Algorithm Development for Detection of Attack Craft within Fishing Clusters

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Abstract

This research work introduces a novel method in order to acquire the potential threats sheltered within a neutral fishing craft cluster, utilising particle swarm optimization (PSO) concepts. This work also introduces derivation of behavioural aspects of a target out of sensor information. Even though the threat of suicidal craft is not prevalent within the present scenario, pirate and drug traffickers may exploit the available freedom, hence the requirement still exists to detect such craft within the fishing clusters especially during the surveillance sessions during dark hours. This method can also be utilized by Merchant vessels, to identify pirate craft. This method is attractive due to obvious difficulty in tracking and monitoring the number of targets and due to performance degradation caused by user fatigue. It is observed that with the present methodology of detection, the user has only got a limited time duration for reaction. Hence it requires a more formidable solution to detect within the preparatory phase with a certain depth for own preparation or for apprehension in the case of a drug trafficker due to possibility of dumping the stocks to sea, prior to arrest. In this backdrop, there certainly exists a vacuum for algorithmic enhancements of detection capabilities of existing sensors for effective future surveillance operations. Here, a novel algorithm based on PSO concepts, is proposed to identify an illegal (gun runner/trafficker/smuggler/attack) craft seeking shelter within neutral fishing clusters. This is fundamentally by modelling the fishing clusters as swarms and thereby detecting deviations from the cluster behaviour of possible illegal craft. It is assumed that the interaction of fishing craft at night is not generally isotropic and is based on visual information. Hence, the interaction with craft in front of a given craft is stronger than that with those behind due to obvious navigational requirements. Finally the paper emphasizes the paramount importance of an initiative for algorithmic enhancements of existing sensors, and in turn customization of sensor capabilities as per target characteristic requirements of Sri Lankan environment.

Introduction

This research formulates a methodology, utilizing PSO concepts, for enhancement of detection and economy of effort of future Fast Attack Craft and Rapid Action Boat operations, against the smaller attack craft sheltered / hidden within neutral fishing clusters. This research work also inducts the concept of derivation of behavioural aspects of a target out of sensor information, which at present only depends on threshold based methods in the case of radar, with respect to local scenario. It predicts [1] a huge enhancement of the ability to see, track and kill targets with the rapid pace of technological innovation. Swarming(hereby referred as the concept) as: a collection of autonomous individuals relying on local sensing and reactive behaviours interacting in such a way that a global behaviour emerges from the interactions[2]. A swarm is defined [3] as: a useful self-organization of multiple entities through local interactions. There are two different descriptions for the word, Swarming is also found[4], firstly in biological systems to describe decentralized self-organizing behaviour in populations of (usually simple) animals and also as a battlefield tactic that involves decentralized and pulsed attacks as described by military historians. Inclining with the former definition and also focusing on the applicability on the future warfare it has been observed [5], that manoeuvring of swarms are mainly to affect psychological strength and cohesion by attacking from multiple and unexpected directions.
In could also be identified that the swarming is a preferred tactical option for irregular forces for leveraging the factors of quantity over quality [6]. (is recognized) new asymmetric surface threat in the cluttered and crowded littoral waters, from a class called fast inshore attack craft[7]. However it is argued that there is no definable criteria for such craft, which could be ranging from commercial types such as Jet ski to coastal patrol fast patrol boats[8].
Swarm Optimization is a population based stochastic optimization method, which was first described in 1995 by James Kennedy and Russell C. Eberhart [9]. It was originally inspired by social behaviour of bird flocking and fish schooling, and has so far been extended in number of flavours. During the past decade the concept of swarming has been addressed in a wide number of disciplines, such as Power system control [10]-[14], Control engineering[15]-[17], Space Applications [18],[19], Multi-robot systems [20]-[22], Traffic flow optimization [23]-[26], Automotive vehicle navigation [26]-[28], Mobile Sensor technology[29]-[31], Satellite Technology [32]-[34], Cargo Management[35],[36], Routing Algorithms [37]-[40], Production Scheduling [41]-[43], and finally also in Military applications [44]-[53]. It was observed that the concept has also been utilized in a number

of practical projects such as algorithms based on ant-foraging principles to route cargo by Southwest Airlines, on routing algorithms by British Telecom, on Scheduling of production machinery by Unilever and algorithms based on honeybee and ant principles to allocate labour in large distribution canters at Dell[54]. It was also observed that some major projects such as, formation flying and coordinated control of satellites at DARWIN project of the European Space Agency (ESA) and the PRISMA project of the Swedish Space Corporation (SSC), which is the first real formation flying space mission, also utilizes the concept [55].

It is observed that the attacking craft are of commercial types and sans any distinguishable features and *identification is to be based on characteristic behaviours* [8]. It has been deduced that successful defence should include *denial or disruption of enemy's elusiveness,* situational awareness [54], With the rapid development of personal computers, *replication of complex behaviours through simulation is a possibility* and also emphasises *interaction rule must be a key ingredient of such a mathematical model* [56]. [57], observe that the collective dynamics of a motile particle group with a leader, the *motion of the all member particle depends on that of the leader* and also coupling weights. It was argued that in collective motion, it cannot be neglected that an agent's *decision to move in a certain direction will determine, the agents with whom it will interact next*[58]. The author further highlights the *analogy between the swarming behaviour and social consensus, human decision making.* In [59], it is stated that the swarm behaviours provide a rich framework for exploring *representational and algorithmic means of addressing difficult problems,* being of high level, with non- symbolic representation and also not constrained to a tightly defined specification. As per [54] two of the attributes of swarming are important for our research work as fundamental assumptions; that is *scalability: ability to add members of the community to match mission requirements, and probabilistic ability: that is emergent and non-deterministic behaviour, where system simple reactions to the presented conditions.*

It is observed that collective animal behaviour could be viewed as a consequence of individuals following a set of *simple behaviour rules, and can thus be modelled by mathematical equations* similar to physical and chemical approaches[60]. Schmidt[61] identifies, improved sensing and Intelligence, Surveillance, Reconnaissance (ISR) functions cooperatively engage targets where *all-source data will outcome a fast, accurate situational picture.*

Motivation

Even though threat of suicidal craft is not prevalent within the present scenario, with the subsequent uprising of piracy and drug trafficking, the *requirement still exists to detect such craft sheltered within fishing clusters* especially during the surveillance sessions during dark hours. This is also *applicable for Merchant vessels in the case of pirate craft*, due to obvious difficulty in tracking and monitoring the number of targets especially *amidst neutral fishing clusters near harbour environments and also due to user fatigue.* At present the radar tracks a potential target by the velocity change of the target and also by whether it has entered a predetermined guard zone. It does so by monitoring the velocity property change of the target or monitoring events of within the predetermined guard zone. This in turn alerts the user when a target enters its sensing radius. But in the case of an attack craft it may be already too late to detect in this manner due to *shorter time duration availability for reaction*. Hence a more *formidable solution is required to detect within the preparatory phase with a certain depth for own preparation or for rapid apprehensive action* in the case of a drug trafficker due to the possibility of conveniently dumping goods in to sea.

It is hypothesized that *superior situational awareness is one of the five core variables* most responsible for swarm related outcomes, based on his case studies[62]. Further it is claimed[4] that a *very little attention has been given to integrate mechanisms of biological systems into military systems.* Further to above, he observes that even though the small boat threat is covered in professional journals and discussed in depth during forums, *very little quantitative analysis has been carried out to determine the extent to which naval platforms deal with as well as no extent of initiation to analyse the threat or identify potential solutions* [4]. One of the four main research components of Multi-Target Track and Terminate program of the Office of US Naval Research is development of algorithms for *detection of potential targets based on shape and behavior*[6]. It is also confirmed that above is based on outcomes of the quoted workshop, as one of the four conceptual conclusions[4]. It is also enumerated [54] that providing existing network with *new dynamic sources of information is one of the three main goals of network centric operations*. The author also proposes swarming as a new means to search physical and information domains of the battle space and has the *potential to improve state-of-the-art knowledge in extraction problems*. With this backdrop, it was found worthwhile, to *model the scenario and propose algorithmic enhancements for detection capabilities of existing sensors*, for effective future naval operations.

Research Objective

The objective of this research work is to develop an algorithm utilizing PSO concepts and also induct the concept of derivation of behavioural aspects of a target out of sensor information, for enhancement of detection and economy of effort of Fast Attack Craft and Rapid Action Boat surveillance operations, against the smaller (gun runner/trafficker/smuggler/attack –henceforth referred only as 'illegal craft') craft seeking natural shelters within fishing clusters.

Existing Research

The utility of swarm tactics constitute an important part of US doctrinal discussions [1]. It was observed that US military is beginning to emphasize on swarming [6]. Defence Advanced Research Projects Agency has recognized *detection, precision identification, tracking and destruction of elusive surface targets as one of the eight strategic research trusts* should be emphasized. Authors observed number of US research and development projects relevant to the concept such as U.S. Army's Army XXI [63],[64] and Army After Next (AAN) work [65],[66] and the Marine Corps' Urban Warrior program [67][68]. Further going an extra step US Navy is extending [1] the concepts of US Army's , utilizing helicopter crew in lieu of drone swarms. Navy is demanding research for swarms, itself *to identify targets and also makes the attacking decision* there on. In addition, the Pentagon is also in the process of development of counter tactics for swarms [1].

Similar to this work, endeavours of enhancement of detection have been proposed by a number of other authors. A software package method based on machine intelligence combined with image and signal processing techniques have been proposed in [69]. Herselman and Baker [70] analyses the temporal characteristics of low gazing angle sea clutter and reflectivity of small boats under fixed and stepped frequency waveforms under a spectrum of environmental and geometrical configurations, both in X and C band frequencies. In [71], an algorithm (is presented) for automatic recognition of bird targets, based on the patterns generated due to wing flapping. A method of target enhancement and sea clutter reduction is proposed in [72], utilizing nonlinear signal processing techniques based on neural networks. The work by Kiriyakidis [73], seems in line with this research work since the former also utilizes the swarm behaviour for detection of small boats in a harbour environment. But the major difference lies with the way of detection this research work selected, i.e. in [73], utilized formation of swarm behaviour to detect small boats, where as we use deviation from the swarm behaviour for detection, considering the whole fishing cluster as a swarm. Further formation of a swarm may be difficult to be detected within a swarm of a large fishing cluster.

Methodology

As per author's knowledge, so far no *PSO based model has also been developed to model fishing craft clusters*. Hence we utilise the model developed by Sugawara et al [74] on collective motion of multi robot systems in multiple environments, to model the fishing craft clusters due to the fact that the characteristics of the said model closely resembles the observed behaviour of such clusters. Our methodology is fundamentally based on representation of the fishing craft cluster (including possible illegal craft) as a dynamic swarm model, comprised of most characteristics. This is well justified due to natural and obvious requirements of coordinated navigation and resource sharing characteristics present in fishing craft clusters. We make predictions on the intent of possible attack craft by monitoring the deviations from the overall swarm behaviour characteristics by attack craft. Even though this could also be achieved by tracking a single craft (*only if known priori as such*), the *experience reveals that attackers/traffickers will seek shelter in clusters* so *individual tracks provide little information on the exact intent of such attack craft*. Further the analysis of collection of tracks for a certain amount of time may provide certain amount of information, *but clearly depends upon the degree of attention and level of fatigue of the user(refer to case studies given in Appendix C for more details).*

Proposed Model

For a typical radar *only the Normalized RCS $\mathfrak{z}_{ni}$ and Distance d_i are required to be taken into consideration as above, and if $\mathfrak{z}_{ni}$ is known the respective image could be regenerated for the standard setting* The above $\mathfrak{z}_n$ will be mapped into a (brightness, size) pair as follows $\mathfrak{z}_{ni} \rightarrow (\mathfrak{B}, \mathfrak{S})$; $\mathfrak{B} \in \mathbb{B}, \mathfrak{S} \in \mathbb{S}$.(4) to create the picture Where $\mathbb{B}$ and $\mathbb{S}$ are sets of predetermined sets of brightness and echo sizes. Hence an echo could be represented as $f_i = (\mathfrak{z}_{ni}, \tilde{x}_i, \tilde{v}_i, \tilde{h}_i)$ (5); Where, $\tilde{x}_i$ is the position vector, $\tilde{v}_i$ is the velocity vector and $\tilde{h}_i$ is the heading vector. *(See Appendix B for more details).*

Assuming the size of the fishing craft cluster with possible attack craft is M, which is sufficiently large, i.e. that is not too large nor too small. Now map the fishing craft cluster into an initial population $\mathfrak{m}$ with, $\mathfrak{m}_{min} \leq \mathfrak{m} \leq \mathfrak{m}_{max}$, so we get echos, $e_1, e_2, \ldots \ldots e_N$, with following state variables: e_i: $[\tilde{x}_i \tilde{v}_i, \tilde{h}_i]$ (6). State variables of i^{th} craft, have following dynamic and coordinated behaviour[74].

$r\dot{\tilde{v}}_i = a\tilde{v}_i + F\tilde{h}_i + \sum_{j \neq i} s_{ij} q_{ij} + \tilde{c}_i$ (7)

$T\dot{\tilde{b}}_i = sin(\tilde{g}_i - \tilde{b}_i) + \sum_{j \neq i} A\, sin(\tilde{b}_j - \tilde{b}_i)$ (8)

Where r - water resistance is based on Stokes's law, a-a variable is proportional to the relaxation time in velocity, F- motile force, s_{ij}- directional sensitivity, q_{ij}- mutual attractive/repulsive forces, $\tilde{c}_i$- force towards centre of the group,T-relaxation time, related to the inertial moment and time scale of manoeuvring of the craft, $\tilde{g}_i$ - angle between velocity vector $\tilde{v}_i$ and north, $\tilde{b}_i$- angle between heading vector $\tilde{h}_i$ and north, A- tendency of i^{th} craft, be aligned with craft j. For more information one may refer [74]

Hence the overall picture of a fishing craft cluster could be represented as, a collection of picture elements as: $= \sum_{i=1}^{m}(\mathfrak{z}_n, \tilde{x}_i, \tilde{v}_i, \tilde{h}_i) + \mathfrak{N}$ (9), Where $\mathfrak{N}$ represents the Noise/clutter component

Schon et al[75] presents a practical marginalized particle filter which is conceptually best for implementation of the proposed concept, however we adopt the design given in [76], due to the fact that it has been practically utilized for radars and certain other characteristics such as much better performance than extended Kalman filter, keeping the computational complexity about the same. Let's take index of time as k, then $e_{i,k}$ represents the echo of i^{th}craft at time instant k.

Calculation of $p(state, t_k | e_{i,k}) \xrightarrow{taking\ position\ state} p(\tilde{x}_i, t_k | e_{i,k}) \xrightarrow{\tilde{\tilde{x}}_i : estimate\ of\ \tilde{x}_i\ at\ t_k} (\tilde{\tilde{x}}_{ik})$

(10)

$p(\tilde{x}_i, t_k | e_{i,k}) = p(\tilde{x}_i, t_k) exp[\varphi^T(\tilde{x}_i, t_k)\, \Upsilon(e_i, t_k)]$ (11),

Of which the prediction equation: $\dot{\Upsilon} = A\Upsilon + \Gamma$, the measurement update of $\Upsilon_k = \bar{\Upsilon}_k + \Phi(e_i, t_k)$ (12). Propagation equation: $\dot{\Upsilon} = A^T\Upsilon + \Gamma$ (13),where $\Gamma = (\Gamma_1, \Gamma_2 \ldots \Gamma_M)^T$ (14); $\Gamma_j = \Upsilon^T B_j \Upsilon$ (15), where Υ, is the sufficient statistic of dimension M. For more explanatory presentation one may refer to [75].As above (10) all other state variable could be calculated

Hence state vector $x = [\tilde{x}_{ik}, \tilde{v}_{ik}, \tilde{h}_{ik}]^T$ (17)

The interaction of fishing craft at night is not generally isotropic and is based on visual information. Hence the interaction with craft in front of a given craft is stronger than that with those behind due to obvious navigational requirements.

Proposition 1: If an illegal craft is considered the attraction force with the centre of the cluster should be lesser with respect to the average value of the same considered with the other craft of the cluster (*refer to appendix for proof*).

Attraction force [74] is given as :

by, $f_{ij} = -I\left\{\left[\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right]^{-1} - \left[\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right]^{-2}\right\}\left(\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right) exp\left(\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right)$ (18)

Where I- parameter represents magnitude of interactions, $\tilde{d}_i$- distance from the instantaneous centre of the cluster, and d_0- typical distance between craft;

$d_0 = \frac{1}{m}\sum_{I=1}^{M} d_i$ (19).

Proposition 2: If the directional sensitivity of a particular craft is higher than within the average predetermined directional sensitivity factor of the cluster and a bias outwards the general direction of the centre of the cluster can be deduced as not a part of a cluster (*refer to appendix for proof*).

Direction Sensitivity factor[74] is given by,

$\mathfrak{s}_{ij} = 1 + d_c\tilde{h}_i\frac{(\tilde{a}_j-\tilde{a}_i)}{|\tilde{a}_j-\tilde{a}_i|}$ (20), with $0 < d_c < 1$; d_c- is the control factor for anisotropy of the sensitivity.

Now let's draw the theorems from the magnitude of above parameters with respect to the predetermined threshold values, calculated for a specific fishing craft cluster:

Theorem 1: For any i^{th} craft if f_{ij} is below the threshold and $\mathfrak{s}_{ij}$ is above the threshold(depicted as same variable figure with additional subscript '*thr*'), then it could be determined that the i^{th} *craft is not collaborating with the cluster.*

$$iff \;\; f_{ij} \underset{H_{01}}{\overset{H_{11}}{\lessgtr}} f_{ij,thr} \;\; \&\& \;\; \mathfrak{s}_{ij} \underset{H_{01}}{\overset{H_{11}}{\gtrless}} \mathfrak{s}_{ij,thr}; \quad (21)$$

$$H_{11} = i^{th} \; craft \; is \; NOT \; collaborating \; with \; cluster. (22)$$

Theorem 2: Further to above, taking two craft as i^{th} and q^{th}, and a j^{th} craft as a randomly closer craft within the cluster: if both f_{ij} and f_{qj} are below the threshold as above, *both the i^{th} and q^{th}craft are not collaborating with the cluster.*

$$Select\ j\ \ such\ that{:}\ d_{ij} \approx d_0,\ d_{qj} \approx d_0 \tag{23}$$

$$iff\ \ f_{ij} \underset{H_{02}}{\overset{H_{12}}{\lessgtr}} f_{ij,thr}\ \ \&\&\ ş_{ij} \underset{H_{02}}{\overset{H_{12}}{\gtrless}} ş_{ij,thr} : f_{qj} \underset{H_{02}}{\overset{H_{12}}{\lessgtr}} f_{qj,thr}\ \ \&\&\ ş_{qj} \underset{H_{02}}{\overset{H_{12}}{\gtrless}} ş_{qj,thr}\ ; \tag{24}$$

$$H_{12} = both\ \ i^{th}\ and\ q^{th} craft\ are\ NOT\ collaborating\ with\ cluster. \tag{25}$$

Theorem 3: On detection of above (2), during the next time instances, if f_{ij} is below the threshold and f_{qj} is above the threshold ,it could be determined that *i^{th} craft is commanded to move towards the q^{th} craft.*

$$iff\ \ f_{ij} < f_{ij,thr}\ \ \&\&\ \ f_{qj} > f_{qj,thr}\ \ \text{then } H_{13} \text{ is true.} \tag{26}$$

$$H_{13} = that\ \ i^{th}\ craft\ is\ commanded\ to\ move\ towards\ the\ q^{th}\ craft. \tag{27}$$

The proposed algorithm will be as follows:

Begin
Initialize % population of craft
$\mathbf{d_c = d_c'}$ % assign a value for control factor for anisotropy of the sensitivity
$\mathbf{d_0 = d_0'}$ % assign a value for typical distance
M=maximum number of crafts
i = 0
J = 0 % initialization of index
while **i** $< M$
for each craft
update position $\mathbf{x_i, h_i}$;
calculate $\mathbf{f_{ij}, ş_{ij}}$; % As per equations (18), (19),(20)

Compare $iff\ \ f_{ij} \underset{H_{01}}{\overset{H_{11}}{\lessgtr}} f_{ij,thr}\ \ \&\&\ \ ş_{ij} \underset{H_{01}}{\overset{H_{11}}{\gtrless}} ş_{ij,thr}$; % checking for deviations H_{11}

$iff\ \ f_{ij} \underset{H_{02}}{\overset{H_{12}}{\lessgtr}} f_{ij,thr}\ \ \&\&\ ş_{ij} \underset{H_{02}}{\overset{H_{12}}{\gtrless}} ş_{ij,thr}\ \&\&\ f_{qj} \underset{H_{02}}{\overset{H_{12}}{\lessgtr}} f_{qj,thr}\ \ \&\&\ ş_{qj} \underset{H_{02}}{\overset{H_{12}}{\gtrless}} ş_{qj,thr}$
%checking for deviations H_{12}

$iff\ \ f_{ij} < f_{ij,thr}\ \ \&\&\ \ f_{qj} > f_{qj,thr}$.% checking for deviations H_{13}

End for

out alarm %Report deviation $H_{1y}; y = 1,2,3$.

out $\tilde{v}_{ik}$ $\tilde{v}_{jk}$ $\tilde{v}_{qk}$ %Report speed values

i + + && j + +

End while
End

Research constraints
The authors observe that *neither measurement facilities*, such as Over-berg test range [77] or US Army Corps of Engineers Field Research facility, Duck, NC[78], are available in Sri Lanka, for this type of application research, and so far *nor sufficient further quantitative observations/data collection of fishing clusters* have been carried out. Hence researchers are compelled to adopt from available models subject to fine tuning of parameters on collection of exact data. Further there are *no PC based models developed to model Sri Lankan harbour environments* or to *simulate different levels of threats* such as presented in [79]. There are a number of simulation applications available [69], however so far *no local endeavours are underway for enhancements of detection algorithms of existing sensors due to obvious restrictions imposed by equipment suppliers*, however felt essentiality of such, in view of customization of sensor capabilities as per target characteristics of Sri Lankan environment with pre-arranged agreements during the pre-evaluation phase of such acquisitions.

Future Research
Future research is required to model, ascertain and fine tune the parameters of the proposed model utilized for modelling of fishing clusters. Further it is essential to note that authors emphasize the requirements: (a) of sufficient further quantitative observations of fishing clusters for formulation of PC based models, (b) of building a simulation application to model different levels of threats, (c) of an initiative for algorithmic enhancements of existing sensors, and in turn (d) customization of sensor capabilities as per target characteristics of Sri Lankan environment, which should be subjected to extensive further research.

Conclusion

In this research work we introduce a novel algorithm for the automation of detection of low silhouette illegal craft seeking shelter within a neutral fishing craft cluster with similar super structural characteristics, utilising PSO theory. This was achieved by modelling the fishing clusters as swarms and thereby detecting deviations of two characteristics from the cluster behaviour. We also induct the concept of derivation of behavioural aspects of a target out of sensor information, which at present only depends on threshold based methods in the case of radar, with respect to local scenario. Further simulation is required to establish proposed methodology. However due to lack of models and radar receiver data for fishing craft clusters and their behavioural patterns they have to be fulfilled prior to such attempts.

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Appendix A : Proof of propositions

From Eqn (18):

Attraction force: $f_{ij} = -I\left\{\left[\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right]^{-1} - \left[\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right]^{-2}\right\}\left(\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right) exp\left(\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right)$

Lets take $\left(\frac{|\tilde{a}_j-\tilde{a}_i|}{d_0}\right) = x_q$; $\quad q = 1,2 \ldots N$

then,

$$f_{ij} = -I\{x_q{}^{-1} - x_q{}^{-2}\}x_q\, e^{x_q} \tag{28}$$

Lets have a minute positive increment of Δx_q,

$$f_{ij+} = -I\left\{\left(x_q + \Delta x_q\right)^{-1} - \left(x_q + \Delta x_q\right)^{-2}\right\}\left(x_q + \Delta x_q\right) e^{(x_q+\Delta x_q)} \tag{29}$$

From (28) and (29):

$$f_{ij+} - f_{ij} = -I\{x_q{}^{-1} - x_q{}^{-2}\}x_q\, e^{x_q} + I\left\{\left(x_q + \Delta x_q\right)^{-1} - \left(x_q + \Delta x_q\right)^{-2}\right\}\left(x_q + \Delta x_q\right) e^{(x_q+\Delta x_q)}$$

Since $\lim_{\Delta x\to 0} e^{\Delta x_q} \to 1$ and all multiplications and higher order terms prefixed with Δ could be considered negligible,

We get:

$$f_{ij+} - f_{ij} \approx -I\frac{\left(3x_q{}^2 . \Delta x_q - 2x_q . \Delta x_q\right)}{x_q + \Delta x_q} e^x$$

Hence $\quad f_{ij+} - f_{ij} < 0$

And $\quad f_{ij+} < f_{ij}$

This concludes the proof of proposition 1.

From Eqn. (20)

Direction Sensitivity factor, $\mathfrak{s}_{ij} = 1 + d_c \tilde{h}_i \frac{(\tilde{d}_j - \tilde{d}_i)}{|\tilde{d}_j - \tilde{d}_i|}$

Substituting $\tilde{d}_j - \tilde{d}_i = y_q$;

$$\mathfrak{s}_{ij} = 1 + d_c \tilde{h}_i \frac{y_q}{|y_q|}$$

(30)

Having a minute positive increments of Δ, for both $\tilde{h}_i$(in positive direction);

$$\mathfrak{s}_{ij+} = 1 + d_c(\tilde{h}_i + \Delta\tilde{h}_i)\frac{(y_q + \Delta y_q)}{|y_q + \Delta y_q|}$$

(31)

From (30) and (31):

$$\mathfrak{s}_{ij+} - \mathfrak{s}_{ij} = 1 + d_c(\tilde{h}_i + \Delta\tilde{h}_i)\frac{(y_q + \Delta y_q)}{|y_q + \Delta y_q|} - \left(1 + d_c \tilde{h}_i \frac{y_q}{|y_q|}\right)$$

$$\mathfrak{s}_{ij+} - \mathfrak{s}_{ij} = \frac{d_c\left(|y_q|(\tilde{h}_i + \Delta\tilde{h}_i)(y_q + \Delta y_q) - |y_q + \Delta y_q|\tilde{h}_i y_q\right)}{y_q \cdot |y_q + \Delta y_q|}$$

Taking all multiplications prefixed with Δ could be considered negligible and subtracting terms within Δ prefixed terms as minute, hence negligible,

$$\mathfrak{s}_{ij+} - \mathfrak{s}_{ij} > 0$$

Therefore $\mathfrak{s}_{ij+} > \mathfrak{s}_{ij}$.

This concludes the proof of proposition 2.

Appendix B : Background Theory

Let us first analyze the detection probability of typical radar to acquire a craft within a fishing craft cluster. Ordinary marine radar typically scans the sea surface at gazing incidence with HH polarization. The radar images are due to the mutual interaction of the EM waves with the ripples, which are a result of friction to local wind forces. Aforesaid interaction results a backscatter of the EM waves and hence an image pattern on the radar display. This effect is commonly known as sea clutter by sea farers and considered as noise in the aspect of navigation. In this process we consider a typical fishing craft is in the class of Swirling model 3(SW3)[80]. For typical marine radar the radar image could be considered as a collection of elements, where each element is a result of backscattered energy either from an object on the ocean or from the ocean surface area illuminated by an electromagnetic pulse prior emitted from the radar.

The radar receiver's threshold power [81]is: $\mathfrak{p}_r = \frac{\mathfrak{v}_t \mathfrak{z}_{ni} \mathfrak{b}_h c\, \mathfrak{w}_p}{4\pi {d_i}^3 \lambda^2} \mathfrak{a}_a^2 \frac{G_{st}\, G_{hpa}\, G_{hps}\, G_d}{G_l}$ (1)

Where, $\mathfrak{v}_t$- transmitters impulse power, $\mathfrak{z}_n$- normalized RCS of craft i, $\mathfrak{b}_h$- horizontal; beam width, c - speed of light, $\mathfrak{w}_p$- pulse width, a_a-effective aperture, d- radar detection range of craft i, λ- working wavelength, G_{st} - function of spherical surface effect of sea and refraction of EM waves in troposphere, G_{hpa}- function of attenuation of useable signal in atmosphere and hydro-precipitations, G_{hps}- function of summery disturbances due to reflection from sea surface and hydro-precipitations, G_d-function of normalized voltage directional characteristic of scanner and G_l- energy loss coefficient of radar transmission lines.

Then the detection probability of a craft (for a SW3) [69]:

$$P_d = \left[1 + \frac{(SNR)(TNR)}{(2+SNR)^2}\right] exp\left(\frac{-2TNR}{2+SNR}\right) \quad (2)$$

Where SNR is the Signal to Noise ratio computed from radar range equation and the TNR is Threshold to Noise ratio.

For a specific pulse width setting above equation can be approximated as: $\mathfrak{p}_r = \frac{\mathfrak{z}_{ni}}{d_i^3} K$, where the constant $K = \frac{\mathfrak{v}_t \mathfrak{b}_h c\, \mathfrak{w}_p}{4\pi\lambda^2} \frac{G_{st}\, G_{hpa}\, G_{hps}\, G_d}{G_l}$ (3)

Hence only the Normalized RCS $\mathfrak{z}_{ni}$ *and Distance* d_i *are required to be taken into consideration as above, and if* $\mathfrak{z}_{ni}$ *is known the respective image could be regenerated for the standard setting.* In a study[82], in which Radar Cross Section(RCS) was determined at all elevations and angles with an angle spacing of 0.5 degree for both S and X band, it had been calculated that a typical fishing craft (10.7m(L), 4.7m(H)) carries a nominal RCS of 22dBsm and Peak RCS 53dBsm,normally on broadside of the vessel. The above $\mathfrak{z}_n$ will be mapped into a (brightness, size) pair as follows $\mathfrak{z}_{ni} \to (\mathfrak{B}, \mathfrak{S})$; $\mathfrak{B} \in \mathbb{B}$, $\mathfrak{S} \in \mathbb{S}$.(4) to create the picture Where $\mathbb{B}$ and $\mathbb{S}$ are sets of predetermined sets of brightness and echo sizes. Hence an echo could be represented as $f_i = (\mathfrak{z}_{ni}, \tilde{x}_i, \tilde{v}_i, \tilde{h}_i)$ (5); Where, $\tilde{x}_i$ is the position vector, $\tilde{v}_i$ is the velocity vector and $\tilde{h}_i$ is the heading vector.

Appendix C : Case Studies on uncertainty of existing detection methods

Let us take two simpler case studies on detection to understand uncertainties involved in present detection methodology.

First case study is to show the degree of uncertainty of the conventional method of detection. We know height above water level is one of the determining factors of visibility in general as well as for the radar or any typical sensor in that sense. The well-known formula for the target visibility range is: $d(km) = 2.23[\sqrt{height_{Scanner}} + \sqrt{height_{target}}]$.Taking the target height as 4.7 m (typical maximum height of a fishing trawler) and the scanner height as 15m(average height of a scanner onboard a Fast Attack Craft),the calculated radar horizon is 8.64km. Up to this distance the entire super structure of a craft could be visible to the radar, under ideal conditions. If the distance to the craft is further increased, it would start dipping in the horizon and virtually vanishes (0m) at a distance of 13.47km. Hence the range difference between 0m and 4.7m target height is approximately 35%, which proves the dimension of uncertainly of depending only on raw RCS method, which indicates the *requirement of a more intelligent approach.*

Second case study is on psychophysical process of target acquisition. Harvey[83] presents the psychophysical process of target acquisition, divided into three tasks as: detection, discrimination and identification. However for the discrimination function the author has utilized High Threshold Model of detection, which has a widely accepted alternative model: signal detection theory [84]. Hence we adopt psychophysical process with signal detection theory for analysis. Let's assume that the stimulus property of required echo as: e_i seen through eyes of an operator is sent to the decision unit(brain) and translated into a discrete response, which is sent to a motoric unit to initiate appropriate behavioral response of 'presence' or 'absence' of a target. Hence the detection process of a practical (imperfect) sensory unit could be modelled as:

$$\text{Echo: } e \xrightarrow[stimulus]{} \mathfrak{n}_e \xrightarrow[neuronal\ response]{} \mathfrak{d}(\mathfrak{n}_e - \mathfrak{t}) \xrightarrow[binary\ decision]{} \begin{matrix} 1 \\ 0 \end{matrix}$$

Where,$\mathfrak{d}(\mathfrak{n}_e - \mathfrak{t})$:=, is the Heaviside step function. $\mathfrak{n}_e$ become a random variable keeping imperfections of sensors and $\mathfrak{t}$ is the threshold; when $\mathfrak{n}_e$, is above a certain internal threshold the response is positive and negative otherwise. By using term imperfect, it considers the fluctuations over time or space or both the dimensions, hence the variables become random. From the above model it is well understood that the *user response* also has certain amount of *uncertainty* due to the magnitude of stimulus and neuronal response which is certainly *user* *specific* as well as *not persistent* with time and *degrades* with the degree of user fatigue and the time duration that the user has spent so far during a particular duty watch.

References

[1] Sean J. A. Edwards, "Swarming on the Battlefield: Past, Present, and Future ",RAND, USA.

[2] B. Clough," Swarming Intelligence", Proc. of Conf. on Swarming: Network Enabled C4ISR, Jan 2003

[3] C .Chartier, "Swarming, Network-Enabled C4ISR, and U.S. Military Transformation"

[4] V. Parunak," Making Swarming Happen", Proc. of Conf. on Swarming: Network Enabled C4ISR, Jan 2003.

[5] S. J. A. Edwards, "Swarming and the Future of Warfare", PhD dissertation, Pardee RAND Graduate School, Sept, 2004.

[6] T. Tether, Defence Advanced Research Projects Agency Strategic statement, submitted to US Subcommittee on Terrorism, unconventional threats and capabilities House armed services committee, March 2005.

[7] R.Scott, "Fighting the FIAC threat", Defence Helicopter, Vol.30, No.1, Feb 2011

[8] D. Galligan et al, "The Future of C2 Net Centric Maritime Warfare – Countering a 'Swarm' of Fast Inshore Attack Craft", 10th International Command and Control Research and Technology Symposium, April 2005.

[9] R.C.Eberhart and J. Kennedy,"A new optimizer using particle swarm theory", Proc. of Sixth Int.Sym. on micro machine and human science, Japan, 1995.

[10] C.B.M. Oliveira et al," New Method based in Particle Swarm Optimization for Power Factor Remote Control and Loss Minimization in Power Systems with Wind Farms Connected", 15th Int. Conf. on Intelligent System Applications to Power Systems ISAP '09, 2009..

[11] B. Zhanget al," Dynamic control of wind/photovoltaic hybrid power systems based on an advanced particle swarm optimization", IEEE Int. Conf. on Industrial Technology, ICIT 2008, 2008.

[12] Y .Fukuyama,. and H. Yoshida," A particle swarm optimization for reactive power and voltage control in electric power systems", Proc. of the 2001 Congress on Evolutionary Computation, 2001.

[13] H. Yoshida et al," A particle swarm optimization for reactive power and voltage control in electric power systems considering voltage security assessment", Proc. of IEEE International Conference on Systems, Man, and Cybernetics, IEEE SMC '99. 1999.

[14] W. Xiuhua et al," Reactive Power and Voltage Control based on improved Particle Swarm Optimization in power system", 8th World Congress on Intelligent Control and Automation (WCICA), 2010.

[15] S. Chenet al," Flocking control of scalable engineering swarm system based on inverse model and PSO algorithm", 8th IEEE Int . Conf.on Control and Automation (ICCA), 2010.

[16] S. Chen and H. Fang," Modelling and Control of Scalable Engineering Swarm", The Sixth World Congress on Intelligent Control and Automation, 2006. WCICA 2006.

[17] X. Zheng and Z. Liu The schedule control of engineering project based on particle swarm algorithm", Second Int. Conf. on Communication Systems, Networks and Applications (ICCSNA), 2010.

[18] J.W. Fronczek and N.R. Prasad," Bio-inspired sensor swarms to detect leaks in pressurized systems", IEEE Int. Conf. on Systems, Man and Cybernetics, 2005.

[19] S. Jain et al," Ad-hoc swarm robotics optimization in grid based navigation", 11th Int. Conf. on Control Automation Robotics & Vision (ICARCV), 2010.

[20] L. Wenfeng," Dual-swarm features and its challenges for system of sensor networks and mobile multi-robots", IEEE Int. Conf. on Systems, Man and Cybernetics, 2009. SMC 2009.

[21] R. Zhang et al," Research on coordination of multi-robots system based on swarm intelligence, Sixth Int. Conf. on Intelligent Systems Design and Applications, ISDA '06,2006.

[22] L. Wang et al," Simulation Study on Searching for Food by Cooperation of Multi-Robots with Swarm Intelligence ", Int. Conf. on Intelligent Control and Automation (WCICA), 2010.

[23] J. Zhao et al," Traffic Flow Forecasting Model of Typical Multi-Intersection for Urban Trunk Road Based on Dissimilation Particle Swarm Optimization ", Cong. on Image and Signal Processing ,CISP '08, 2008.

[24] H. Gao et al," Short-term Traffic Flow Forecasting Model of Elman Neural Network Based on Dissimilation Particle Swarm Optimization " Int. Conf. on Networking, Sensing and Control, ICNSC 2008, 2008.

[25] L. Xiaobin," RBF Neural Network Optimized by Particle Swarm Optimization for Forecasting Urban Traffic Flow", Third Int. Sym .on Intelligent Information Technology Application, IITA 2009, 2009.

[26] A.J. Sengstacken et al," Fuzzy logic control for shared-autonomy in automotive swarm environment", Int. Conf. on Systems, Man and Cybernetics, 2007

[27] A.J. Sengstacken et al," Optimization of Shared Autonomy Vehicle Control Architectures for Swarm Operations ",IEEE Trans. on Systems, Man, and Cybernetics, Part B: Cybernetics, Vol.40, Issue 4, 2010.

[28] Y. Owechko and S. Medasani," Cognitive swarms for rapid detection of objects and associations in visual imagery", Proc. of Swarm Intelligence Symposium, SIS 2005, 2005.

[29] C. Cui, "A swarm-based fuzzy logic control mobile sensor network for hazardous contaminants localization", IEEE International Conference on .Mobile Ad-hoc and Sensor Systems, 2004

[30] M. Gerla and X. Kaixin "Integrating mobile swarms with large-scale sensor networks using satellites", IEEE 59th Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004

[31] P. Ekberg and E.C. Ngai," Bio-inspired sensor swarms to detect leaks in pressurized systems", 7th Int. Wireless Communications and Mobile Computing Conference (IWCMC), 2011.

[32] L. Jian and W. Cheng, "Resource planning and scheduling of payload for satellite with genetic particles swarm optimization", IEEE Cong. on Evolutionary Computation, (IEEE World Congress on Computational Intelligence), CEC 2008, 2008

[33] C. Pinciroli et al," Self-Organizing and Scalable Shape Formation for a Swarm of Pico Satellites",NASA/ESA Conference Adaptive Hardware and Systems, 2008. AHS '08.

[34] L. Qiang, "A New Satellite-to-Satellite Passive Locating Method Using Frequency-Only Measurements Based on Particle Swarm Optimization ", Int. Conf. on Control and Automation, ICCA 2007, 2007.

[35] T.O. Ting et al,"A novel approach for unit commitment problem via an effective hybrid particle swarm optimization", IEEE Trans on Power Systems, Vol. 21, 2011.

[36] M. Forcolin," EURIDICE — IoT applied to logistics using the Intelligent Cargo concept", 17th International Conf. on Concurrent Enterprising (ICE), 2011.

[37] H. Sizu et al," Research on particle swarm optimization algorithm in route selection of power communication", Int. Conf. Intelligent Computing and Intelligent

Systems (ICIS), 2010.

[38] C.J.A. Bastos - Filho," Routing algorithm based on Swarm Intelligence and Hopfield Neural Network applied to communication networks " Electronics Letters ,Volume: 44 , Issue: 16, 2008.

[39] R.L. Lidowski, "A novel communications protocol using geographic routing for swarming UAVs performing a Search Mission", IEEE Int. Conf. on Pervasive Computing and Communications, 2009. PerCom 2009.2009.

[40] I. Kassabalidis, "Swarm intelligence for routing in communication networks", IEEE Global Telecommunications Conference, 2001. GLOBECOM '01. 2001.

[41] T. Lixin et al, "An Improved Particle Swarm Optimization Algorithm for the Hybrid Flowshop Scheduling to Minimize Total Weighted Completion Time in Process Industry ", IEEE Trans. On Control Systems Technology, Vol.18, Issue: 6, 2010.

[42] O.Wei et al, "Flexible flow-shop scheduling approach based on hybrid particle swarm optimization", Chinese Control and Decision Conference, 2008. CCDC 2008, 2008.

[43] I.Escamilla, "Optimization Using Neural Network Modelling and Swarm Intelligence in the Machining of Titanium (Ti 6Al 4V) Alloy", Eighth Mexican Int. Conf. on Artificial Intelligence, 2009. MICAI 2009, 2009.

[44] C.J.R. McCook and J.M.Esposito," Flocking for Heterogeneous Robot Swarms: A Military Convoy Scenario", Thirty-Ninth Southeastern Sym. on System Theory, 2007. SSST '07, 2007.

[45] I.Gonzalez and L. Garrido," Spatial Distribution through Swarm Behaviour on a Military Group in the Starcraft Video Game", 10th Mexican International Conf. on Artificial Intelligence (MICAI), 2011.

[46] C.J. Augeri et al, "Harvest: A Framework and Co-Simulation Environment for Analysing Unmanned Aerial Vehicle Swarms", IEEE Military Communications Conference, 2006. MILCOM 2006, 2006

[47] J.M. Daladier and M.A. Labrador, "A data link layer in support of swarming of autonomous underwater vehicles", OCEANS 2009 - EUROPE, 2009.

[48] Y. Chuan Yan et al, "Optimal location and sizing of energy storage modules for a smart electric ship power system", IEEE Sym. on Computational Intelligence Applications in Smart Grid (CIASG), 2011.

[49] Y. Chuan et al, "Hardware Implementation of an AIS-Based Optimal Excitation Controller for an Electric Ship", IEEE Trans. on Industry Applications, Volume: 47 , Issue: 2, 2011.

[50] E.J Hughes and M.B. Lewis, "A multiple intelligent software agent based technique for improving radar detection of low observable small craft in sea clutter", The IEE Seminar on Signal Processing Solutions for Homeland Security, 2005.

[51] P. Weber et al," Low-cost radar surveillance of inland waterways for homeland security applications", Proc. of Radar Conference, 2004.

[52] D.J. Meggitt et al, "Advanced technologies for undersea surveillance of modern threats",OCEANS '99 MTS/IEEE. Riding the Crest into the 21st Century, 1999 .

[53] B.G. Ferguson et al, "Advances in High-Frequency Active Sonars for Countering Asymmetric Threats in Littoral Waters ", 2006.OCEANS 2006

[54] C.Chartier, "Swarming, Network-Enabled C4ISR, and U.S.Military Transformation", Proc. of Conf. on Swarming: Network Enabled C4ISR, Jan 2003.

[55] G. Albi and L. Pareschi, "Binary interaction algorithms for the simulation of flocking and swarming dynamics", Univ. of Ferrara, Italy, 2012.

[56] M. Agueh et al, "Analysis and simulations of a refined flocking and swarming model of cucker-smale type", AIMscience.org.

[57] C. Yang and D. Simon," A New Particle Swarm Optimization Technique", Electrical and Computer Engineering Department, Cleveland State University.

[58] M.Reyes-Sierra and C.A. Coello Coello, "Multi-Objective Particle Swarm Optimizers: A Survey of the State-of-the-Art", International Journal of Computational Intelligence Research, Vol.2, No.3,2006

[59] K.E. Parsopoulos and M.N. Vrahatis, "Recent approaches to global optimization problems through Particle Swarm Optimization", *Natural Computing* 1, 2002

[60] S.M.Shamsuddin et al, "Particle swarm Optimization: Techniques, System and Challenges", International Journal of Computer Applications, Vol.14, No.1, Jan 2011.

[61] J.Schmidt," Future Combat Systems", Proc. of Conf. on Swarming: Network Enabled C4ISR, Jan 2003.

[62] S. J. A. Edwards, "Swarming and the Future of Warfare", PhD dissertation, Pardee RAND Graduate School, Sept, 2004.

[63] Y.Ben-Horin and B. Schwarz," Army 21 as the U.S. Army's future warfighting concept: a critical review of approach and assumptions", Rand Report, 1988.

[64] W. T. Johnsen, "Force Planning Considerations for Army XXI", Strategic Studies Institute, U.S. Army War College, Feb 1998.

[65] Yves J. Fontaine et al, "Army After Next Project", Strategic Studies Institute, U.S. Army War College,Apr 1998.

[66] John Matsumura et al,"The Army After Next: Exploring New Concepts and Technologies for the Light Battle Force", Rand Report, 1989.

[67] G. Anderson, "Urban warrior and USMC urban operations", Rand Report.

[68] U.S. Army, "Joint Urban Warrior 2009 - Examining A Comprehensive Approach to Conflict Prevention",Wargaming Division, Marine Corps Warfighting Laboratory, 2009.

[69] M.C. Budge, "Detection theory", 2005.

[70] P.L. Herselman and C.J. Baker, "Analysis of calibrated sea clutter and boat reflectivity data at C-band and X-band in south African coastal waters", Council of Scientific and Industrial Research, South Africa.

[71] S. Zaugg, "Automatic identification of bird targets with radar via patterns produced by wing flapping", J.of Royal Soc. Interface, Vol. 5, 2008.

[72] R. Vicen-Bueno, "Sea clutter reduction and target enhancement by neural networks in a marine radar system", Sensors, Vol. 9, 2009.

[73] K. Kiriyakidis, "Detection of Swarming behaviour among Small boats in the harbour traffic environment", US Naval Academy, Annapolis, Sept 2007.

[74] K.Sugawara et al, "Collective motion of multi robot system based on simple dynamics", Human Robot interaction, Itech Education and Publishing, Austria, Sept 2007.

[75] T.B. Schon et al, "The marginalized particle filter in practice", Linkoping University, Sweden.

[76] F.E. Daum, "Beyond Kalman filters: practical design of nonlinear filters", SPIE, Vol.2561.

[77] P.L. Herselman et al, "An analysis of X-band calibrated sea clutter and small boat reflectivity at medium to low grazing angles", Int. J. of Navigation and Observation, Vol. 2008.

[78] www.frf.usace.army.mil.

[79] J.P.Sullivan, "Evaluating the Effectiveness of Waterside Security Alternatives for Force Protection of Navy Ships and Installations Using X3D Graphics and Agent-Based Simulation", Naval Postgraduate School, 2006.

[80] P. Swerling "Probability of detection for fluctuating targets ", US Air force project RAND research memo, Mar 1954.

[81] K. Czaplewski, "Simulation method of range detection of marine navigation radars", Institution of Navigation and Hydrography, Polish Naval Academy.

[82] Report of the effect on radar performance of the proposed cape wind project, US Coast Guard, Dec 2006.

[83] L.O.Harvey, "Detection theory: Sensory and detection processes", Department of Psycology, University of Colorado, Boulder, Spring 2012.

[84] K. Bostrom, "Signal detection theory", March 2006.