Speed > 23 knots	3 s
Speed > 23 knots and changing course	2 s

The application of AIS data make it possible to investigate accurate and actual behavior of ships which can be used in ship manoeuvring forecast.

Calculation of rudder angle from AIS data

In this research, the algorithm that predicts the *K-T* indices just applies to specific AIS data which include rate of turn.

There are 3 steps in predicting the *K–T* indices based on AIS data:

1) Find appropriate AIS data that can be used for manoeuvring indices predicting. The specific methodology and technology will be discussed in the next chapter.
2) Calculate rudder angle. Because the Nomoto's equation reflects the relationship between rudder angle and rate of turn, in this step we use the rate of turn data included in AIS and appropriate initial value of *K* and *T*. The initial *K* and *T* are on the basis of empirical formula [3].

$$K' = 0.428419 + 0.19936 L/B \tag{10}$$

$$T' = 1.94599 - 0.04104 L/B \tag{11}$$

Table 2. Particulars of "413433740"

MMSI	Ship type	Length over all [m]	Beam [m]	Draught [m]	Speed [knot]
413433740	Cargo	97	16	6	12.75

3) According to the step 2, we determine the initial *K–T* indices are 0.2152 and 12.9118 respectively. Rudder angle is updated each time by above Nomoto's equation. Figure 5 shows the calculated rudder angle of "413433740".

In the second step, rudder angle is calculated in each time. Then apply ridge regression mentioned above to determine the *K–T* indices. In this step, *K* and *T* is refreshed each time until find the best *K–T* indices that can match the rate of turn and rudder angle data. The predicted manoeuvring indices are illustrated in table 3.

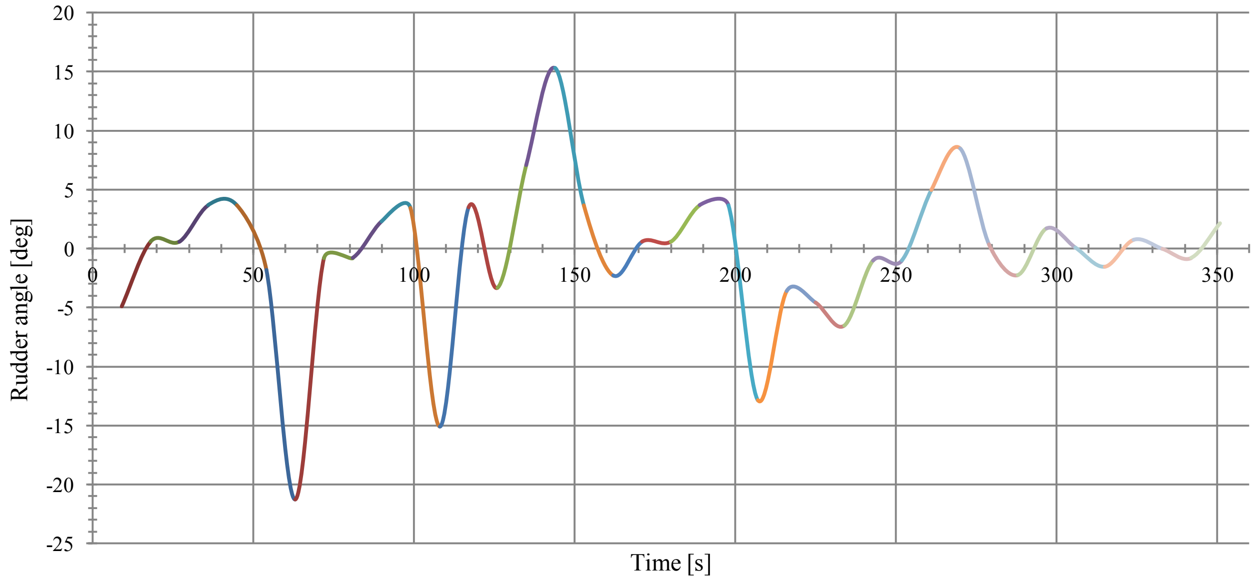

Fig. 5. Rudder angle of "413433740"

Table 3. Predicted manoeuvring indices of "413433740"

MMSI	*K*	*T*	Speed [knot]
413433740	0.2518	15.1746	12.75

The above 3 steps is how to predict *K*–*T* indices by AIS data. Initial value of *K* and *T* must be determined appropriately, because in the third step, rudder angle is calculated according to the initial *K* and *T*. That means the ridge regression just can optimize the initial *K* and *T*. Therefore, it is important to determine the appropriate initial *K*–*T* data.

Case study

In order to validate the proposed methodology, the calculated rudder angle and manoeuvrability are compared with the "Mariner" ship's simulation data. Table 4 shows the characteristics of "Mariner".

Table 4. Characteristics of ship

Length overall	160 m
Beam	23.2 m
Draught	7.467 m
Block coefficient	0.588
Area of Rudder	14.407 m^2
Diameter of propeller	6.707 m

Table 5. Manoeuvrability of ship

Experiment condition	*K'*	*T'*
10 degree	2.848	2.549

In this case, the initial value of *K*, *T* is 0.1792 and 16.7341 respectively. These manoeuvring indices are calculated by using result of zigzag simulation test. The solvers used were ode-45, as well as a fourth-order Runge-Kutta method-based solver.

For a typical zigzag manoeuvring test, the *x*–*y* plot is shown in figure 2, $\psi(t)$ and $\delta(t)$ plots are shown in figure 5. The data used in this manoeuvre are service speed $\bar{u}_0 = 15.9$ kn, preselected rudder angle (δ_s) = ±20 deg.

Figure 6 shows the results for rudder angle. The dot line is simulation rudder angle and the solid line is calculated rudder angle. It is clear that the tendency of these two lines is similar while the calculated rudder angles are slight bigger than simulation rudder angle. It is because that the initial *K* determined will be smaller than actual one.

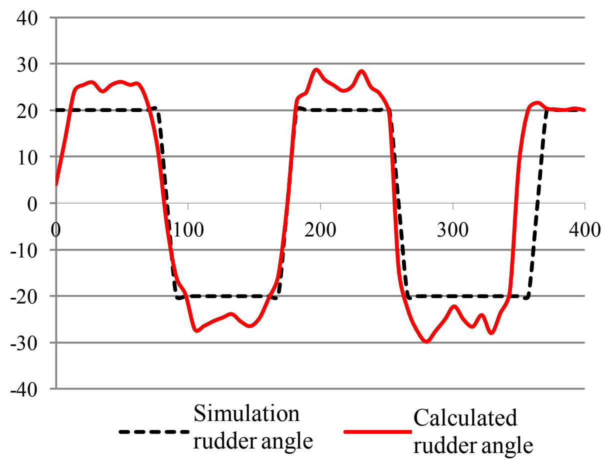

Fig. 6. Comparison of calculated and predicted rudder angle

Table 5 shows the calculated manoeuvrability of "Mariner", and figure 7 shows the comparison of heading angle. The line 2 is Mariner's simulation heading angle and the line 1 is the calculated one.

Compare this value with actual manoeuvrability on table 6, this optimized result seems to be slightly smaller. This is because regarding *T′*, it is affected by initial value of *T* and this may cause small differences. Even though there are small differences between actual manoeuvrability with calculated indices, the simulation results seem good enough to predict manoeuvrability indices. Thus, it is also applied to actual AIS data, and an automatic system that can find appropriate data is proposed.

Table 6. Calculated manoeuvrability of "Mariner"

Maximum rudder angle	*T* [s]	*K* [1/s]	*T′*	*K′*	Velocity [knot]
20 degree	19.4539	0.2174	1.9332	1.9454	15.9

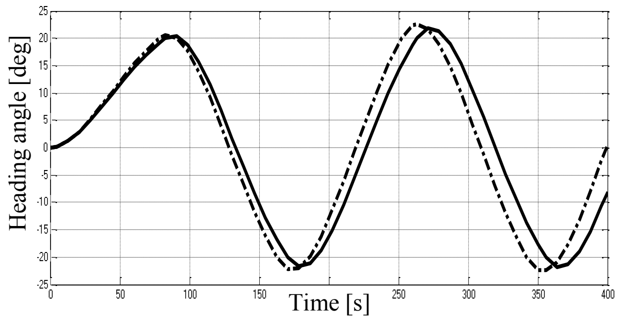

Fig. 7. Comparison of heading angle

Conclusions

This paper presented a detailed method for predicting manoeuvring indices by using AIS data. In this research, ridge regression is applied for identify the *K–T* indices in Nomoto's model. This method is turned out to be reliable by the simulation of "Mariner".

The presence of a scaling regime in the power spectrum of the ROT time series indicated the possibility of selecting appropriate data for SI automatically.

References

1. HASEGAWA K.: An Attempt to Predict Manoeuvring Indices Using AIS Data for Automatic OD Data Acquisition. In Proceedings: International Workshop of Next Generation Nautical Traffic Models, IWNTM, Delft 2013, Netherlands.
2. TIKHONOV A.N., GONCHARSKY A.V., STEPANOV V.V., YAGOLA A.G.: Numarical Methods for the Solution of Ill-Posed Problems. Kluwer Academic Publishers, 1995.
3. CHEN L.: Study on simulation calculation for inland ship manoeuvrability K and T indexes. Master thesis, Jiaotong University of Chongqing, 2009, China.
4. HARATI-MOKHTARI A., WALL A., BROOKS P., WANG J.: Automatic Identification System (AIS): Data Reliability and Human Error Implications. Journal of Navigation 60, 2007, 373–389.
5. VAN AMERONGEN J.: Adaptive Steering of ships-A Model Reference Approach to Improved Maneuvering and Economical Course Keeping. Ph.D. thesis, Delft University of Technology, 1982, Netherlands.
6. CHATFIELD C.: The Analysis of Time Series. An Introduction. Chapman and Hall, London 1989.
7. LUO W.L., ZOU Z.J.: Ship Maneuvering Modeling based on Ridge Regression. Ship & Ocean Engineering, Vol. 38, No. 6, 2009, 17–19.
8. ABKOWITZ M.A.: Measurement of hydrodynamic characteristics from ship manoeuvring trials by system identification.Transactions of the Society of Naval Architects and Marine Engineers 88, 1980, 283–318.
9. HADDARA M., WANG Y.: Parametric identification of manoevring models for ships. International Shipbuilding Progress, 46, 445, 1999, 5–27.