An intelligent and Auto-Response System toward Fixed point Marine Wind/Wave forecast

Jian Jun, **Sun** Zheng, **Xu** Ke, **Wang** Heng
Dalian Maritime University, Dalian, Liaoning, 116026 China

keywords：Intelligent response system; Numerical model; Web crawler; Open CV image processing

Abstract

In order to improve the accuracy and timeliness of marine weather forecasts and the intelligence of marine weather forecast information response, and to fill the gap of real-time hydrographic information sharing between ships at sea and land, this paper investigates an intelligent response system for winds and waves over the sea. This study investigates multiple sources of comprehensive weather forecast information and provides ships at sea after processing on demand with them.

The system can identify the request mail sent from the sea intelligently, extract the sea area, latitude and longitude coordinates in the mail subject automatically, analyze the latest numerical model meteorological data automatically by interpolation, and calculate the wind speed and wind direction change at a specific point in the next few days. At the same time, the system will automatically grab the latest weather forecast model maps issued by national specialized meteorological agencies, use Python OpenCV image processing to identify wind scales and wave heights at specific points.

1 Introduction

At present, large vessels shipping in the far open ocean generally sail according to the pre-set routes or apply for commercial weather navigation services, which combine the weather situation, forecast and navigation service[9] for a single ship. When encountering sudden strong winds, they cannot respond in time, so that the risk factor is relatively large [16]. However, due to various conditions, meteorological navigation service[7]should not only consider navigation safety, try to avoid bad weather in actual operation[10], but also take into account the shipping companies and charterers. Due to the requirements of schedule arrangement, voyage time and fuel consumption, the calculated recommended route [14] may not be the most satisfactory for the captain; at the same time, commercial weather navigation services are expensive, and the market has long been monopolized by countries such as Japan and the United States.

Meteorological navigation [19] can be divided into three modes: purely shore-based meteorological navigation (also called shore navigation), purely ship-self-meteorological navigation (also called ship-self navigation) and ship-shore integrated navigation. At present, the shore-navigation is very mature [1] and the ship-self navigation is also improving gradually. No doubt the combination of ship-self and shore-navigation is inevitable in the future which has many advantages [11]. For example, it can help the captain to fully understand shore alignment intentions and cooperate with shore pilot company to complete navigation tasks to the maximum extent. The ship-shore integrated meteorological navigation [13]can reduce the complicated communication and telegraph service so as to save the navigation cost.

Jun Jian[5] designed an automatic marine surface wind prediction system. Based on meso-scale numerical products of the European Centre for Medium-Range Weather Forecasts (ECMWF), and finally sends it to the ship via the INMARST ground server at Beijing. It was tested that 13 minutes (or 30 minutes) by using INMARST F station (or C station) time was needed to get the return email on board. However, the continuous use of this system in China has too many uncontrollable factors. The total number of utilized servers from mainland China the US servers are unstable, slow. Thus the total process time is long; and if any one of the servers fails, the whole forecasting system will not be able to deliver timely and accurate forecasts.

Based on the latest weather forecast calculation by numerical models, The intelligent auto-response system designed here aims to avoid the above problems to the greatest extent, puts all computational models into one server, while crawling the latest weather forecast information and forecast maps released by several official meteorological stations in the northwest Pacific Ocean based on the use of numerical models to calculate the latest weather forecasts, with identifying weather forecast pixels by using OpenCV. Get the wind scale and wave height changes[2] of specific points in the sea surface request mail, and return the two results to the sea surface at the same time, so as to provide more comprehensive information for the sea surface drivers and make a more reasonable navigation plan. The whole process accomplished without manual operation will be carried out within three minutes. The latest wind speed, direction and wave height changes in the next few days will be automatically returned to the ship at sea. The system can greatly optimize the marine regional forecast and reduce the numerical weather prediction results, which contribute to the effective prevention of large storm and wave weather disasters and the safe navigation of ships.

2 Meteorological data sources and acquisition

2.1 Global Forecast System and the Navigators' Association

The National Oceanic and Atmospheric Administration (NOAA) is a scientific agency of the U.S. Department of Commerce that focuses on ocean and atmospheric environment research[3]. Its Global Forecast System (GFS) can extract open data according to individual needs. Standby data sources include CMC GEM(Canadian Global Environmental Model), the US Navy NAVGEM, the French ARPEGE and the German (DWD)ICON. Judging from the authority of these institutions alone, the accuracy of the data is guaranteed.

SailMail, the navigators' association, has developed a free Grib service for navigators. The MailASail Weather Service is a free service provided by communications operator MailASail, which is available via email, file transfer protocol and browser.

2.2 Professional meteorological agencies

Besides raw numerical weather model data, the system chooses four major public-free official institutions and one private sector which are making prediction in the Northwest Pacific. The characteristics of their prediction model are shown in Table 1. In order to make sure the server is able to automatically access the hydrological and meteorological information of the website in Table 1, our system uses the web crawler [20] to view the source code on the web page, converts the obtained source code into BeautifulSoup object, saves the content under the obtained path, and specifies the execution time according to the meteorological forecast update time of the network.

Table 1. Forecast model table of main official institutions in Northwest Pacific

Website	www.nmc.cn	www.nmefc.cn	www.imocwx.com	www.tmd.go.th	www.cfanclimate.net
Data source	China National Meteorological Center	China National Marine Environmental Forecasting Center	Japan Meteorological Agency	Thailand Meteorological Agency	US Corporation CFAN
Forecast content	Wind	Wind	Wave height	Wave height	Wind
Forecast range	88°E~142°E，0°N~45°N	90°E~180°E，0°N~65°N	120°E~140°E，22°N~38°N	95°E~105°E，5°N~15°N	100°E~160°E，0°N~50°N
Turnover time	0200UTC 1000UTC	1200UTC	0000UTC	0000UTC	0200UTC 1000UTC
Initial lead	72h	72h	72h	96h	240h
Time step	24h	6h	3h	3h	6h
Wind scale/wave height range	Grade 6~13	Grade 5~15	0~450cm	0~250cm	0~75kts
Map Projection mode	Mercator	Lambert	Mercator	Mercator	Mercator
Image resolution ratio	795*793	790*660	640*640	494*640	1036*822
Pixel point	33~66km^2	114~494km^2	6~11km^2	4~5km^2	46~75km^2

3 Interactive mail automation

In the era of big data, with the rapid development of network technology and information technology, artificial intelligence-related technologies have been applied to all walks of life. As one of the communication and office methods, email automation is indispensable. Due to limited communication conditions on ships and marine platforms[12], network terminals cannot be used as easily as on land[17].Therefore, from the perspective of convenience, bandwidth, and cost-saving, the design uses cloud services and E-mail interaction methods to access, receive, process and send various data information.

The Python standard library provides the SMTP and Zmail module for implementing the SMTP protocol to send mail. Meanwhile, it provides the email module to help construct the mail format. However, because the SMTP module has complex problems such as server denial and the need to find the server address, port number and parse mail, the test adopts the Zmail module with simple code, which can automatically fill in the header information leading to server denial and automatically find the server address and port number.

In the mail returned from the Navigators Association SaiMail, the latest weather data required is loaded in the attachment. We set the receiving rules in the mailbox so that the mail from weather@mailasail.com is stored in the specific folder "XXX", which not only reduces the time to traverse all mailboxes, but also detects the latest e-mails from the navigators' association quickly. In order to carry out bidirectional communication between Webmail and email clients, the system uses IMAP protocol to download attachments.

4. Data processing

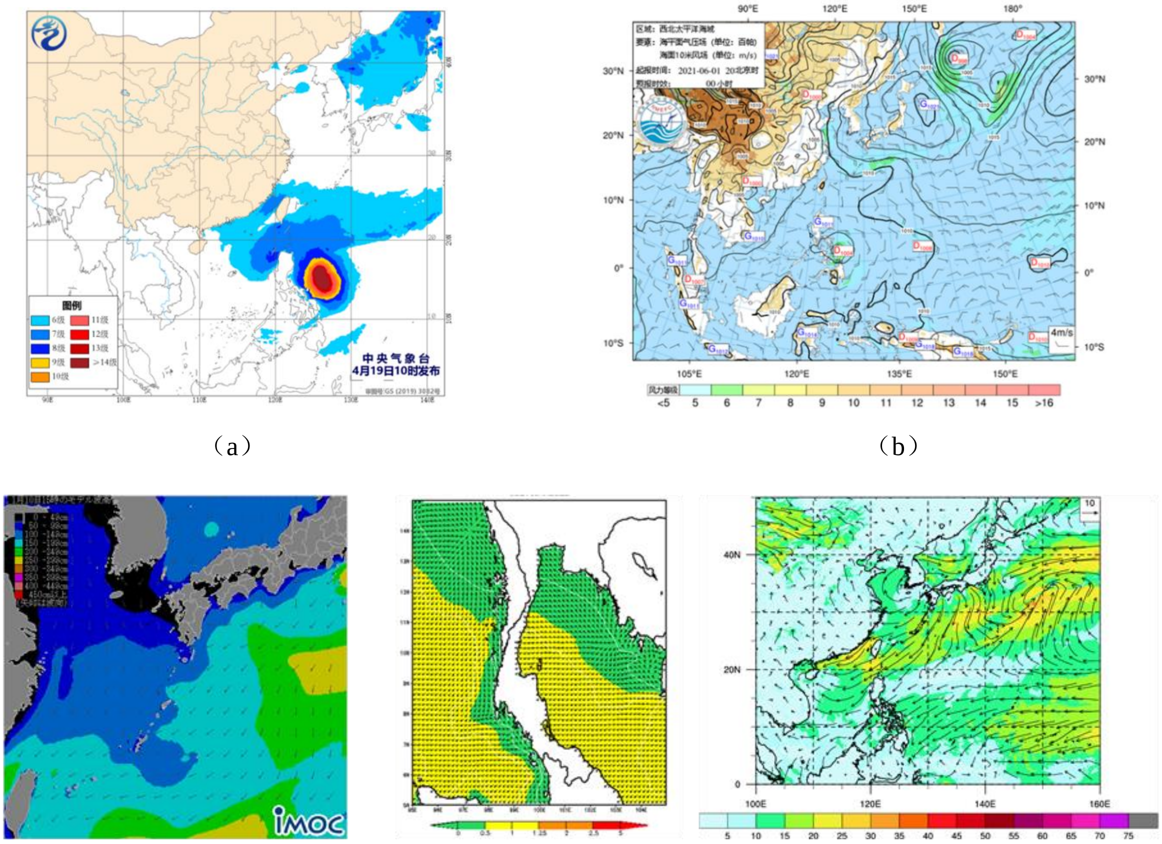
4.1 GFS numerical prediction

GFS, in short for Global Forecast System, is built by the National Oceanic and Atmospheric Administration, USA, with a resolution of one degree, time span 0-180h, and time step 3h. The Navigators' Association SailMail has developed a free service for navigators, available via email, file transfer protocol and browser.

4.2 Classification and storage of weather forecast

For the weather forecast map, based on the different image attributes, a simple classification is carried out first. Attributes of pictures include content, shape, file type, color, brightness, resolution, etc. Take pictures from China National Meteorological Center as an example, eliminate unnecessary pictures with content > 100000 first, then classify the remaining three types of pictures according to different shapes. Shape = 7937953 is the wind forecast map, shape = 6988603 is the sea fog forecast map, and shape = 7168603 is the strong convection forecast map. And finally sort the pictures according to time and store them in the designated folder.

GBK-means algorithm[6] is used to classify the weather forecast map which is difficult to be classified by image attributes. Firstly, standardize and cut all the pictures, and eliminate some abnormal pictures. Secondly, randomly select K centers and assign each picture to the nearest center. The cluster centres compete with each other to change their positions so that their distance from the maximum possible data is less than that of other cluster centers, and then recalculate the centers of each category. Repeat the previous step until the change in each type of center triggers a set threshold to complete the picture classification.



（a） （b）

（c） （d） （e）

Figure 1. wind and wave forecast map from from(a,b) China, (c) Japan, (d) Thailand, and (e) USA forecasting institutes

4.3 Interpolation method to calculate the wind speed

For navigation purpose, the fixed-point wind speed forecast has to be accurate to point, which is usually not at the grid point. So we use the interpolation method combining with the nearest coordinate point of this point to obtain the corresponding wind speed. We compared the cubic spline interpolation method and the bilinear interpolation method[15], selected some GRIB data are, and obtained the original data and interpolated data through two-dimensional and three-dimensional visualization respectively. In the case of less data, the bilinear interpolation results are rough, while after cubic spline interpolation, the results appear much smoother. Therefore, cubic spline interpolation is selected to process GRIB data.

Spline$S(x)$is a formula defined by segments. There are $n+1$ points and n intervals. The cubic spline equation satisfies the following three conditions:

(1)In each segmentation interval$[x_i, x_{i+1}]$$(i=0,1,\dots,n-1, x$increasing), $S(x)=S_i(x)$is a cubic polynomial.

(2) Satisfy $S(x_i)=y_i(i=0,1,\dots,n)$.

(3) $S(x)$, $S'(x)$ and$S''(x)$ are continuous in the interval $[a,b]$.So, the $S(x)$curve is smooth.

Therefore, n cubic polynomial segments can be written as:

$S_i(x) = a_i + b_i(x - x_i) + c_i(x - x_i)^2 + d_i(x - x_i)^3 (i = 0,1, \ldots, n - 1).$

(a_i, b_i, c_i, d_i are unknown coefficients).

4.4 Coordinate transformation of forecast map

Because the earth is an irregular pear-shaped sphere with slightly wider equator and slightly flat poles, its surface is a curved surface that cannot be flattened. And it is necessary to use certain mathematical rules to convert the longitude and latitude lines to the plane. Taking Mercator projection and Lambert projection as examples, this paper expounds the coordinate transformation of forecast map.

As for the wind forecast map of Mercator projection[18], as shown in Figure 1(a), due to the increasing latitude, to make the coordinate points correspond to the pixel points one by one, it is required to convert the longitude and latitude coordinates (x, y).

$$\begin{cases} \varphi = y \\ X = kx + a \\ MP = \int_0^{\varphi} dMP = \int_0^{\varphi} \frac{3437.746771(1 - e^2)}{1 - e^2 sin^2\varphi} * \frac{d\varphi}{cos\varphi} = 7915.70447lg\ [tan\left(\frac{\pi}{4} + \frac{\varphi}{2}\right) * \left(\frac{1 - esin\varphi}{1 + esin\varphi}\right)^{\frac{e}{2}}] \\ Y = b - p * MP \end{cases}$$

(a,b are constants. X is the horizontal value of the pixel matrix arrangement.Y is the vertical value of the pixel matrix arrangement.k is the number of pixels with a length of 1 ° at any longitude in the figure. MP is the latitudinal lengthening rate.p is the number of pixels with a length of 1'at the equator in the figure.)

For the wind forecast map of Lambert projection[8], as shown in Figure 1(b), the pixel matrix arrangement corresponding to the longitude and latitude coordinates (x, y) is obtained by using the variable rate interpolation method. The picture is divided into several coordinate systems according to the grid lines in the figure, and the coordinate change in each grid is approximately equal to the proportional change. Set the four angular coordinates of the grid where the longitude and latitude coordinates are located as $(a_1,b_1),(a_2,b_1),(a_1,b_2),(a_2,b_2)$, and the corresponding pixel matrix is $(a_{11},b_{11}),(a_{21},b_{12}),(a_{12},b_{21}),(a_{22},b_{22})$, as shown in Figure 2(a).

$$\begin{cases} X = a_{12} + \frac{\partial z}{\partial x}(x - a_1) + \frac{\partial z}{\partial y}(y - b_2) \\ Y = b_{11} + \frac{b_{22} - b_{21}}{5}(x - a_1) + \frac{b_{22} - b_{12}}{5}(y - b_2) \end{cases}$$

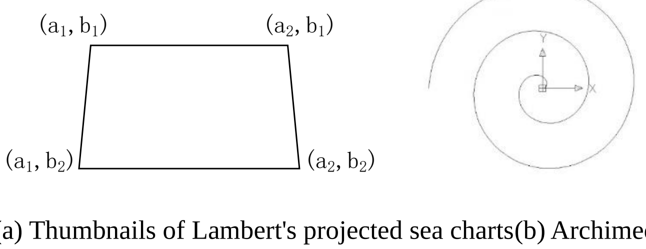


Figure2.(a) Thumbnails of Lambert's projected sea charts(b) Archimedes spiral

In addition, special point processing is required, as shown in Figure 2(b).If the selected pixel point is on the grid line of the weather forecast map or the land, island and its edge line, the pixel value corresponding to this point maybe not the pixel value corresponding to the wind power of this point.Sothern Archimedes spiral is used to spread from this point to all sides until the nearest pixel point which is not on the grid line of the weather forecast map or the land, island and its edge line is selected.

$$\begin{cases} x = (\alpha + \beta\theta)cos\ (\theta) \\ y = (\alpha + \beta\theta)sin\ (\theta) \\ \theta = \theta + \frac{\pi}{4} \end{cases}$$

(Order α = 0, β = 1 . The initial value of θ is 0 and π/4 is added each time.)

4.5 Pixel processing of forecast image

Combined with the pixel values of the legend of the forecast map, the pixel values of the pixel points of the coordinate point in the weather forecast picture are identified and compared by OpenCV[4] in python, and the forecast results are obtained. The main functions of OpenCV are image processing and computer vision,to provide open source and optimized basic code for advanced visual research and to spread visual related knowledge by providing a common interface where developers can do the development on this basis.

4.6 System flow chart

All the work of this system is completed on the server in Dalian Maritime University. The server obtains the latest meteorological data at a routine basis, detects the mailbox every 5 minutes, extracts the meteorological forecast content required by the request email, calculates the meteorological changes, and returns to the ship sending the request email through the maritime satellite communication (Figure 3).

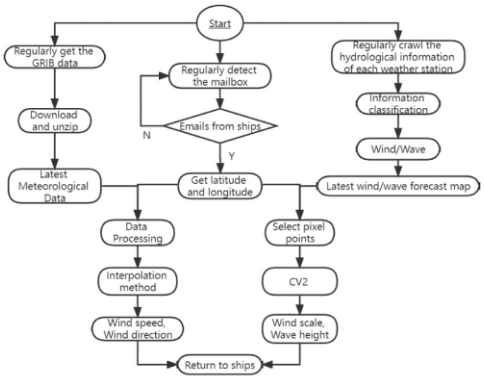


Figure 3. Work flow chart of the system

5 Field test on Ship

After setting up the intelligent and auto-response System on the server of Dalian Maritime University, we conducted multiple ship-based field tests. The 6300-ton Dalian Maritime University teaching practice ship ‘Yukun’ and another 10,000-ton bulk carrier "B" were applied to test the systematic request-response interaction via INMARST C, F, and FBB stations respectively.

5.1 Obtain GFS wind forecast via INMARST stations

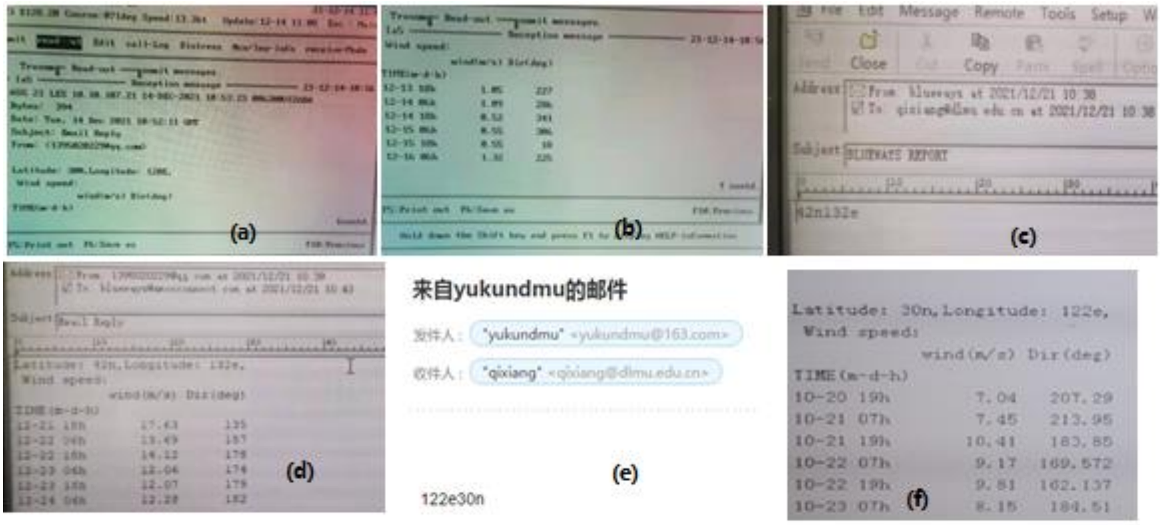


Figure 4. Field test by INMARST stations

Figure 4 (a)(b) show the wind speed forecast to ship “B” using INMARST C to send the coordinate request "120E30N ", (c)(d) show the interaction from the same ship using INMARST F for coordinate request "130E29N ", and (e)(f) show the interaction from ‘Yukun’, using INMARST FBB on coordinate "122E30N".

The intelligent forecasting system was tested on each station of two ships respectively, and the test results are shown in Table 2. In the future, the intelligent forecasting system needs to be tested on various ships and stations to solve the problems in time, and to take into account the suggestions made by the captain or other requirements combined with the actual situation to adjust and improve the intelligent forecasting system so that it can operate successfully under various environmental conditions and send timely and accurate numerical forecasting results.

Table 2. Timetable for email interaction at ship station

Ship	Communication Channel	Request time from ship	Message receive time to ship	Time taking
Bulk ship B	Inmarsat-C	2021-12-14 18:49	2021-12-14 18:56	7min
Bulk ship B	Inmarsat-F	2021-12-21 10:21	2021-12-21 10:27	6min
Yukun	Inmarsat-FBB	2021-12-21 9:57	2021-12-21 9:59	2min

5.2 Forecast results from multiple institutions

The system can also return the meteorological and sea state forecast results of multiple countries’ institutions for coordinates according to the methods described in sections 4.2-4.5 for ship officers to compare. The specific operation method is similar to Section 5.1. The system will detect the mailbox every 5 minutes. If the location exceeds the range or the format is error, then a format error prompt will be returned. Otherwise the system will calculate the weather map forecast results according to the requirements of the ship and return them to the ship. The application email is shown in Table 3.

Table 3. Application email example

TO: qixiang@dlmu.edu.cn	**TO:** qixiang@dlmu.edu.cn
SUBJECT: FORECAST	SUBJECT: FORECAST
TEXT: April 30th 7UTC 122E 24N	TEXT: April 30th 7UTC 103E 10N
Reply:	**Reply:**
SUBJECT: FORECAST	SUBJECT: FORECAST
TEXT: (CHINA) April 30th 7UTC less than 6BF, 5-10.8m/s	TEXT: (CHINA) April 30th 7UTC less than 6BF, 5-10.8m/s
(JAPAN) April 30th 7UTC Wave High 200-249cm	(THAILAND) April 30th 7UTC Wave High 0-125cm
(US) April 30th 7UTCless than 6BF, 5-10.8m/s	(US) April 30th 7UTCless than 6BF, 5-10.8m/s

6 Conclusions

The intelligent and auto-response system toward fixed point marine wind and wave forecast can provide the wind and wave forecast of authoritative institutions with accurate location in real time according to the longitude, latitude and sea area requested by the ship at sea and realize the automatic acquisition, request and feedback of meteorological information. The system have low price and rapid response, and can be easily extended to more target sea areas and institutional prediction results, so it has broad application prospects. But it has some limitations because it only selects the coastal areas of China and the Northwest Pacific Ocean for wind and wave prediction. In addition, there are some deficiencies, such as stiff language and inability to realize route planning. In the future, a perfect meteorological corpus will be created to provide more humanized meteorological service information and contribute to the construction of marine meteorological forecasting system.

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About the Author:

Jun Jian got his BS in 1998 and MS in 2001 from Department of Earth and Space Sciences, University of Science and Technology of China. In 2007 he got Doctoral degree from School of Earth and Atmospheric Sciences, Georgia Institute of Technology in USA. In 2010 he returned to China and served Navigation College, Dalian Maritime University since then. Currently Dr. Jian is working on Marine Meteorology and medium-range tropical convective system forecast.