MULTI-OBJECTIVE OPTIMIZATION EVOLUTIONARY ALGORITHM FOR RETRIEVING INDIAN OCEAN CIRCULATION IMPACT ON MH370 DEBRIS

Maged Marghany and Shattri Mansor
Geospatial Information Science Research
Centre, Faculty of Engineering
University Putra Malaysia
43400 UPM, Serdang, Selangor
Email :magedupm@hotmail.com

KEYWORDS : Multi-objective algorithm. Pareto optimization, Indian Ocean circulation, MH370 flight, debris.

Abstract. Although the advanced remote sensing sensors and communication technologies, the MH370 debris cannot be found since March 8, 2014. This study aims to retrieve the impact of Indian ocean circulation on debris movements across the Indian Ocean. The multi-objective algorithm based Pareto optimization has used to retrieve ocean circulation from Jason altimetry data. Evolutionary stochastic optimization algorithm to reveal the Pareto front. The study shows that the ocean surface current of Indian Ocean is varied from season to season with maximum speed of 0.7 m/s. The study shows that the Indian ocean current is dominated by series of eddies specially along Reunion Island and Madagascar with maximum speed of 0.6 m/s. The multi-objective evolutionary algorithm is able to predict the path of MH370 debris across the Indian Ocean. It is investigated that MH370 debris cannot be float on the water longer than two months. In conclusion, multi-objective algorithm based Pareto optimization can be used an accurate tool for retrieving Indian Ocean circulation impact on MH370 debris.

1. INTRODUCTION

Despite the superior space, marine, and communication technologies, the mystery of the Malaysia Airline flight MH370 cannot be explicated. In spite of twelve countries that joined in for the search and rescue efforts of missing the flight MH370 on March 8th, 2014, it is extremely complicated to investigate the dramatic scenario of the flight MH370 that vanished from secondary radar (Figure 1). 5 nmi / 8–10 km wide, MH370 routes are depicted but differed in width as 20 nmi / 35–40 km (Figure 1) (Asia News 2014 and Excell , 2014; Zweck, 2014a; Staff Writer 2014).

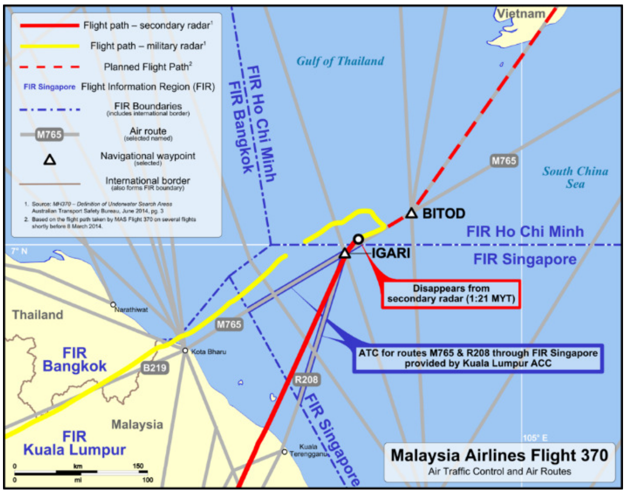

Figure 1. Location where the MH370 disappeared from radar screen.

Consequently, the Malaysian military radar showed that MH370 travelled over the Straits of Malacca while the white circle indicates disappearing of flight from the radar screen (Figure 2). In this context, China deployed 10 high-resolution satellites to scurry the South China Sea, Digital Globe opened its crowdsourcing platform

Tomnod and Airbus Defense and Space mobilized its five satellites to find some leads (Marghany 2014; Grady 2014; Linlin, 2014; Zweck, 2014b)

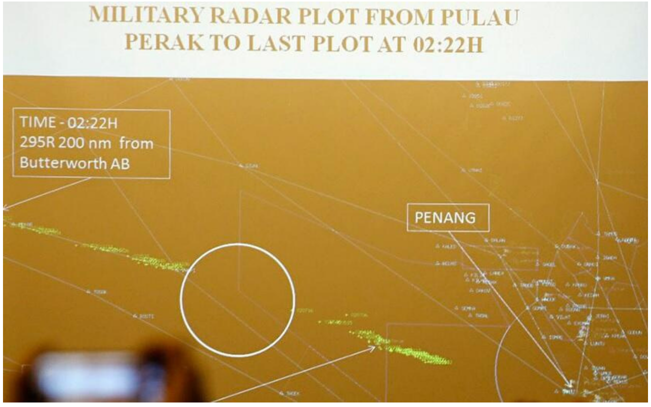

Figure 2. Tracking MH370 over the Straits of Malacca by military radar.

Under this circumstance, physical oceanography theories and models must extremely be instigated to investigate the mystery of the flight MH370. The observation procedures that are taught for the undergraduates of Physical Oceanography students does not work in this case. Indeed, standard and modified models are required to verify the information of Inmarsat satellite. In fact, there are many of researchers who just used the physical oceanography models and do not really understand how the models are operated.The scientists implemented the drifter models to track the trajectory model of MH370 debris (Figure 2). According to Martini (2015), massive scribble of red debris trajectories were found on the coastal waters of Réunion island which is located east of Madagascar. She commented that a prediction model and the timing is a little off since it is only been 18 months since the crash. She added this mismatch most likely raised since the model was prospective loped with historical surface current data and unrealistic numerical debris. Martini (2015), nonetheless, raised up the following question why has not any debris been found on Australian and Tasmanian beaches as predicted by numerical debris model (Figure 3)? Indeed, that model is not accurate enough to track the debris of crashed flight MH370 that scattered in the search area. In addition, there are many other dynamic ocean parameters extremely affected by the debris movements on the surface and through the water column.

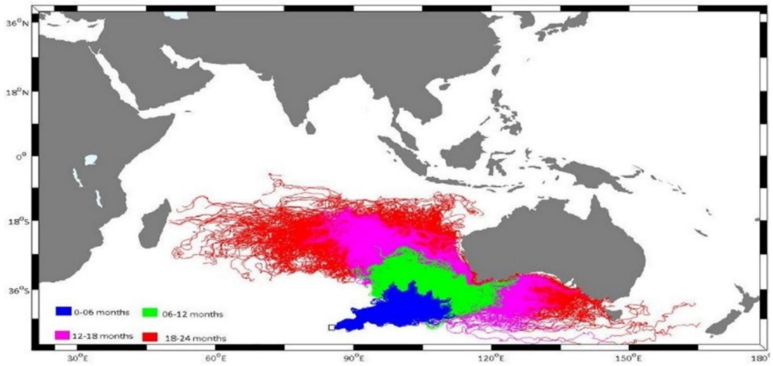

Figure 3. Predicted debris trajectory model by Australian scientists.

Regardless of the advanced remote sensing sensors and communication technologies, the flight MH370 debris cannot be found since March 8, 2014. There were several satellite images that have been claimed to be objects belonging to the flight MH370. One of these satellite data is a Thai satellite which has detected 300 floating objects in the Indian Ocean, about 200 kilometres from the international search area for the missing Malaysia Airlines MH 370 at 10am Perth local time on the 24th of March. In this context, the THEOS satellite payload features both high resolution in panchromatic mode and wide field of view in multispectral mode and has been tailored to Thailand's specific needs with a worldwide imaging capability. In addition, it contains 2m resolution for black and white images and 15m resolution for panchromatic image. However, the images claimed to belong to flight MH370 are dominated by cloud covers (Marghany, 2015).

The main question can be raised up what appropriate sensors can be used to monitor and detect flight MH370 debris? The high-resolution sensors either on board of satellite or airborne can detect and identify the flight MH370 debris. Even HF ground radar can detect any foreign objects moving in the coastal zone. This also is required the standard methods of object automatic detection by using high resolution microwave satellite data with 1 m as in the spot mode of both RADARSAT-2 SAR, TerraSAR-X satellite data. The RADARSAT-2 SAR satellite has a synthetic aperture Radar (SAR) with multiple polarization modes, including a fully polarimetric mode in which HH, HV, VV and VH polarized data are acquired. Its highest resolution is 1 m in Spotlight mode (3 m in Ultra-Fine mode) with 100 m positional accuracy requirement. In addition, RADARDSAT-2 SAR Scan Narrow SCNB beam is its and a high revisit period of 7 days. Further, has nominal near and far resolutions of 7 m. If the length of the flight is 24 m, means it could clearly be detected in RADARDSAT-2 SAR Scan Narrow. This suggests that, as high cloud covers are dominated in the southern Indian Ocean, it is suggested to use airborne SAR sensors like uninhabited aerial vehicle Synthetic aperture radar (UAVSAR, by JPL, L-band) with a 22-km-wide ground swath at 22° to 65° (Marghany 2014 and Marghany et al., 2016).

The main objective is to develop a multi-objective optimization via Pareto dominance to reduce the uncertainties for the debris automatic detection in satellite data such as China satellite. In addition, multi-objective optimization based on Genetic algorithm is developed to forecast the debris trajectory movements from Perth, west of Australia i.e. the crashed claimed area.

2. SEARCH AREA

The bathymetry of the search area is simulated from a survey which was conducted from May to December 2014, collecting data over 200,000 square kilometres through the Joint Agency Coordination Centre (JACC) of geoscience Australia. The seabed is dominated around Broken Ridge, an extensive linear, mountainous sea floor structure that once formed the margin between two geological plates. These plates evolved and spread apart between 20 and 100 million years ago, under similar processes found today at spreading plate margins (such as the Mid-Atlantic Ridge) (Geoscience Australia, 2015). Figure 4 shows a discovered new seabed features which are: (i) seamounts (remnant submarine volcanoes), up to 1400 metres high and often forming a semi-linear chain; (ii) ridges (semi-parallel) up to 300 meters high, and (iii) depressions up to 1400 metres deep (compared to the surrounding seafloor depths) and often perpendicular to the smaller semi-parallel ridges (Smith and Marks 2014).

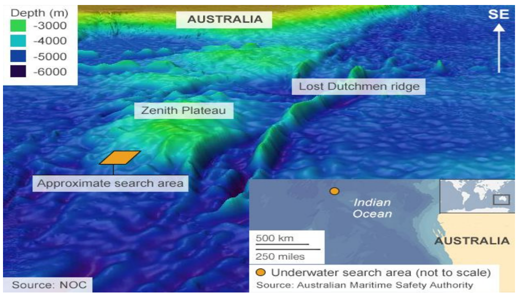

Figure 4. Bathymetry of MH370 search area.

The main question is how the searching operation failed to detect any wreckage with the topography under water? Side scan sonar delivers a two dimensional map of an area on either side of the sonar which cannot detect far enough due to the complicated water topography with outcrops, seamounts and various other changes in relief in many places throughout the deep Indian Ocean. This is concluded that it is very difficult to detect wreckage with complicated topography of the Indian Ocean.

3. MULTI-OBJECTIVE EVOLUTIONARY ALGORITHM

We assume that large parameter space $\mathbb{R}$ could be searched by the genetic algorithm (GA) to determine efficient solutions. With regard to this, the predictive algorithm involves the nonlinear approximation function which is based on historical time series information of sea surface current, sea level variation, wave height variation and the Indian Ocean floor features to forecast the current location of MH370 debris to any feature state (Anderson et al., 2003; Anderson 2013; Anderson 2014). Let $\{x_i\}$ be the observation made with generic function φ which can state as follows:

$$\bigcap_{m=1}^{\infty}\bigcup_{n=1}^{\infty}\left(x_n-\frac{1}{2^{n+m}},\,x_n+\frac{1}{2^{n+m}}\right) \quad (1)$$

The sequence observations that itemize the rational numbers is represented by $\{x_n\}_{n=1}^{\infty}$.This means that generic function φ is satisfying

$$\{x_n\}_{n=1}^{\infty}=\sum_{n=1}^{\infty}\varphi(x_i) \quad (2)$$

In the genome, for each member of the population, the population is initialized by random assignment of a 0 or 1 to each of the 32 bits. Subsequently, the first 20 and 12 bits are transcribed into an integer representing the *i,j* coordinates, respectively to evaluate the fitness. The locations of trajectory movement of debris thenceforth are simulated (Anderson et al., 2013; 2013Serafino,2015; Marghany et al., 2016). Let X be a compact set of feasible decisions in the Euclidean space with $\mathbb{R}^n$ *closed* unit interval [0, 1], and Y is the feasible set of criterion vectors in $\mathbb{R}^m$. Then Pareto front can be expressed as

$$P(Y)=\{y_1\in Y:\{y_2\in Y: y_2\succ y_1, y_2\neq y_1\}=0\} \quad (3)$$

Let a hydrodynamic system of the southern Indian Ocean with *m* hydrodynamic parameters and *n* flight MH370 debris, and a utility function of each hydrodynamic parameters as

$$\psi=f(\vec{v}_i) \quad (4)$$

where v_i is vector of the flight MH370 debris and $\vec{v}_i=(\vec{v}_1,\vec{v}_2,......,\vec{v}_n)$. Then the feasibility constraint equals $\sum_{j=1}^{m}\vec{v}_j=b_j$ for j=(1,2,3,…….,n). Finally, the Euler–Lagrange equations are maximized to find the Pareto optimal allocation for the flight MH370 debris trajectory movements across the southern Indian Ocean.

$$L_i((x_j^k)_{k.j},(\lambda_k)_k,(\mu_j)_j)=f(\vec{v})+\sum_{k=2}^{m}\lambda_k(\psi_k-f^k(v^k))+\sum_{j=1}^{n}\mu_j(b_j-\sum_{k=1}^{m}\vec{v}_j) \quad (4)$$

Whereby, L is Lagrangian with respect to each debris v^k for k=1,….,m and the vectors of multipliers are λ_k and $(\mu_j)_j$, respectively and $k\neq j$. The historical data of significant wave heights, sea surface current, sea level variations and wind speed March 2014 to March 2016 are collected from the Jason-2/Ocean Surface Topography Mission (OSTM), and QuikSCAT respectively to simulate the current and possible debris trajectory movements across the southern Indian Ocean.

4. RESULTS AND DISCUSSION

The multi-objective algorithm has used to reconstruct MH370 debris from delivered Chinese satellite information (Figure 5a). Figure 5b shows the simulated MH370 debris by using multi-objective algorithm in 44° 57'S 90° 13'E in the southern Indian ocean with the length of 24 m. With this regard, the correlation between real aircraft carrier and one simulated by multi-objective algorithm is 0.87 with standard errors of 0.002. Figure 5c, confirmed that the bright object which claimed by Chinese satellite as MH370 debris is belong to aircraft carrier. This means that the delivered information by remote sensing satellite are unusual uncertainty.

(a) (b) (c)

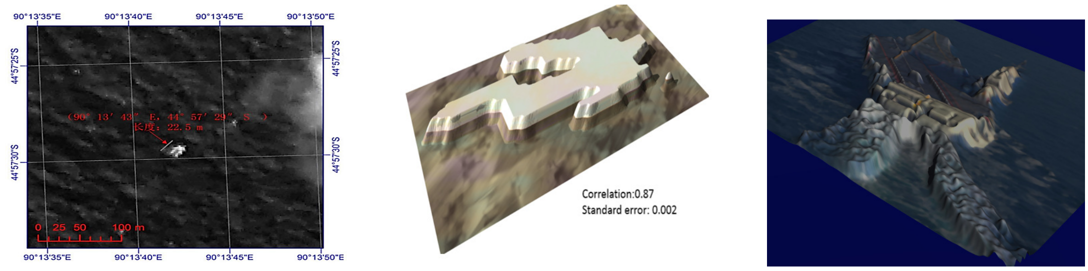

Figure 5. Flight MH370 debris in (a) China satellite , (b) GA segmentation results correlated to (c) aircraft carrier as example.

Figure 6 shows the simulated trajectory movements of MH370 (white circles and blue rectangular). Figure 6 shows that debris must flow in anti-clockwise direction with root mean square error of current velocity of 10 cm/sec which is coincided with the Southern Indian current movement. It is interesting to find that the MH370 debris under the current effects had sunk in deep water of Indian ocean within the month of September and October 2014.

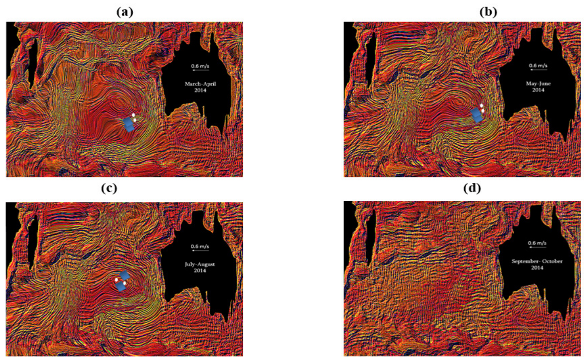

Figure 5. Multi-objective algorithm for suspected MH370 debris trajectory movements during (a)March-April 2014,(b)May-June, (c) July-August 2014, and (d) September-October 2014.

However, the element of the debris would not have floated for several months at the water's surface but would have drifted underwater thousand meters deep. In fact, the Antarctic Circumpolar Current (ACC) will cause instabilities for the debris trajectory movements. In this regard, the MH370 debris could transport westward and spin in a large scale counter-clockwise eddies rotation and drifted westward to the African east i.e. Mozambique and Madagascar coastal waters. During this dynamic instability, either debris are more buoyant than water, in which case they float, or they are less buoyant, in which case they sink. Therefore, the turbulent movements with 50 km/ day of the large southern Indian gyre with width of 100 km would cause the debris to submerged in depth of 3,000 m to 8,000 m across the Southern Indian Ocean (Marghany 2015). The debris has been found in Reunion Island are not belong to MH370. In fact, the debris would sink under sea surface of 3000 water depth within less than few months as explained above. If there is no clue confirms the existence of debris either from remote sensing data or ground search across the Southern Indian Ocean, this means the MH370 have landed vertically through the ocean surface and broke down to several pieces through the water column due to huge hydrostatic pressure of more than 2,000 m water depth. This confirms the theory of Chen et al., (2015).

5. CONCLUSIONS

This study has used optimization techniques of Genetic algorithm to investigate the impact of ocean surface current on flight MH370 debris. The southern Indian Ocean during the months of March-April has dominated by anticlockwise large gyre moving with maximum velocity of 0.5 m/s and slowly drifts westward. It means that flight MH370 debris can potentially travel up to 50 km/day with large eddies of a width of 100 km wide. The study shows that flight MH370 debris could not move to Africa within 24 months and with less than 2 months it would sink before washed up on Réunion Island. However, it can be said that the turbulent flow due to large Southern Indian gyre would make the debris submerged in deep water more than 3000 m across the Southern Indian Ocean. In conclusion, intelligent system based on multi-objectives Genetic algorithm can be used to investigate uncertainties in data and information. In conclusion, it is difficult to determine the MH370 debris in the Southern Indian Ocean because of sophisticated and turbulent current, which could drift the debris away to westward that required large-scale search areas.

References

Anderson S.J., Edwards P.J., Marrone P., and Abramovich Y.A. 2003. Investigations with SECAR - a bistatic HF surface wave radar, *Proceedings of IEEE International Conference on Radar, RADAR 2003*, Adelaide.

Anderson S.J., Darces M., Helier M., and Payet N. 2013 . Accelerated convergence of Genetic algorithms for application to real-time inverse problems, Proceedings of the 4th Inverse Problems, Design and Optimization Symposium, IPDO-2013, Albi, France, 149-152.

Anderson S.J., 2013. Optimizing HF Radar Siting for Surveillance and Remote Sensing in the Strait of Malacca IEEE Tran. on Geosc. and Rem. Sens., **51**, 1805-1816.

Anderson S.J., 2014. HF radar network design for remote sensing of the South China Sea: In Marghany M.(ed.), Advanced Geoscience Remote Sensing. Intech, Retrieved August 10, 2014, from http://cdn.intechopen.com/pdfs-wm/46613.pdf.

Asia News 2014. Missing Malaysian flight MH370: Is satellite data not enough? 2014 Geospatial World, 9:13.

Chen, G., Gu, C., Morris, P. J., Paterson, E. G., Sergeev, A., Wang, Y. C., & Wierzbicki, T. (2015). Malaysia Airlines Flight MH370: Water Entry of an Airliner. *Notices of the American Mathematical Society*, *62*(4), 330-344.

Excell J. 2014. Down deep. The Engineer, 296 3.

Grady B. 2014 NSR Analysis: OU Or Contribution The Business of Pre-Planning For Breaking News. Sat magazine, June , 2014 p.60.

Geoscience Australia (2015). MH370: Bathymetric Survey. http://www.ga.gov.au/about/what-we-do/projects/marine/mh370-bathymetric-survey. [Access on August 29 2015].

Linlin G., (2014). Opinion can satellites help find flight MH370?https://newsroom.unsw.edu.au/news/science-technology/can-satellites-help-find-flight-mh370. [Access on August 28 2015].

Marghany M. (2014). Developing genetic algorithm for surveying of MH370 flight in Indian Ocean using altimetry satellite data. 35th Asian conference of remote sensing, at Nay Pyi Taw, Mynamar, 27-31 October 2014. a-a-r-s.org/acrs/administrator/components/com.../OS-081%20.pdf.

Marghany M. (2015). Intelligent Optimization system for uncertainty MH370 debris detection. 36th Asian conference of remote sensing, at the Crowne Plaza Manila Galleria in Metro Manila, Philippines, 19-23 October 2015. acrs2015.ccgeo.info/proceedings/TH4-5-6.pdf.

Marghany, M., Mansor, S. and Shariff, A.R.B.M., 2016, June. Genetic algorithm for investigating flight MH370 in Indian Ocean using remotely sensed data. In *IOP Conference Series: Earth and Environmental Science*(Vol. 37, No. 1, p. 012001). IOP Publishing.

Martini K. (2015). How currents pushed debris from the missing Malaysian Air flight across the Indian Ocean to Réunion. Deep sea news [http://www.deepseanews.com/2015/07/how-currents-pushed-debris-from-the-missing-malaysian-air-flight-across-the-indian-ocean-to-reunion/]

Staff writer (2014). Missing flight satellite finds 122 floating objects http://whotv.com/2014/03/26/missing-flight-satellite-finds-122-floating-objects/[Acess on August 28 2015].

Serafino, G. (2015). "Multi-objective Aircraft Trajectory Optimization for Weather Avoidance and Emissions Reduction." *Modelling and Simulation for Autonomous Systems*. Springer International Publishing, 226-239

Smith, W.H. and Marks, K.M., 2014. Seafloor in the Malaysia airlines flight MH370 search area. *Eos, Transactions American Geophysical Union*, *95*(21), pp.173-174.

Zweck J. 2014a. How Satellite Engineers are Using Math to Deduce the Flight Path of the Missing Malaysian Airliner. Retrieved August 10, 2014, from www.utdallas.edu/~zweck/MH370.pdf.

Zweck J. 2014b. How Did Inmarsat Deduce Possible Flight Paths for MH370? SIAM News. Retrieved August 10, 2014, from http://www.siam.org/news/news.php?id=2151.