Supplementary Material of “A Feature-Aided Multiple Model Algorithm for Maneuvering Target Tracking”

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Fig. S1, where each node receives the acoustic signals in the environment. Nodes communicate with each other by acoustic signals, cables, or drifting buoys on the surface [1].

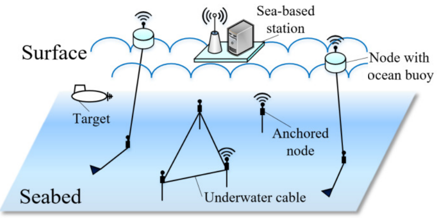

Fig. S1. Detection environment.

Fig. S2 displays the sound collected by an actual hydrophone when a ship passes by.

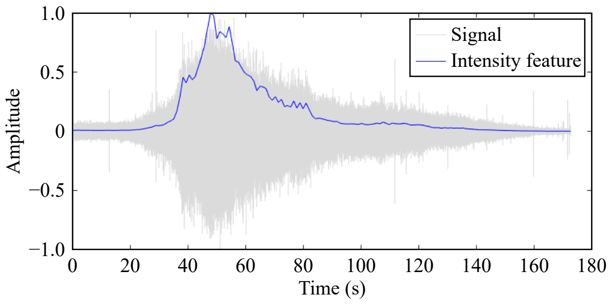

Fig. S2. Actual sound and intensity feature.

Fig. S3 is the state transformation and model selection diagram.

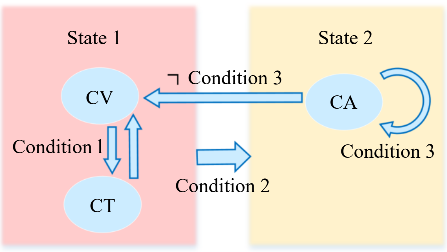

Fig. S3. State transformation and model selection.

Fig. S4 is the flow chart of the whole tracking method.

Fig. S5 displays the feature of the signal intensity received by a node.

1) Intensity models of the received acoustic signal

Mechanical noise and hydrodynamic noise are dominant types of sound exposed by underwater targets. Generated intensity P_E is primarily determined by the steady part of mechanical noise which comes from the engine operation. The frequency of the noise usually falls within 100 Hz to 1 kHz [2]. In a certain range, the sound intensity of different kinds of underwater targets has an approximately linear relationship with the speed, as Section 2.5.4 in [3] shows. Therefore, the relationship between the signal intensity and the speed can be expressed as $P_E = a + b|\boldsymbol{v}|$.

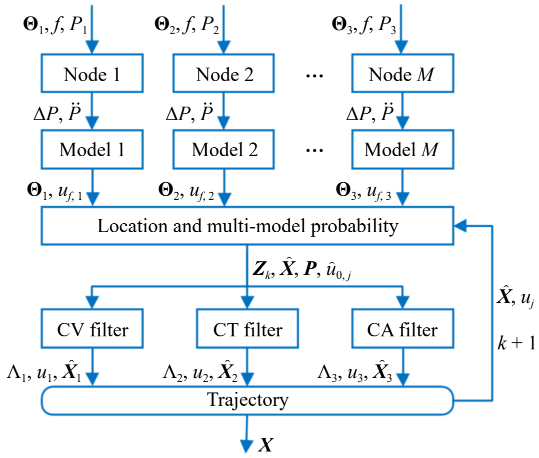

Fig. S4. Schematic of the FAMM method.

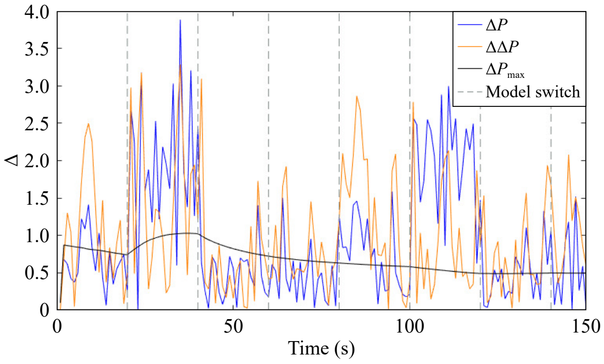

Fig. S5. Feature of the signal intensity.

The lost signal intensity from the target to the sensor is the path loss, which includes the absorption loss P_A and the spreading loss P_S. According to the findings in [4], the spreading loss is caused by the expansion of the sound and is dependent on the distance between the target and the receiver. Different models are appropriate for different transmission environments. In the case of bounded spreading in shallow ocean areas, P_S is equivalent as cylindrical where the diffusion coefficient $c = 1$, and

$$P_S(R) = c \times 10\log\left(R \times 10^{-3}\right). \tag{1}$$

The absorption loss P_A [dB] is an energy loss in form of heat and varies linearly with a range as [4]

$$P_A(R, f) = 10\log(\alpha(f)) \times R \tag{2}$$

where R [km] is the distance between the node and the target, and $\alpha(f)$ is the absorption coefficient related to the signal frequency. Within the frequency range of 100 Hz to 3 kHz using Thorp’s formula [4], $\alpha(f)$ [dB/m] with f in kHz is empirically denoted as

$$\alpha(f) = \left(\frac{0.11f^2}{f^2+1} + \frac{44f^2}{f^2+4100} + 2.75\times 10^{-4} f^2 + 3\times 10^{-4}\right)\times 10^{-3}. \tag{3}$$

In this way, we obtain the following formula for the intensity of sound received by a passive node from the underwater target as:

$$P_{\text{total}} = P_E - P_S - P_A + Q_c = a + b|\boldsymbol{v}| - \log R - 10\log(\alpha(f)) \times R + Q_c \quad (4)$$

where Q_c is the random noise of background in the target-free case.

2) Selection of parameters

The switching of models can be treated as a problem of hypothesis testing [5]. Thus, parameters η_1, η_2 and η_3 in the coditions determine the thesholds for model switching, and can be calculated and choosen based on the probability of false judgment. For example, Condition 1 is used to determine whether the target is in a CV model or a CT model. As Fig. S6 shows, when we know the probability distribution function (PDF) of ΔP in different states, the probability of false judgment under different parameters are obtained. The PDF of ΔP follows the Gaussian distribution approximately. In the CV state, $f(\Delta P \mid H_0) \sim N(P_{\max}, q_c^2)$, where H_0 denotes the hypothesis when the judgment is correct. Similarly in the CT model, $f(\Delta P \mid H_0) \sim N(\Delta \bar{P}_t, q_c^2)$, where $\bar{P}_t$ is the average variation related to the motion and acoustic characteristics of a target, that is, related to the target type. The optimal thesholds and parameters are calculated by minimizing the comprehensive false judgment probability. In this letter, we set $\eta_1 = 1.2$, $\eta_2 = 1.8$ and $\eta_3 = 2$ for typical scenarios. In practice, these parameters can be adjusted based on the target of interest and the accuracy of model judgment at each node through experiments.

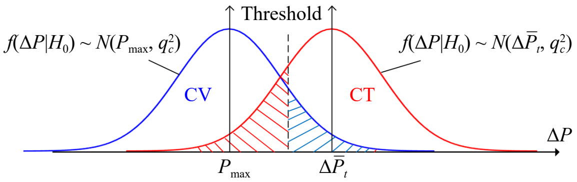

Fig. S6. State transformation and model selection.

References

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