

Target maneuver onset time detection using acoustic features

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Abstract—In the paper, we considered the problem to estimate the underwater target maneuver onset time as quickly as possible using the acoustic features of ship's radiated noise.. Based on the statistical analysis of many acoustic features of different targets, the distribution of a certain estimated feature value in a single motion state is approximately normal. Base on the normal distribution, we defined the acoustic feature difference index to select the most sensitive feature to the change of target motion state. Using the most sensitive feature, we proposed an online method to estimate the target maneuver onset time by testing the significance of acoustic feature difference. Experiment results show that the proposed method is more rapid to estimate the maneuver onset time after the target maneuver occurs.

Keywords—target maneuver; onset time detection; acoustic feature

I. INTRODUCTION

Rapid and robust target maneuver onset time detection is crucial to obtain comparable target tracking accuracy [1-6]. Many algorithms and techniques have been developed to detect maneuvers. Most of the detectors attempt to identify a maneuver by predicting the expected target position and comparing it to the measured track. The difference between the predicted position and the measured named innovation. Ref. [6] presents six traditional and two novel maneuver detection algorithms. They are all innovation-based. These methods are quite slow. In the radar area, it typically requires a few seconds to detect a maneuver. But in the sonar area the observer is normally far from the target and the bearing of target is changed very slowly, so it typically requires several minutes to detect a maneuver. It is not acceptable for many practical situations in sonar system.

Feature-based maneuver detection techniques have been proposed in radar area using radar glint noise [7] and range-Doppler images [8]. In fact, radar target feature retains strong link with target motion mode. Compared with innovation-based techniques, the feature-based technique is fast response and more reliable.

In this paper, we exploited the problem using the acoustic features of ship's radiated noise. Since the features of ship's radiated noise have direct link with target motion state, the detector is devised by detecting the acoustic feature differences.

Form the ship's radiated noise, we can extract many features. Most of the features are changed during maneuvers, but some of the features are more sensitive to target motion state. We defined the acoustic feature difference index (AFDI) to select the most sensitive feature, and use it to develop the detector by testing the significance of acoustic feature difference. Some experiments were carried out to illustrate the capability of the proposed detector. Experiment results show that the proposed method is more rapid to estimate the maneuver onset time after the target maneuver occurs.

II. DISTRIBUTION OF THE ESTIMATED FEATURE VALUE

In the practical situation, we get the target's radiated noise $s(t)$ in real time. The fix length window can be used to get signal segments with certain duration T , such as 0.5s. Using each signal segment, many features can be extracted by different methods. We use f_k^l representing the l th feature value of these extracted features estimated by the k th signal segment. Assuming the target's motion state is not change in the $k = 1, \dots, K$, the l th feature value set can be given by

$$f^l = \{f_k^l, k = 1, \dots, K\} \quad (1)$$

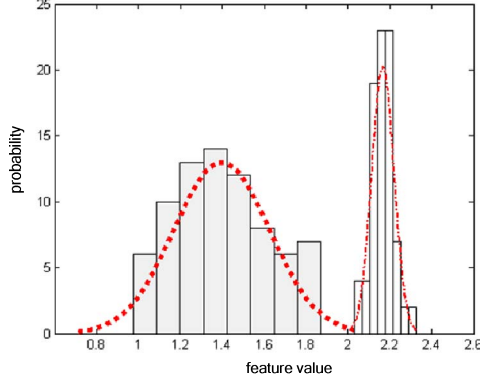
According to the central limit theorem, the distribution of f_k^l is approximately normal. Its mean and variance can be estimated by the feature value set f^l :

$$\overline{f^l} = \frac{1}{K} \sum_{k=1}^K f_k^l \quad (2)$$

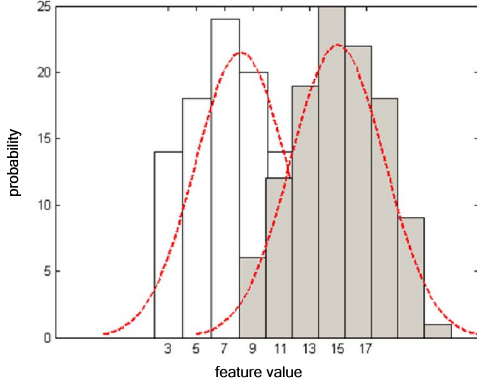
$$\sigma_{f^l}^2 = \frac{1}{K} \sum_{k=1}^K [f_k^l - \overline{f^l}]^2 \quad (3)$$

Considering the radiated noise of a small ship in two speeds, v_1 and v_2 ($v_1 > v_2$), using $T=1s$ and $K=80$, we estimated two typical acoustic features. One feature is the slope of wideband spectrum (SWS), defined by the rate of the largest value and its left boundary of the wideband spectrum. Another feature is the number of line spectrum (NLS) in 10-300Hz. Figure 1 gives plots of the histograms of the two feature values in two speeds, the fitted normal distributions are superimposed using the estimated mean and variance by feature value sets. Fig.1 indicates that the SWS decreases and NLS increases as the speed increases, and the histograms of the estimated feature values are reasonably well

approximated by the normal probability density.



(a) the slope of wideband spectrum



(b) the number of line spectrum

FIG. 1. histograms of the two feature values in two speeds (dashed curves: approximating normal functions, white histogram: speed v_1 , grey histogram: speed v_2)

From Fig.1, we also can see the difference of feature value caused by the same speed change is not consistent. The speed change can make the SWS change more than the NLS, so the SWS can distinguish the speed change better than NLS. We introduce the acoustic feature difference index (AFDI) to select the most sensitive feature, which defined by

$$\gamma(f^l, v_1, v_2) = \frac{[\bar{f}^l(v_1) - \bar{f}^l(v_2)]^2}{\sigma_{f^l}^2(v_1) + \sigma_{f^l}^2(v_2)} \quad (4)$$

If the difference of the mean of certain feature values at two speeds is larger, and the variance of each feature values is smaller in the same time, the AFDI will be larger for the feature. That's mean the feature can distinguish the speed change better than other features. We can use the feature which has largest AFDI to develop the detector to improve the computational efficiency.

III. TARGET MANEUVER ONSET TIME DETECTION

A. The significance test of acoustic feature difference

Denote the present time by k and assume that the target starts maneuvering at time K . That is, in the $k=1, \dots, K$, the target motion state is not change. The feature value f_k^l ($k=1, \dots, K$) is approximately normal $f_k^l \sim N(\bar{f}^l, \sigma_{f^l}^2)$. After the time K , the target motion state may be changed. We defined the test feature value set use the S signal segments after K

$$\tilde{f}^l = \{f_k^l, k = K + m, \dots, K + m + S\} \quad (5)$$

where m is a given constant, representing the constant delay after K . The reason using m is that some features are not change immediately after the change of target motion state occurs for underwater ships, such as acoustic feature caused by cavitation noise. From the test feature set, we get its mean denoted by $\bar{f}_T^l$.

If the target is not maneuver in the period $k = K + m, \dots, K + m + S$, $\bar{f}_T^l$ will be close to the $\bar{f}^l$, otherwise the difference between them will be significant. We introduced the threshold λ_l to test whether the difference is significant or not. When $\bar{f}_T^l$ falls in the region $[\bar{f}^l - \lambda_l, \bar{f}^l + \lambda_l]$, the difference is not significant. Because the f_k^l is approximately normal, its mean is also approximately normal, then the threshold λ_l can be given by

$$\int_{\bar{f}^l - \lambda_l}^{\bar{f}^l + \lambda_l} N(z; \bar{f}^l, \sigma_{f^l}^2 / K) dz = 1 - \alpha \quad (6)$$

where α is the confidence level of the test.

when $|\bar{f}_T^l - \bar{f}^l| \geq \lambda_l$, the difference is significant and

decision of the target motion state changed is made, the K is the estimated onset time.

B. Online realization

The online realization of the detection can be divided into two main procedures: initial procedure and cycle procedure. After we get $K_0 + m + S$ signal segments, we start to initial procedure:

Step1 : Compute the feature value set $f^l = \{f_k^l, k = 1, \dots, K_0\}$, and estimate its mean and variance;

Step2: Given the α , compute the threshold λ_l ;

Step3 : Compute the test feature set $\tilde{f}^l = \{f_k^l, k = K_0 + m, \dots, K_0 + m + S\}$, and estimate $\bar{f}_T^l$.

When we get a new signal segment after initial procedure, we start to cycle procedure:

Step1: Estimate the $f^l(K_0 + m + S + 1)$ using the new

signal segment , and renew the test feature set $\tilde{f}^l = \{f_k^l, k = K_0 + m + 1, \dots, K_0 + m + S + 1\}$, estimate the new $\bar{f}_T^l$;

Step2 : Do significance test of acoustic feature difference;

Step3: If the difference is insignificant, the target motion state is not change, renew the feature value set $f^l = \{f_k^l, k = 1, \dots, K_0 + 1\}$, and estimate its mean and variance, renew the threshold λ_l , receive the next signal segment and jump to step1;

Step4: If the difference is significant, the target motion state is change, and output the estimated maneuver onset time; at the same time, jump to initial procedure.

IV. SOME EXPERIMENTAL RESULTS

Some experiments were carried out in a lake to illustrate the capability of the detector proposed in the paper. A small boat was used and its track is specified in the experiment. A broadband underwater recording buoy was used to record the boat's radiated noise. The position of the buoy and the boat was recorded by onboard GPS receiver. Some analysis had done using the recorded data after the experiment. Compared with the true motion state according to the GPS, the estimated result can be checked.

Firstly, a series of straight runs with two constant speeds was performed. Using the recorded data, four acoustic features are extracted, including NLS (f^1), SWS (f^2), largest line spectrum in the low frequency band (f^3), and power in the frequency band 2000Hz—2250Hz (f^4). Table 1 gives the AFDI of the four features.

Table 1. the AFDI of the four features

	v_1		v_2		$\gamma(f, v_1, v_2)$
	$\bar{f}(v_1)$	$\sigma_f^2(v_1)$	$\bar{f}(v_2)$	$\sigma_f^2(v_2)$	
f^1	8.14	10.54	14.98	11.08	2.16
f^2	2.167	0.0028	1.398	0.052	10.79
f^3	235.82	2785.47	255.38	573.12	0.11
f^4	0.124	0.0169	0.361	0.00048	3.23

Then several maneuver runs was performed. For a special run, Fig. 2 gives its spectrum-time-recording in the frequency band 0-5000Hz, and Fig.3 gives the speed in the function of time according to the GPS. From the Fig.3, we can see the boat have significant speed change at 65s, and its

spectrum also changed at 75s from the Fig.2.

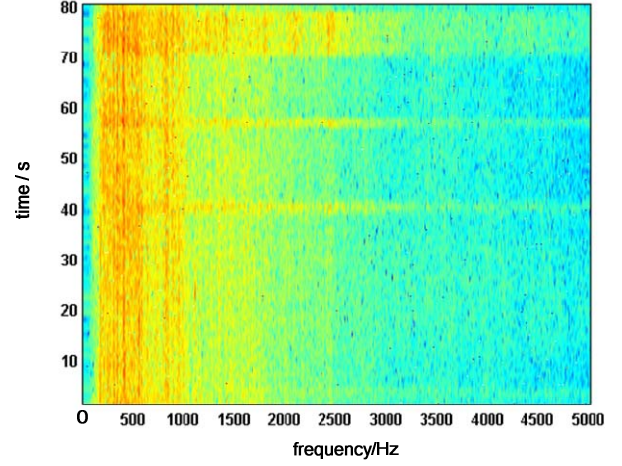


FIG. 2. The spectrum-time-recording in the frequency band 0-5000Hz

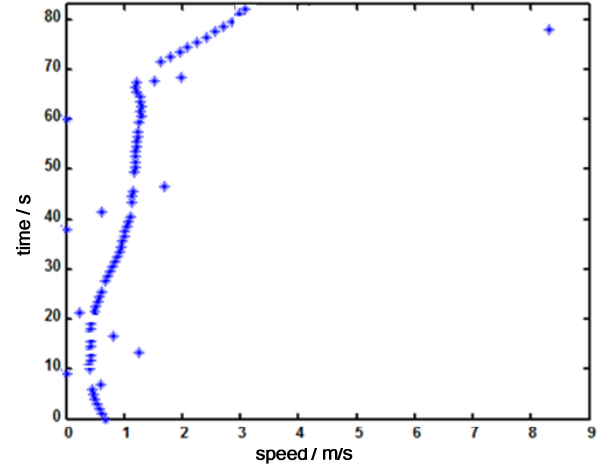


FIG. 3. the speed in the function of time according to the GPS

According to the table 1, SWS (f^2) has the largest AFDI, so we chose the SWS to detect the maneuver onset time. We use $T=1s$, $K_0 = 30$, $m=0$, $S=10$, and $\alpha = 0.8$ to develop the detector. Fig.4 gives f_k^2 in the function of k . obviously the estimated feature value is fluctuant due to all kinds of interference noise, especially at 40s and 60s. After the 70s, the estimated feature value is decreasing continuously.

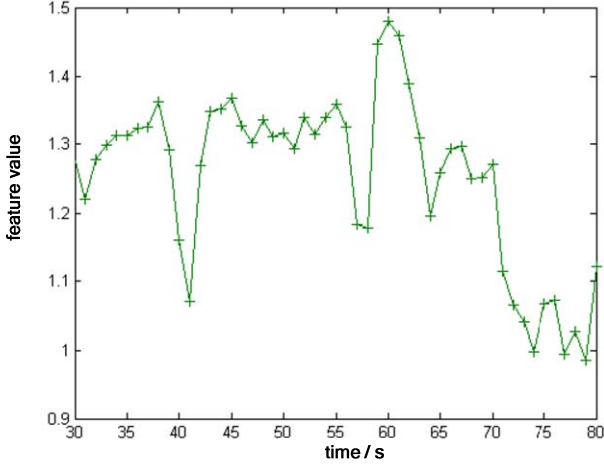


FIG. 4. the estimated feature value in the function of time

Fig.5 describes the estimated $\overline{f^2}$ (curve with asterisk) and $\overline{f_T^2}$ (curve with circle) in the function of time. Compared to Fig.4, the mean of the feature value is more smoothly, and the difference between $\overline{f^2}$ and $\overline{f_T^2}$ is increasing after 70s.

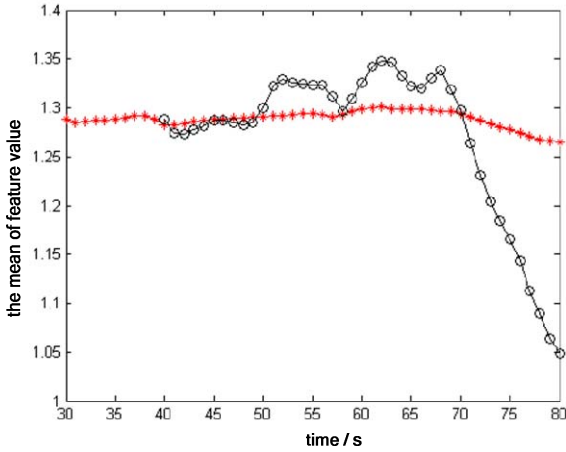


FIG. 5. The estimated $\overline{f^2}$ (denoted by asterisk) and $\overline{f_T^2}$ (denoted by circle) in the function of time

Fig.6 gives the difference of feature value $\left| \overline{f_T^2} - \overline{f^2} \right|$ and threshold λ_2 in the function of time. From Fig. 6, we can see the target maneuver onset time is at 75s. The actual time according to the ship's GPS is at 70s. The proposed method is more rapid to estimate the maneuver onset time after the target maneuver occurs.

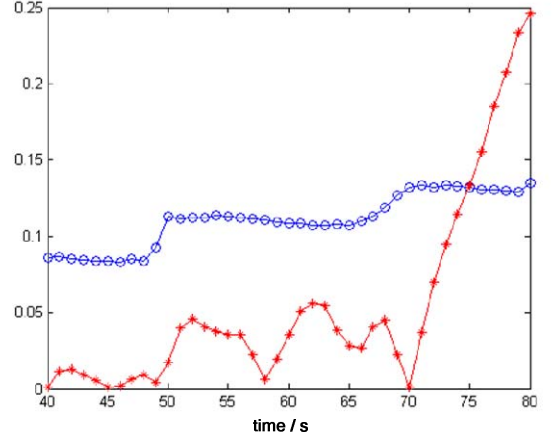


FIG. 6 the difference of feature value $\left| \overline{f_T^2} - \overline{f^2} \right|$ (denoted by asterisk) and threshold λ_2 (denoted by circle) in the function of time

V. CONCLUSION

Rapid and robust target maneuver onset time detection is crucial to obtain comparable target tracking accuracy. In this paper, we exploited the problem using the acoustic features of ship's radiated noise. By testing the significance of acoustic feature difference, an online method is proposed to estimate the target maneuver onset time. Experiment results show that the proposed method is more rapid to estimate the maneuver onset time after the target maneuver occurs.

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