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Track Fusion Performance of Multi-Track Integration System with a Test Vessel

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Abstract: A vessel traffic service (VTS) system is a marine traffic monitor and control system established by public safety or security authorities in order to forestall a maritime accidents such ship collision and stranding. Hence the VTS system always collects target data containing location and velocity of vessels within its purview using multi sensors, mainly radars built in several areas and AIS transponders installed in vessels. However, the collected target data can be incorrect due to measurement errors, failure of sensors, bad weather conditions, and so on. In this manuscript, we propose a multi-track integration system (MTIS) which can generate a relatively correct track information via the fusions of the collected target data and then we prove that the MTIS provides more accurate track information than its original target data, through experiments using a test vessel.

Key–Words: Track fusion, multi-track integration, position correction, fused track

1 Introduction

A vessel traffic service (VTS) is designed to provide the safety of vessels at sea, the marine accident prevention, and the efficiency of navigation. The VTS is governed by the international maritime treaty, SOLAS, together with the Guidelines for Vessel Traffic Services, IMO Resolution A.857(20) [1]. Generally, the VTS system operates various sensors, e.g., radars which can cover a limited geographical area, automatic identification system (AIS) broadcasting dynamic data of the vessel, closed-circuit television (CCTV) for video surveillance, and VHF radiotelephony, in order to maintain track of vessel movements and offer navigational safety.

For effective monitoring of vessels, the VTS system definitely needs radar (target) data from radars and AIS (target) data from AIS transponder embedded in vessels for its given roles. Here, both target data types have advantages and disadvantages, respectively. Radar data can be collected anytime without an extra device in a vessel, as long as the vessel is located within a radar detection range except for a shadow zone. However, radar data is strongly influenced by open-nature environment. Choppy waters and heavy rain significantly drop the reliability of radar data. Besides, if a monitoring object is far from the radar, the overall radar measurement error increases largely. Unlike radar data, the accuracy level of AIS data is almost constant regardless of the environment, since an AIS transponder transmits its own AIS data via wireless communication channel. The flaws of AIS data are the equipment breakdown or none of transmission because of intentional power off. Small fishing boats often turn off its AIS transponder in order to avoid the exposure of its location.

The VTS system may generate one or more target data for an object, for example, which is detected by several radars, or which transmits its AIS data together with detected by a radar or more. In this case, we can make an improved track which can alleviate the flaws of each data type through a track fusion using the radar and AIS data. In this manuscript, we call the improved track as a fused track.

We have been developing VTS system from the past a few years. The VTS system consists of various sub-systems. One of them manages all track information used in the whole subsystems. We define the sub-system as Multi-Track Integration System (MTIS). The MTIS predicts the next position of the targets for track-to-track synchronization and it controls the track information in response to the targets' circumstances. The MTIS also integrates different radar and AIS data into a fused track for an identical target. Specially, the track fusion is executed in the track fusion module (TFM) of the MTIS. We have built a test-bed for realistic experiments of the developing VTS system. In the test-bed using a vessel, we proved that the fused track has more accurate track information than its original data, that is, radar target data collected from several radars.

The remainder of this paper is organized as follows. Section 2 introduces our system model. In Section 3, we describe the outline of the MTIS and the principle of the TFM. Section 4 explains our experiment environments and also summarizes the experiment results. Finally, we conclude this paper in Section 5.

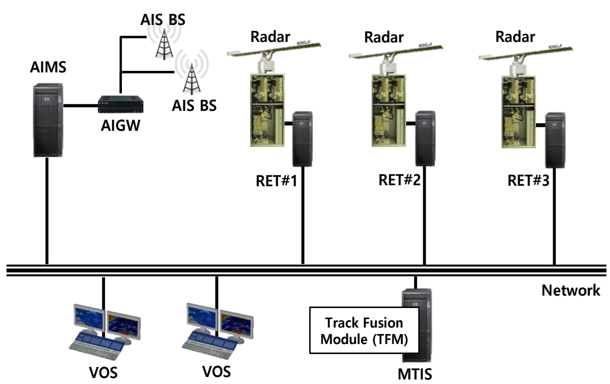


Figure 1: Outline of our VTS system mo

Our VTS system, still under development, co various sub-systems. In this manuscript, we some of them which are needed to introduce o fusion module (TFM). Although each sub-syst forms a variety of functions, here, we explain c only associated with track fusion. Figure 1 sh sub-systems, each of which is interconnected network and is defined as follows:

- **AIMS** (AIs Management System) collects formation of vessels via AIGW (AIs Ga which receives AIS information from seve BSs (AIS Base Stations). Each AIS BS is i by region and it aperiodically receives AIS i tion from AIS transponders of vessels in i The AIMS transmits the collected AIS info to the MTIS on receiving the AIS informatic
- **RET** (Radar image Extracting and Tracking extracts digital radar images from the analog signal while tracking them. Then it transr corresponding radar target information to the MTIS every RPM (Rotation Per Minute) of the connected radar.
- **MTIS** (Multi-Track Integration System) gathers AIS information and radar target information from the AIMS and several RETs respectively, while integrating different information into a fused track for an identical target, using TFM (Track Fusion Module). The TFM incorporates track fusion algorithm and it works depending on the target situation. Finally, the MTIS periodically distributes the fused track information to several VOSs.
- **VOS** (Vts Operating System) displays all the fused track information as well as radar images per a given period. Each VOS is generally used for one VTS operator. A VTS operator can monitor hazardous situation of vessels via the VOS and deal with the situation.

Since the aim of this manuscript is to show track fusion performance of several track information for each identical track, we focus on the TFM of the MTIS in this manuscipt.

3 Proposed Strategy

In this section, after we explain how the TFM processes radar and AIS target data, we describe a fundamental principle of the TFM.

3.1 Outline of Target Data Process

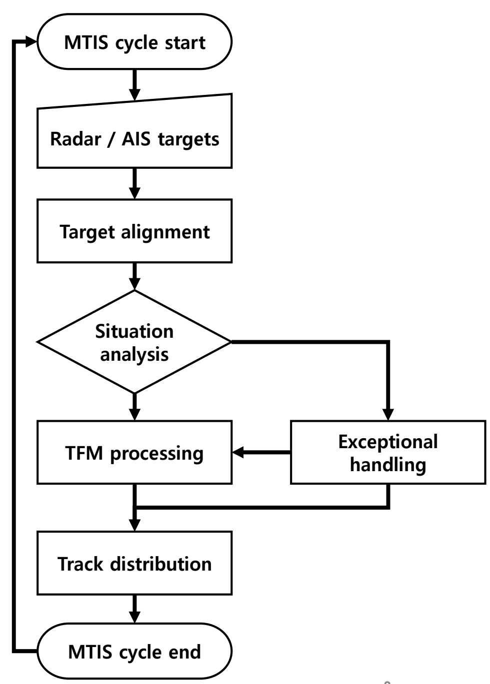


Figure 2: Target data processing procedure

As we mentioned in section 2, MTIS collects a lot of target data and the system can make useful fused track information within a given time. That is, the MTIS should be able to distribute fresh and corrected fused track information to several VOSs every a given time. We outline the track fusion processing procedure in Figure 2. The procedure consists of eight stages. We explain them as below:

(i) **MTIS cycle start:** This means that MTIS cycle begins. MTIS cycle is a time interval between fused/AIS track transmission of the MTIS. In other words, it is a time period in which the MTIS carries out track fusion while distributing the track information to VOSs. Generally, in our VTS system, the MTIS cycle is defined as a maximum value among RPMs of radars.

(ii) **Radar/AIS targets:** MTIS receives many messages containing radar target information from different RETs and AIS target information from AIMS during a MTIS cycle. This stage indicates that the MTIS receives radar/AIS target information from RETs and the AIMS for the inputs of the TFM processing.

(iii) **Target alignment:** While multiple RETs transmit their radar target information to the MTIS, AIMS also sends AIS target information to the MTIS on their individual transmission time criteria. That is, the MTIS are given many messages irregularly. Therefore, according to time interval between a updated time of the MTIS's fused track and the transmission time of the corresponding radar/AIS target information, the MTIS should predict the fused track information or the radar/AIS target information as reasonable track fusion.

(iv) **Situation analysis:** The MTIS continuously updates fused tracks using the recent radar/AIS target information. However, the track update may sometimes be not required under certain situations such as receipt of past target information, an excess of tolerance, and a false-positive error of determining different tracks as the same track. This stage determines whether the next stage is the TFM processing stage or the exceptional handling stage according to given situations.

(v) **TFM processing:** In a normal situation, the MTIS updates its own fused tracks in order to keep them up to date with track fusion. The TFM carries out the track fusion on receiving radar/AIS targets. Here, the track fusion must be done within a MTIS cycle in order to avoid track transmission delays. We will introduce a basic track fusion algorithm in the following subsection.

(vi) **Exceptional handling:** It is easy to predict the next position of big vessels, e.g., a passenger ship, a cargo ship, and a deep-sea fishing vessel. On the other hand, the position prediction of small boats may be difficult under their frequent veering and their slow movement in their congested area. Above this, the MTIS can receive earlier target information than its own information. In that case, the target information may be ignored depending on the time interval. Aside from these situations, there are various other exceptional situations. The MTIS should be able to cope with all possible exceptional situations. In this manuscript, we do not handle them.

(vii) **Track distribution:** After finishing the above stages, the MTIS transmits the updated fused track information to several VOSs.

(viii) **MTIS cycle end:** If all the above stages are completed, a MTIS cycle is terminated and then new MTIS cycle starts from the first stage again. The track fusion processing procedure must be finished in less than a given MTIS cycle.

3.2 Fundamental Principle of Track Fusion

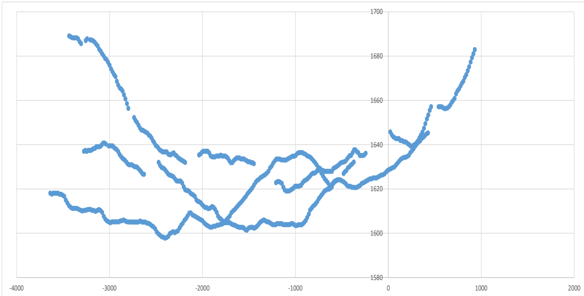
The principle of track fusion developed in the TFM is based on convex combination (CC)[2], which is one of simple algorithms for track fusion. Since it assumes that each individual track is independent, it does not requires cross-covariance between tracks. The CC uses each track's combined state $\hat{x}_{k|k}$ and its covariance $\hat{P}_{k|k}$, which are defined as:

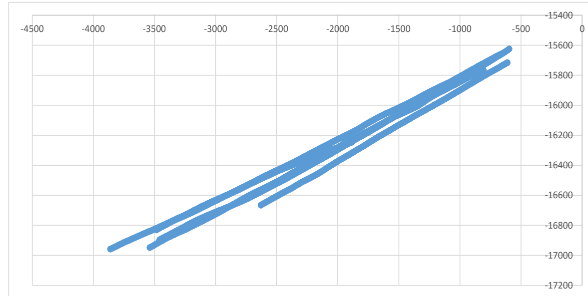
$$\hat{x}_{k|k} = \hat{P}_{k|k}(\sum_{i=1}^{N}(\hat{P}^{i}_{k|k})^{-1}\ \hat{x}^{i}_{k|k}) \tag{1}$$

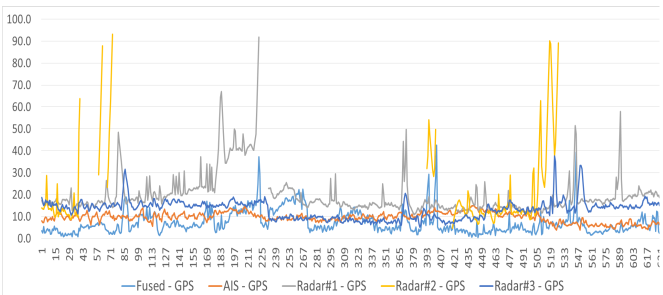
$$\hat{P}_{k|k} = (\sum_{i=1}^{N}(\hat{P}^{i}_{k|k})^{-1})^{-1} \tag{2}$$

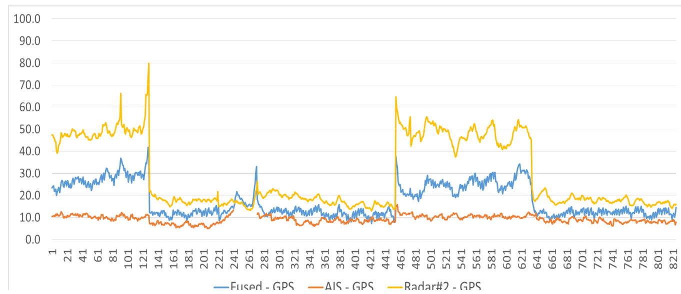
where N is the number of individual tracks to be fused for an identical track, $\hat{x}^{i}_{k|k}$ is the i-th individual track state vector to fuse at k-th prediction time, $\hat{P}^{i}_{k|k}$ is the error covariance of $\hat{x}^{i}_{k|k}$, $\hat{x}_{k|k}$ is the track state vector which is fused by N number of $\hat{x}^{i}_{k|k}$, and $\hat{P}_{k|k}$ is the total error covariance of $\hat{x}_{k|k}$.

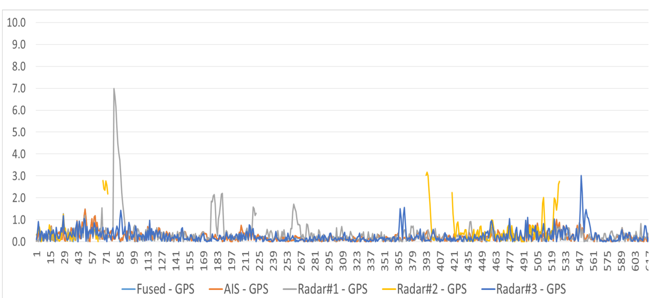
On receiving radar/AIS target information, the TFM predicts $\hat{x}_{k|k}$ and $\hat{P}_{k|k}$ using Kalman filter [3], which is one of optimal estimators, for more realistic track fusion. In fact, this track prediction is executed in the Target alignment stage in section 3.1. After the prediction, the TFM adjusts weight parameters α_j of



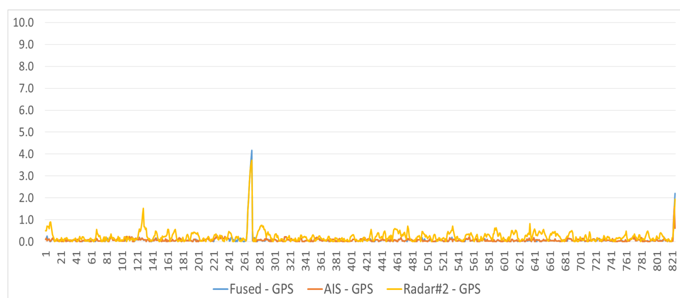








(a) Near the coast



(b) Inside the seawall

Figure 5: Velocity errors of test vessel

$\hat{P}^i_{k|k}$ according to the track's situation. We define it in the following equation where n is the number of weight parameters to be considered in the TFM and $F_j(\cdot)$ is an exceptional handling function.

$$\hat{P}_{k|k} = \hat{P}_{k|k} \times \prod_{j=1}^{n} F_j(\alpha_j) \tag{3}$$

4 Performance Analysis

We simply introduce our test-bed and we also show performance results of track fusion using a test ship in this section.

4.1 Test Environment

For continuous diagnostic tests of our developing VTS system, we have built a test-bed which is made up of entire sub-systems including sub-systems described in Figure 1. We rent a ship in order to test track fusion performance and we set up a high-quality GPS device (having an error of less than $1m$) as well as an AIS transponder of class A in the test ship.

In accordance with the guideline of the technical performance requirements [4], the test ship has to move under certain conditions for accurate performance measurements. The certain conditions includes that the vessel should be without manoeuvre for the determination of COG and maintain a minimum speed of ten knots. However, it is close to impossible to operate a vessel with fulfilling such conditions on sea waves, even though the wave is calm. For our experiments s as stable as possible, we operated the test ship in the following two environments:

▷ **Near the coast:** Although the wave is low, the test ship is close to the radar. The distance between the both is approximatively 6 km. Generally, the closer a radar and its target are, the higher the detection accuracy of the radar is. In this area, the test ship can be detected by three radars. Figure 3(a) depicts the vessel route used for the test near the coast.

▷ **Inside the seawall:** The water is almost no waves inside the seawall. However, as the distance between the test ship and the radar is about 13 km, it is relatively far. Only a radar is able to find the test ship in this area. The test route inside the seawall is shown in Figure 3(b).

Additionally, X-axis and Y-axis of Figures 3(a) and 3(b) stand for the history of the vessel location, respectively.

4.2 Experimental Results

We record position and velocity of the test ship logged from the GPS device installed in the test ship during its navigation. In the same period, we also log the position and velocity of the MTIS. In Figures 4 and 5, X-axis and Y-axis stand for time and errors, respectively. The comparison results for position and velocity parameters are as below.

1) **Position errors:** Figures 4(a) and 4(b) describe the distances between the records of the GPS and those of the MTIS (that is, fused tracks) in case of near the coast and inside the seawall, respectively. As you can see, the position errors of the fused tracks are mostly lower than those of radar tracks.

2) **Velocity errors:** The velocity difference between the records of the GPS and those of the MTIS near the coast is shown in Figure 5(a), while that inside the seawall is shown in Figure 5(b). Most of the velocity errors in the fused tracks, like the one above, are lower than those in radar tracks.

We calculaed RMSEs (Root Mean Square Errors) between the GPS and the MTIS logs for performance comparisons of the track fusion. We summarize the analysis results in Tables 1 and 2, in which $\triangle P$ and $\triangle V$ means the RMSE of position and that of velocity for "near the coast" and "inside the seawall" environments, respectively. In near the coast, the fused tracks have the highest accuracy in position and velocity. However, inside the seawall, AIS information errors are lower than other tracks. The reason is because that an AIS device has a self-GPS module for its own position measurement whereas MTIS and RET do not depend on additional position measurement device. Consequently, the MTIS can offer more improved track information to VOSs by reducing potential errors of radar tracks via the track fusion.

Table 1: Performance results in near the coast

Track type	$\triangle P$ **(m)**	$\triangle V$ **(knots)**
Fused (MTIS)	8.854	0.306
AIS	9.817	0.311
Radar1	22.070	0.733
Radar2	32.962	0.912
Radar3	13.929	0.397

Table 2: Performance results inside the seawall

Track type	$\triangle P$ **(m)**	$\triangle V$ **(knots)**
Fused (MTIS)	19.062	0.293
AIS	9.332	0.110
Radar2	33.067	0.375

5 Conclusion

With the use of a vessel, we demonstrated that the fused track generated by the TFM of the MTIS has more accurate track information, i.e., position and velocity, than its original radar data in near the coast and inside the seawall. In near future, we will test the accuracy of COG (course of ground), which is one of the important track information, in the above environment. Furthermore, we will prove the efficiency of the MTIS in other environments.

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