Journal of Marine Science and Technology

Volume 22 | Issue 3 Article 4

DESIGN OF A CHART-BASED RADAR SIMULATOR AUGMENTED WITH A MULTI-AGENT SHIP TRAFFIC SIMULATION PLATFORM

Shwu-Jing Chang
Electronic Chart Research Center, Department of Communications, Navigation and Control Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C., jchang@mail.ntou.edu.tw

Yu-Ting Lai
Electronic Chart Research Center, Department of Communications, Navigation and Control Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Chun-Mai Hsu
Electronic Chart Research Center, Department of Communications, Navigation and Control Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

Recommended Citation

Chang, Shwu-Jing; Lai, Yu-Ting; and Hsu, Chun-Mai (2014) "DESIGN OF A CHART-BASED RADAR SIMULATOR AUGMENTED WITH A MULTI-AGENT SHIP TRAFFIC SIMULATION PLATFORM," *Journal of Marine Science and Technology*: Vol. 22: Iss. 3, Article 4.
DOI: 10.6119/JMST-013-0909-3
Available at: https://jmstt.ntou.edu.tw/journal/vol22/iss3/4

Journal of Marine Science and Technology, Vol. 22, No. 3, pp. 304-311 (2014)
DOI: 10.6119/JMST-013-0909-3

DESIGN OF A CHART-BASED RADAR SIMULATOR AUGMENTED WITH A MULTI-AGENT SHIP TRAFFIC SIMULATION PLATFORM

Shwu-Jing Chang, Yu-Ting Lai, and Chun-Mai Hsu

Key words: radar, navigation, electronic navigational chart, vessel traffic, simulation.

ABSTRACT

This paper presents a radar simulation system developed under a request to deliver a radar and an Electronic Chart Display and Information System (ECDIS) for the navigation bridge of a ship maneuvering simulator. It is designed to dynamically generate radar image based on the electronic navigational chart database and sensor information to provide flexibility in navigation area for exercise and maintain consistency with other sensors or systems of the bridge, especially the ECDIS. Since the successful delivery of our study, the radar simulation system has been augmented with a Multi-Agent Ship Traffic (MAST) simulation platform and evolved into a versatile platform for training as well as research and development.

I. INTRODUCTION

Simulators are getting more and more important for the training of seafarers. As they can simulate scenarios rare or dangerous to encounter in real life, simulators may serve the training purpose even better than in-service training. Simulator-based training is actually made mandatory by the International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers (STCW) in some cases, such as radar [7].

For decades, mariners have relied on radar for safe passage and collision avoidance, especially in poor visibility. New technologies such as Automatic Identification System (AIS) and Electronic Chart Display and Information System (ECDIS) never diminish the importance of radar in modern bridge. Instead, modern radar evolves to integrate supporting features from AIS and ECDIS. For example, "Chart Radar", a new category of radar in the revised radar standard [3], can overlay electronic navigational charts with the radar image and associate AIS targets with radar targets. Chart overlay facilitates the identification of radar echo from charted features, while AIS enhances the target identification and tracking function of radar. Such development trend leads to new design methodologies of simulators, too.

This paper presents a radar simulation system developed in the Electronic Chart Research Center of National Taiwan Ocean University (NTOU). The original request, received in 2008, was to deliver a Radar simulator and an ECDIS for the navigation bridge of a ship maneuvering simulator. Radar simulators rely on a database to generate radar pictures for the exercise area. In most cases, this database is created from nautical charts and other sources, e.g. digital terrain elevation model, by using proprietary database generation tools. ECDIS requires a database of Electronic Navigational Charts (ENCs) produced by hydrographic offices. ENC database contains almost all the static information that a Radar simulator needs for the navigation area [5]. It consists of non-overlapping cells of multiple scale levels, which correspond to different navigational purpose and radar range scales. As the worldwide ENC database coverage expands, some database generation tools can now extract ENC information for radar simulations. However, if the radar simulator can operate directly on the ENC database just like ECDIS, it would give users more flexible and seamless selection of the exercise area. Simulated radar picture would correlate more with the ECDIS chart display as well as the visual of the simulated bridge environment. Implementation of additional features such as radar maps and chart radar would also benefit from such design approach. Above is the concept that we proposed in the design of this radar simulation system.

In order to test the radar simulator and augment its functionality, we developed a platform of Multi-Agent Ship Traffic simulation (MAST) [2]. With MAST, traffic scenes may be created with ships, represented and operated by software agents, navigating along selected routes either planned on the chart display of MAST or imported from existing route files. The arrival rate that ships enter the traffic scene via each route

Paper submitted: 08/20/12; accepted 09/09/13. Author for correspondence: Shwu-Jing Chang (e-mail: sjchang@mail.ntou.edu.tw).
Electronic Chart Research Center, Department of Communications, Navigation and Control Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

can be set, too. Information exchange between ships via AIS is simulated so that collision threats, in terms of the calculated Closest Point of Approach (CPA) and Time to CPA (TCPA), may be detected. Collision avoidance maneuvering mechanism is also implemented in the agents to take actions according to the encountering situation and International Regulations for Preventing Collisions at Sea (COLREGS). After the threat is cleared, they will then re-enter their planned routes. With MAST, the whole radar simulation system becomes a versatile platform for training as well as research and development.

The remaining part of this paper is organized as follows: Section II focuses on the radar image simulation of the system to describe the design methodology. Simulation results are verified and discussed in section III. Section IV further describes the design of the MAST platform. Section V outlines related work of other researchers for possible comparison. Conclusions of this work are then given in Section VI.

II. SYSTEM DESIGN METHODOLOGY

The first version of this radar simulator was implemented with Python programming language and successfully delivered within 5 months as requested. The radar simulation part of the system consists of the following major modules: Sensor Interface, Chart Information, Radar Image, Mathematical Utility, and Operation Interface.

1. Sensor Interface Module

Radar requires heading input to support Head up or North up display. To have course up display, true motion display, integrate with AIS or ECDIS, it needs the course over ground, speed over ground, and position coordinates, which may be provided by GPS. As for a radar simulator, even the basic Head up/ Relative Motion display mode requires own ship's position to retrieve surrounding spatial information for the generation of radar image.

The sensor interface module handles the required sensor data which is encoded into IEC 61162 [4] standard interface sentences and input via serial ports and Ethernet interface. Common output sentence types from Compass, GPS, AIS, and Automatic Radar Plotting Aid (ARPA) are supported, including e.g. $--HDT, $--GGA, $--RMC, $--TLL, and $--TTM. These sensor data may be disseminated by the ship handling simulator, generated by using NMEA simulators (e.g. MAST). Users may also enter the heading, position, course, and speed manually.

2. Chart Information Module

Chart information module takes care of the chart selection and information retrieval for radar image as well as overlay. Many of the functionalities developed for ECDIS can be reused in this module.

The ENC database that ECDIS uses conforms to the S57 standard specified by the International Hydrographic Organization (IHO), as mandated by the International Maritime

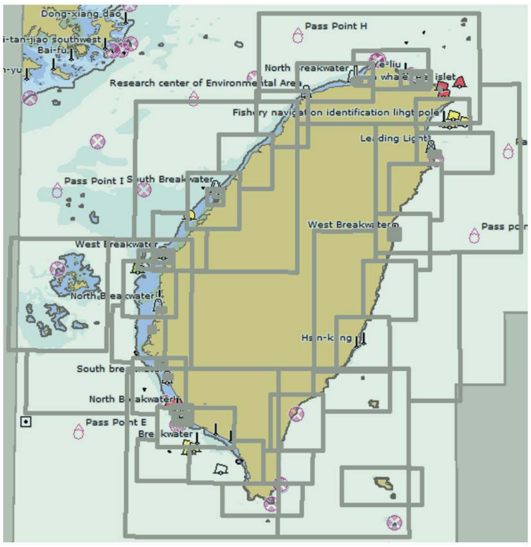


Fig. 1. ENC database (coverage in grey boxes) available for radar simulation in Taiwan waters.

Organization. S57 ENCs store chart information as objects, namely feature and spatial objects. Spatial objects use vector data model to define the spatial properties of feature objects. According to S57, ENC base cells and their updates are encapsulated as ISO 8211 files for transfer.

To support radar image generation, an algorithm is designed for the chart information module to select a suitable combination of charts from the available file-based ENC database (see Fig. 1 for waters around Taiwan). For each available chart file, this module gets the cell boundary, compilation scale and data coverage area from the header and objects in the file. Based on these meta data, the chart selection is made according to own ship's position and the radar display range.

For those charts covering own ship's position, chart corners are checked to see if any of them extends beyond the radar range. If multiple charts satisfy the above criteria, compilation scale of the chart is considered.

According to S57, ENCs are classified into 6 navigational purposes or usage bands of complication scales, namely overview, general, coastal, approach, harbor and berthing. ENCs of the same navigational purpose must not overlap each other. IHO further recommends that the setting of compilation scales for all ENCs should be based upon standard radar range scales as shown in Table 1, to improve world-wide ENC consistency. Therefore, this table is looked up when selecting charts via the compilation scales. Finally, neighboring ENC cells of the same navigational purpose are included to fill up the simulated radar screen.

From the selected charts, feature attributes and spatial geometries of the desired layers (i.e. object classes) are retrieved. A spatial filter is applied at this stage so that only features within range are retrieved.

Feature classes related to radar image generation must be identified first, and the clue may lie in the attributes. S57 chart

Table 1. IHO recommended chart scales for different radar ranges.

navigational purpose	complication scales	Standard radar ranges
3 (coastal)	180,000 90,000	12 NM 6 NM
4 (approach)	45,000 22,000	3 NM 1.5 NM
5 (harbor)	12,000 8,000 4,000	0.75 NM 0.5 NM 0.25 NM

Note: only those of interest to this radar simulator are listed here.

features are grouped into object classes. Each object class has a six-letter acronym and its applicable set of spatial primitives and attributes. For example, in S57 ENC, natural coastlines and those with shoreline constructions are encoded as COALNE and SLCONS objects, respectively. COALNE objects have attributes such as category of coastline, elevation, and radar conspicuity. On the other hand, feature objects with "radar conspicuity", "elevation" or "height" attributes, such as "shoreline construction (SLCONS)", "built-up area (BUAARE)", and "landmark (LNDMRK)", may all affect the radar image. Terrain is encoded in ENC as point or linear type "land elevation (LNDELV)" objects. Another ENC object class that requires special processing in the context of radar simulation is the "radar transponder beacon (RTPBCN)", which includes Ramark and Racon.

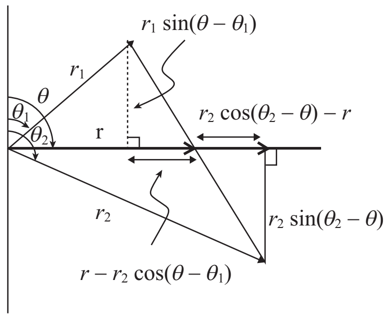
Besides the radar image, radar maps or chart overlays need information from ENC layers, too. 'Radar map' refers to a layer consisting of marks and lines that can be produced and overlaid onto the radar display. It is a common feature of radar intended for indicating safety-related areas and objects. This radar simulator provides user interface to select groups of ENC feature classes for display as background map overlays. When the map overlay is turned on, the depth contour which corresponds to own ship's safety depth will be highlighted.

3. Radar Image Module

This module generates the radar image in a scan-to-scan mode. Each scan corresponds to a radial line originated from own ship's position at radar antenna site. Echo intensity along each scan line is determined according to radar wave propagation characteristics, radar antenna height and information obtained from ENCs.

For feature classes such as shoreline construction, built-up area, and landmarks, "elevation" attribute is optional. In case the elevation value is not encoded in ENCs, a random value within a configurable range is used instead. For example, "built-up area" can be set to be 5~15 m high, while the default height of shoreline construction is set to 2 m.

In ENCs, spatial geometries of feature objects are stored in vector data records with geographic coordinates in WGS84 datum. In most cases, they retain just enough point coordinates to describe the geometries for the intended usage or



$$r = \frac{r_1 r_2 \sin(\theta_2 - \theta_1)}{r_2 \sin(\theta_2 - \theta) + r_1 \sin(\theta - \theta_1)}$$

Fig. 2. Line interpolation in polar coordinate system.

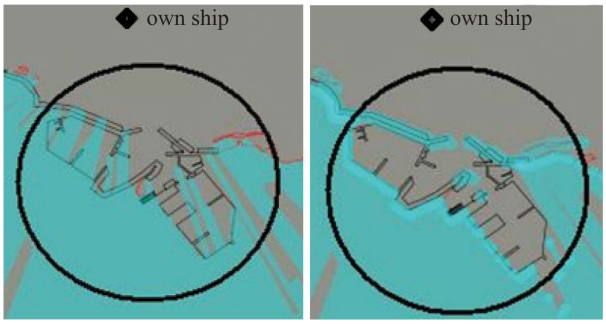


Fig. 3. Radar image generated without (left) and with (right) interpolations applied to features' lines and area boundaries.

scale, e.g. vertices of an area type BUAARE object, or turning points of a linear type of SLCONS objects. Therefore, intersection points with these features' geometries have to be computed to obtain their height along each radar scan line. In order to speed up the image generation process, such intersections are actually calculated as line interpolations in the polar coordinate system. Equation for such line interpolation is derived as shown in Fig. 2. Fig. 3 shows the generated radar image with and without line interpolations.

The next step is to build the height profile from intersections along each scan line. The problem is how high it is between intersection points. Each scan line may cross the coastline several times. How do we know which sections belong to land area instead of sea area? To solve this problem, we propose to treat the height profile layer by layer, e.g. starting from land area, land elevation contours, then built up areas. For ENCs, skin of the earth is completely covered by area type objects, especially land areas and (water) depth areas. Therefore, intersections with the boundaries of land area objects may delimit the sections between land and sea. However, implementation of this algorithm requires careful consideration of some special cases, similar to the 'point in polygon' test. For example, even if own ship position should always be in the sea area, there may not be even number of scan line intersection points with the land area boundary, e.g. due to extreme vertex. As for the height between land elevation contours, linear interpolation is applied.

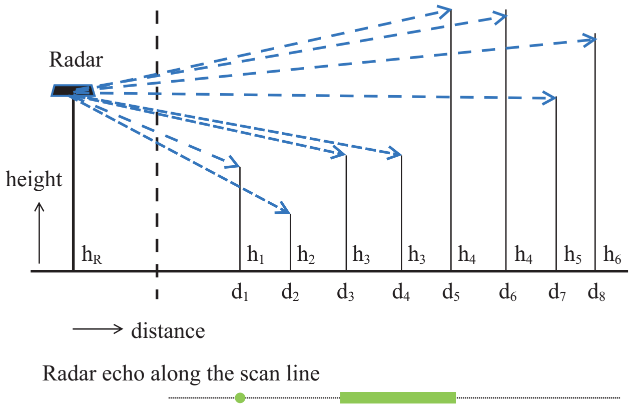


Fig. 4. Height profile obtained from chart features and corresponding echo simulated along a radar scan line.

Radar echo from these feature objects are inferred from the height profiles along scan lines by comparing the vertical angles relative to the radar antenna, as illustrated in Fig. 4.

Radar echo from other moving targets (vessels) and signals from radar transponder beacons are simulated and rendered as overlays. 'Racon' is a radar transponder beacon commonly used to mark navigational hazards. On reception of ship's radar transmission, it replies with a pulsed radar transmission, coded in international Morse code. Mariners can thus identify and determine the relative bearing and range of the racon according to the echo and Morse symbol painted on screen.

Echo from radar transponder beacon is simulated only when own ship is within its maximum detectable range, given in the "value of maximum range (VALMXR)" attribute of the RTPBCN feature in the ENC. Simulated signal for the RTPBCN located near Keelung harbor entrance is shown in the upper left of Fig. 5. It's a racon with Morse code "C"(一·一·), as retrieved from the "category of radar transponder beacon (CATRTB)" and "signal group (SIGGRP)" attributes. On the other hand, a 'ramark' is a continuously transmitting radar beacon that provides bearings only. If we replace the racon with a ramark, its radar signal would be as shown in the upper right of Fig. 5.

4. User Operation Interface Module

This module takes care of the user interface and operation setting-related tasks, such as Head-Up (H/U) or North-Up (N/U) radar display mode, sea/ground stabilization, Electronic Bearing Lines (EBL), Variable Range Markers (VRM), range scale and range ring intervals, heading line, cursor location, radar map, display of own ship's sensor data, display of target data, CPA/TCPA warning, etc.. Fig. 6 illustrates the difference between N/U and H/U display mode, while Fig. 7 demonstrates the use of VRM and EBL in measuring range and bearing.

5. Mathematical Utility Module

This module consists of utility functions required to support other modules in this system. Functions implemented include conversion between coordinate systems, line intersection and interpolation, rotation of markers placed on radar maps while in H/U mode, etc. There are four coordinate systems involved, including geographic latitude and longitude in WGS84 datum, projected northing and easting, range and bearing from radar antenna, and screen coordinates.

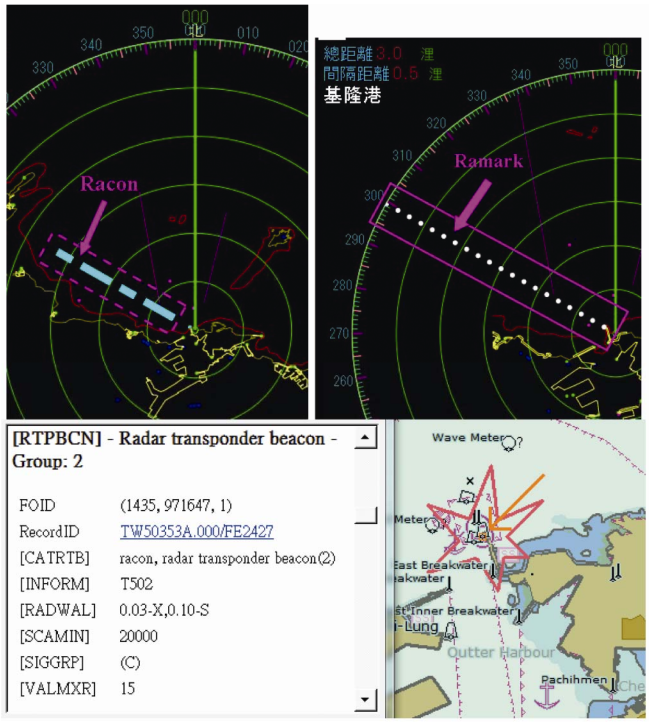


Fig. 5. Racon response and ramark signals simulated and rendered as overlays for the radar image according to the feature object and attributes encoded in the electronic navigational chart.

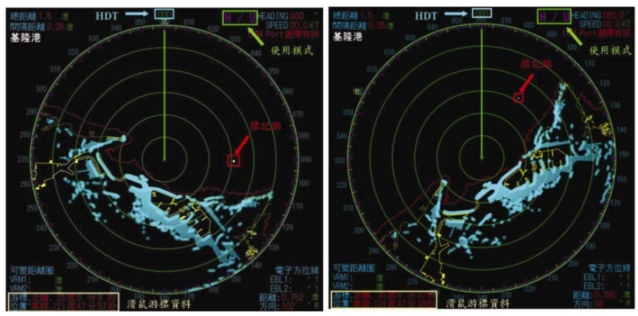


Fig. 6. Radar image rotated according to ship's heading while in the H/U display mode. Heading = 0° (left) *vs.* 60° (right).

Radar wave propagates on a geodesic path which is of the shortest distance across the Earth's surface. When assuming a spherical Earth with radius R, the great circle path length r between two points, with latitudes θ_1 and θ_2, longitude λ_1 and λ_2, is given by equation (1) and the relative bearing θ is given by equation (2).

$$r = R\cos^{-1}[\cos\theta_1 \cos\theta_2 \cos(\lambda_1 - \lambda_2) + \sin\theta_1 \sin\theta_2] \quad (1)$$

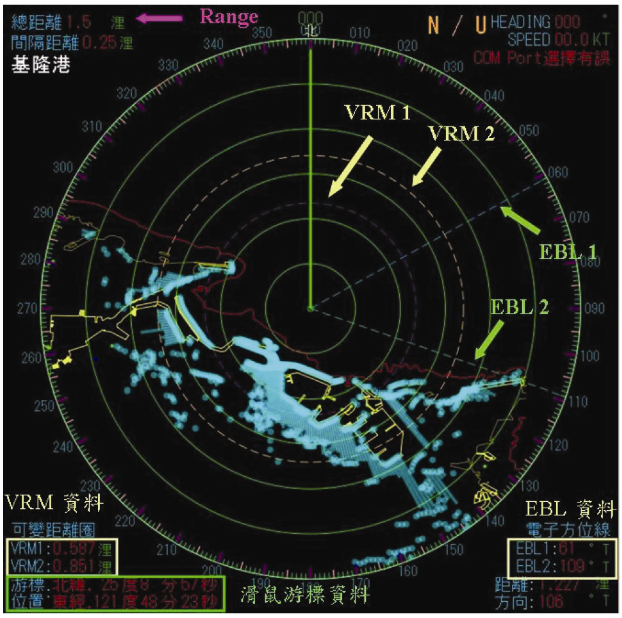


Fig. 7. Tools for measurement or query, such as variable range markers, electronic bearing lines and cursor location.

$$x = \cos\theta_1 \sin\theta_2 - \sin\theta_1 \cos\theta_2 \cos(\lambda_1 - \lambda_2)$$

$$y = \sin(\lambda_2 - \lambda_1)\cos\theta_2$$

$$\theta = \tan^{-1}(y/x) \quad (2)$$

When calculating the bearing with equation (2), the arc-tangent value should be evaluated with special care in different quadrants. The result should be converted to a compass bearing in the range between 0° and 360°, with 0° in the true north.

According to the performance standards of radar equipment, the radar system bearing accuracy should be within 1°, and the range accuracy is required to be within 30 m or 1% of the range scale in use, whichever is greater [8]. At 12NM range, 1% accuracy equals 222 m. Compared with more precise calculations using the formula of Vincenty [10] based on ellipsoidal model, distance calculation using spherical Earth approximation is accurate to about 0.3%, enough for this radar simulation application. Table 2 shows the difference in distance calculated using Vincenty's formula and the spherical great circle one for a point located 12 nautical miles away from the origin in the east or north direction. Therefore, this simulator adopts the great circle formula to save the unnecessary computation cost.

Table 2. Difference in distance calculation at 12 NM range.

origin (θ_0, λ_0)	compass bearing	difference in distance (relative difference)
23°N, 0°E	90°	34 m (0.2%)
45°N, 0°E	90°	64 m (0.3%)
70°N, 0°E	90°	94 m (0.4%)
0°N, 0°E	0°	126 m (0.6%)
70°N, 0°E	0°	74 m (0.3%)

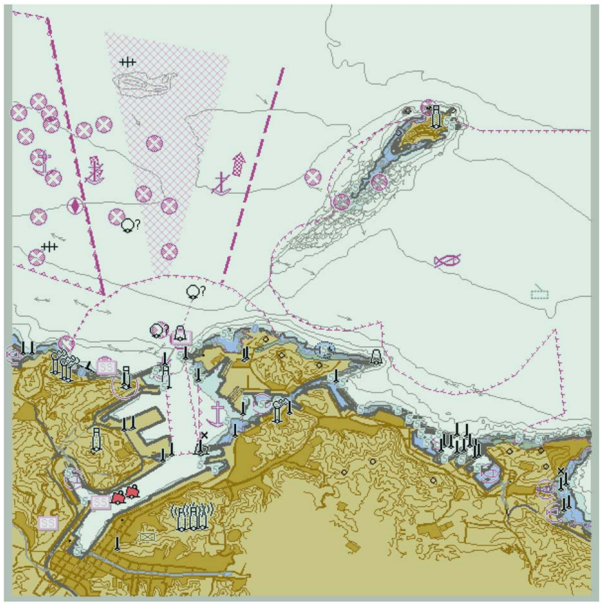


Fig. 8. ECDIS display of Keelung Harbor ENC (TW50353A.000).

III. VERIFICATION OF SIMULATED RADAR IMAGES

1. Verification with the ECDIS Display of ENC

For the following verifications, only one ENC file named TW50353A.000 is used. This ENC is of the largest scale among ENCs covering Keelung harbor, and it belongs to navigation purpose 5 (harbor). Fig. 8 is the ECDIS display of this ENC and the simulated radar display based on this ENC is shown in Fig. 9. There at the harbor entrance is a racon with Morse code signal to the left of the own ship. In ECDIS, safety contours are rendered as thick grey lines. On the simulated radar display, safety depth contour is set to 20 m, retrieved from ENC, and then drawn as red lines. Coastlines, natural or man-made, are chosen to be drawn on radar as yellow lines, too.

2. Verification with Real Radar Pictures

Fig. 10 compares the simulated image (upper right) with real radar screen displays, all with radar range set to 0.5 nautical miles and own ship located at the same location, heading to 030°. However, the radar antenna height is only roughly estimated. The two real radar pictures were taken onboard the research vessel of NTOU when the vessel was berthed inside Pi-Sha fishing harbor. The upper left picture was taken in 2008, while the lower picture was taken from newly installed radar in 2011. ECDIS display of the Pi-Sha fishing harbor is also shown in Fig. 11 for comparison.

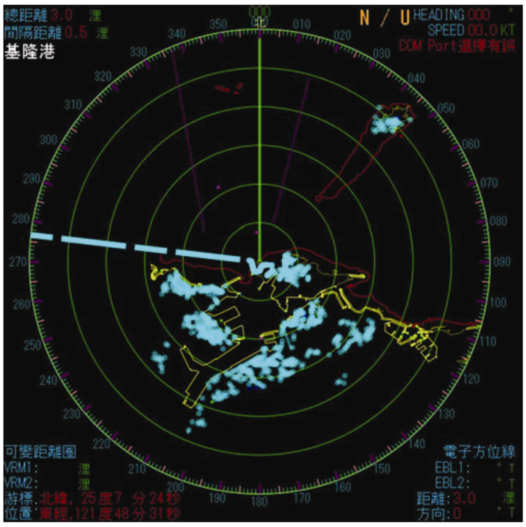


Fig. 9. Simulated radar display for own ship outside the harbor entrance.

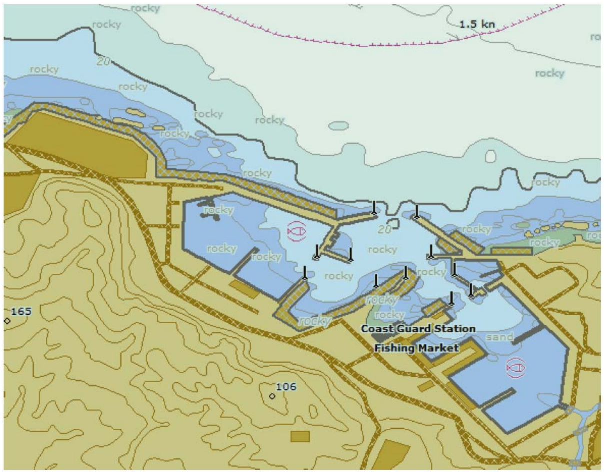


Fig. 11. ECDIS display of the Pi-Sha fishing harbor's ENC data used to generate the radar image shown in Fig. 10.

Fig. 10. Real (upper left and lower) and simulated (upper right) radar image of NTOU's research vessel berthed in the Pi-Sha fishing harbor.

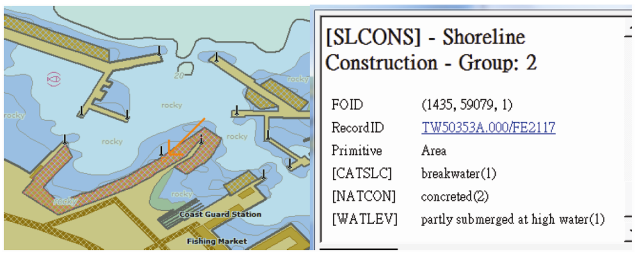


Fig. 12. One of the shoreline construction objects which cause the discrepancies is highlighted in red patterns, with its details shown in the pick report on the right.

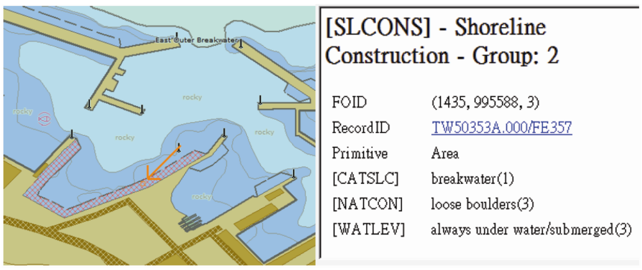


Fig. 13. Cause of the discrepancy examined by using updated ENC data.

The simulated radar image matches quite well with the real one. When we take a closer look at the discrepancies at about 0.2 nautical miles range in the 95°~205° sector, it is found that simulated radar image shows extra strong echo around the jetty and quay. These simulated echoes come from the SLCONS objects. According to their attributes, as queried and shown in Fig. 12, they are concreted breakwaters partly submerged at high water.

The ENC data used in Fig. 10 is dated 2006/10/19. New edition of that ENC dated 2009/12/01 depicts this area differently. As shown in Fig. 13, the shoreline constructions have been updated to be breakwaters in loose boulders always under water or submerged. When we use the updated ENC and take "water level (WATLEV)" attribute into account when setting the height of the shoreline constructions, such discrepancies disappears, resulting in a more perfect match. Automatic updating is actually an important advantage of our design. Since this radar simulator operates on ENC database, the ENC updating mechanism in place for ECDIS [6] can be utilized directly. No matter for individual feature updates or entirely new editions, all it requires is to place the received ENC update files, under the same directory as all other charts.

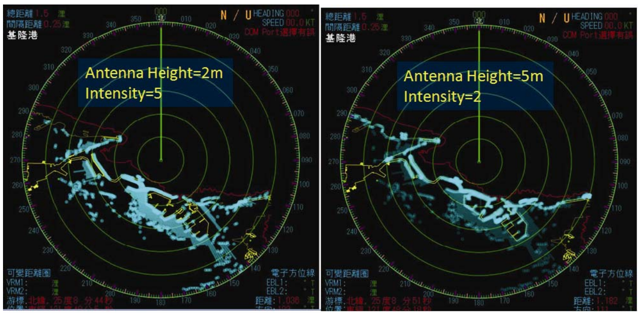


Fig. 14. Radar image simulated with different antenna height and intensity setting.

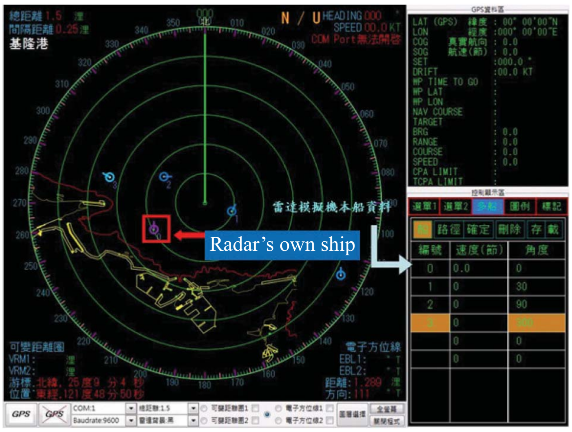


Fig. 15. A snapshot of MAST's screen. Five targets are created. Target#0 is chosen as the own ship for the radar simulator.

3. Effect of Parameter Settings

Fig. 14 demonstrates the effect of parameter setting on the simulated radar image. When the antenna height is raised from 2 m to 5 m, we get more echoes from inside the Pi-Sha fishing harbor, even with the intensity set to a lower value.

4. Scenario Creation and Integration with MAST

Target ships can be generated by using MAST and broadcast via user datagram protocol (UDP) over internet to every interconnected radar simulators. Fig. 15 illustrates the case where five targets are created in MAST, and the target labeled "0" is chosen as the own ship for the radar simulator shown in Fig. 16.

5. Real-Time Performance

The implemented radar simulation system can run smoothly on ordinary PCs, even laptop ones, as shown in Fig. 17. Complete refresh of the radar image takes less than 1 second, fully in pace with the position update.

IV. MULTI-AGENT SHIP TRAFFIC SIMULATION

Navigation and collision avoidance are the two major uses of shipborne radar. Radar navigation relies on identifying the echo from surrounding terrestrial objects for position fixing and safe passage. The challenge of using radar as an aid for collision avoidance lies in a different aspect from radar image. Mariners need to interpret the situation from relative position and movement of other vessels and, if necessary, take actions according to international maritime practices and norms. Newly revised performance standard of radar specifies that all SOLAS shipborne radar must provide the integration and display of AIS information. Radar target tracking function is also specified to be built in radar instead of treated separately in ARPA. Therefore, in regard of collision avoidance, it is more important for a radar simulator to provide realistic traffic situation and interactions of encountering ships.

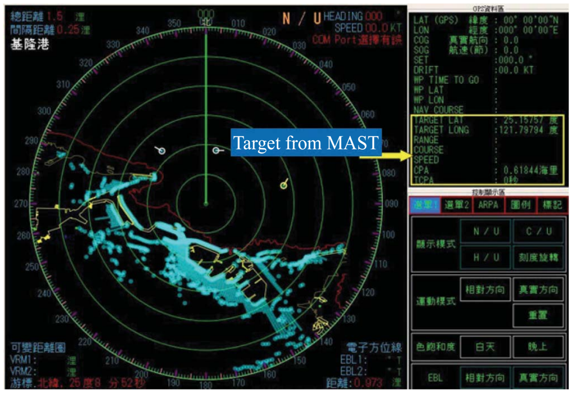


Fig. 16. A snapshot of the radar simulator fed with targets and own ship data from the connected MAST.

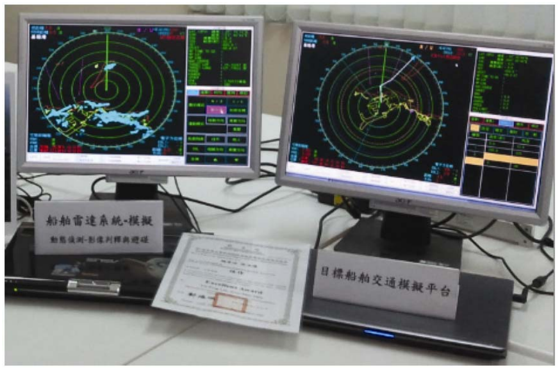


Fig. 17. Demonstration of a radar simulator (left) connected with a multi-agent ship traffic simulation platform (right), operated on laptop PCs.

Functionalities of the developed Multi-Agent Ship Traffic simulation platform, MAST, are already outlined in Section I. This section further illustrates the key points in the design of MAST.

In MAST, the traffic scene can be created by several different ways in combination. Each individual ship may be added as a target with assigned location, speed and heading. Navigation routes may be created with waypoints and leg speeds, then assigned a starting point and ship arrival rate for

MAST to automatically generate target ships navigating along selected route. The basic idea of this navigation route and the procedure we use in our practice is to extract realistic information, such as the most taken routes and the interval between vessel arrivals on each route, from analyzing vessel traffic data collected via AIS [1].

Each target is managed by a software agent which follows the assigned route or settings. When making turns to follow the route, minimum turning radius is considered to calculate the wheel-over point.

MAST can be connected with multiple radar simulators. Own ship for each connected radar simulator may be selected from the targets generated by MAST or operated by a user/trainee via a ship handling interface. MAST takes care of the CPA/TCPA calculations and target information exchange of all the connected radar simulators via broadcast over Ethernet. Therefore, each trainee can have the full picture of the traffic on the screen of the radar simulator he operates. With MAST, the whole radar simulation system becomes an effective tool for highly interactive training, and a versatile platform for research and development, too.

V. RELATED WORK

Using ENC feature objects and attributes in real-time to generate radar image for a radar simulator is not found in the literature.

Ren *et al*. [9] proposed to simulate radar image based on 3d scene database created for the visual of the ship bridge simulation system. In their work, circularly scanning ray is adopted to simulate the radar beam, object echo position is calculated by using ray-triangle intersection algorithm, and attributes of object reflecting surface are considered in the calculation of echo intensity. However, the only simulated result given in that paper is of some islands and it looks more like a 3d display. The real-time capability they achieved is to complete one circle of radar scan in 3 seconds for less than 50,000 triangles in 3D scene database.

Wakabayashi *et al.* [11] used AIS for ship data in their development of radar simulator software. Two functions are achieved by using AIS data for the simulation of surrounding ships, including the radar target echo for radar image and the overlay of AIS target information. It is thus possible to train individuals in ship maneuvering using actual ship traffic of a specific ocean area. However, since the movement of target ships is presented only as a reproduction of recorded AIS data, target ships never know the existence of the trainees' own ships, thus no attempt will ever be made to avoid collision.

VI. CONCLUSIONS AND FUTURE WORK

In this work, a chart-based radar simulator augmented with a vessel traffic simulation platform was designed and implemented. The most important concept and strength of this design is to make the most use of the ENC database already available worldwide in almost every major shipping routes and harbors. Intelligence in the target ships generated by the multi-agent ship traffic simulation platform is another key feature in this design.

In view of training, this simulator helps mariners build the ability to recognize surrounding navigation environment, interpret radar echoes, and identify critical echoes. It also provides an interactive environment with dynamic situations for mariners to learn about how to take actions to avoid collision in terms of international maritime practices and norms.

This system can be further improved and extended in many ways for both training and research. For example, the effect of noise and clutter from sea surface or rain and even false echo should be incorporated. Such effects may be implemented as filters. The radar image module may make further use of ENC information. In addition, computer graphics and rendering should utilize more of the hardware supported libraries.

REFERENCES

1. Chang, S. J., Hsu, G. Y., Yang, J. A., Chen, K. N., Chiu, Y. F., and Chang, F. T., "Vessel traffic analysis for maritime Intelligent Transportation System," *Proceedings of the IEEE 71st Vehicular Technology Conference, VTC 2010 Spring*, Taipei, Taiwan, pp. 1-4 (2010).
2. Hsu, C. M. and Chang, S. J., *Multi-Agent Ship Traffic Simulation Platform with Autonomous Navigation Route and Collision Avoidance Manoeuvre Mechanism*, Master Thesis, Department of Communications, Navigation and Control Engineering, National Taiwan Ocean University, Keelung, Taiwan (2009). (in Chinese)
3. International Electrotechnical Commission, *IEC62388: Maritime Navigation and Radio-Communication Equipment and Systems- Shipborne Radar -Performance Requirements, Methods of Testing and Required Test Results, Ed. 1.0* (2007).
4. International Electrotechnical Commission, *IEC61162-1: Maritime Navigation and Radio-Communication Equipment and Systems - Digital Interfaces - Part 1: Single Talker and Multiple Listeners, Ed. 4.0* (2010).
5. International Hydrographic Organization, *S-57: IHO Transfer Standard for Digital Hydrographic Data, Appendix B.1 ENC Product Specification, Ed. 2.0* (2000).
6. International Hydrographic Organization, *Guidance on Updating the Electronic Navigational Chart, 3rd Ed., Appendix 1 to the 5th Ed. of S-52* (1996).
7. International Maritime Organization, 1978 *STCW Convention*: *International Convention on Standards of Training, Certification, and Watchkeeping for Seafarers, 2011 Edition* (2011).
8. International Maritime Organization, *Resolution MSC.192(79): Adoption of the Revised Performance Standards for Radar Equipment* (2004).
9. Ren, H., Wang, K., and Jin, Y., "Radar image simulation based on 3d scene database in marine simulator," *Proceeding of International Conference on Computational Intelligence and Software Engineering, CiSE 2009*, Wuhan, pp. 1-3 (2009).
10. Vincenty, T., "Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations," *Survey Review*, Vol. XXII, No. 176, pp. 88-93 (1975).
11. Wakabayashi, N., Makino, H., Mori, K., and Shiotani, S., "Development of radar simulator software using AIS data for ship data," *Proceedings of 2010 IEEE OCEANS Conference*, Sydney, pp. 1-5 (2010).