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Role of PSO in formation of Underwater Autonomous Vehicles (UAV)

G. R. Khan[1], C. Novara[2], S. Ahmed[3], K. Haseeb[4], A.Ishtiaq[5]

[1]*Higher Education Commission, Regional Center Peshawar, Pakistan.*
[2]*Computing and Control Systems Engineering Department, (DAUIN), Polito, Italy*
[4]*Islamia College University, Peshawar, Pakistan.*
[3,5]*Iqra National University, department of Computer Science, Pakistan.*
[1]grkhan@hec.gov.pk

Abstract-PSO plays an important role in formation control of underwater swarm robots that is based on Assisting Mechanism Theory (AMT) of underwater autonomous vehicles (UAVs) in group surveillance. This article enables formation stabilization of underwater swarm robots, obstacles and collision avoidance in between and outside the group. It is also ensuring locating and detecting intruders with the clearance of communication issue of the decentralized and self-organized behavior of PSO from the beginning time instance. This article is also very helpful in serving as reference model for detecting multiple intruders and also in assisting mechanism theory of multiple UAVs.

Keywords-Control Systems, Underwater Autonomous Vehicles (UAV), Assisting Mechanism Theory, PSO Swarm, Formation Control, Tracking Control, Self-Organized, Decentralized Control, Regulatory Control.

I. INTRODUCTION WITH LITERATURE REVIEW

Intelligent groups are a trait of the system, that is, the behavior of the agents (simple) interacting with their local environment leads to the emergence of a consistent global functional model [i-ii]. The underwater autonomous vehicle (UAV) with sub-merged squeezed, self-regulating and short profile is designed with direct current thrust, assisted by on-board computer to accomplish a mission. UAVs contain sensors with the capability to measure distance from the objects, water temperature, salinity and water pollution. The conceptual labeled diagram of underwater swarm robot is given in Fig. 1.

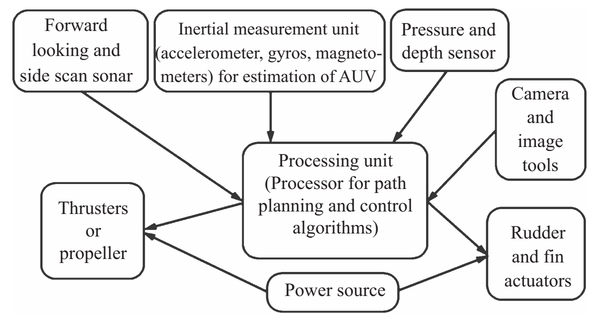

Fig. 1. conceptual diagram of underwater swarm robots

The automation system has been tested in a variety of different situations for monitoring, searching and data mining, with good sensing capabilities, and with positive financial/ commercial results [iii], [i]. For the first time, under one roof, U. T. SEC will bring together manufacturers of unmanned aerial systems and other unmanned vehicles as well as systems for surveillance, communication, data transfer, drone defense and position sensing. The controller controls the position and guides the robot to perform the required rolling, pitching and yaw while maintaining a constant nominal thrust in the body frame[iv]. Secondly, hover regulators for maintaining, achieving the desired 3D-angular position [v-vi]. Thirdly, 3D tracking of the trajectory controlling the center of mass following the specified 3D path, preserving the specified and probably changing the angle of deviation, setting of angular acceleration distribution moving along the plane [vii], [iv],[viii].

To achieve high-speed and well in time operations, unmanned vehicles/ ships/boats are becoming the entire need to be used in naval environment, where operative squads are difficult and very costly to be adopted[ix-x].

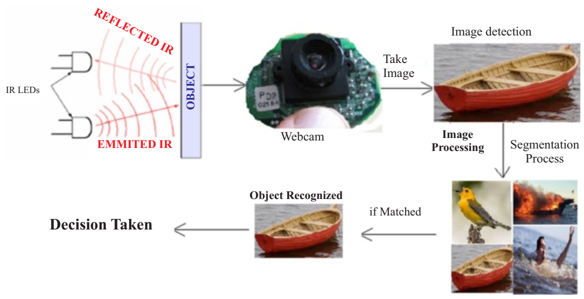

Fig. 2. Intruder detection and recognition scenario

As this paper deals with grouped-automated underwater vehicles (linear continuous system), so use of heuristic and meta-heuristic techniques, such as Ant Colony Optimization, PSO [ix], GA, Simulated Annealing (SA), Modified Cuckoo Search (MCS), ABC and BAT-algorithm in finding optimal-solutions with different scenarios in achieving the target [xi]. In 2013 according to CoCoRo (EU funded) project, Italy for the stoppage of unlawful immigrants, 4.08 Billion budget was spent including 302 boats, 86 Helicopters, 16 Air Planes with 59400 army men [i]. On the other hand, in Spain and in Germany, for aquatic and aerial vehicles, mobile-radars and infrared sensors were introduced to stop unlawful arrivals. On achieving high-speed and well in time operations, unmanned vehicles are becoming the entire need to be used in naval operations, where operative squads are difficult and very costly to be adopted. A pilot and road initiative CPEC project between China and Pakistan, at Gwadar Port has territorial importance and the same research work is of great importance and rendered active promotion. This article describes, the strategy of particle Swarm Optimization (PSO) deployed with unmanned vehicles with the use of PID controllers to assist in various naval environment for numerous tasks. In formation tracking control the swarm robots need to communicate with its neighbors [ix-x]. Swarm robotics are mainly focused on control systems (robots) with high degree of software and hardware complications [xii]. Swarm robotics have been tested in a variety of different circumstances for monitoring, searching and data mining with good sensing capabilities and with positive results financially and commercially [xiii-xv]. Fig. 2 describes, sensing capability of a sensor that how that sensor measures the distance of an object on detection and then take an image to compare it with stored images in the database through segmentation algorithm of clustering for object recognition. Fig. 3 describes the synchronization of minimum three swarm robots that are responsible to locate the exact position of an object as intruder.

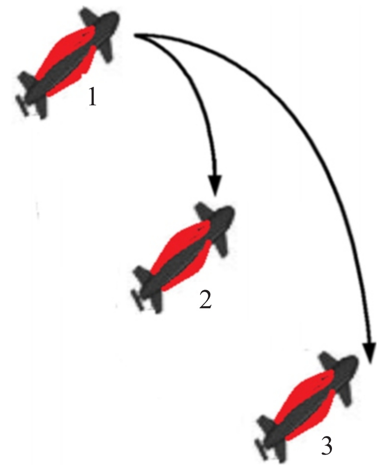

Fig. 3. Synchronization of 3 Swarm robots

The overview of this research activity has of great importance to a major and pilot project of the Belt and Road Initiative at Gwadar Port, of Pakistan, namely China-Pakistan Economic Corridor (CPEC). In swarm robotics, Communication and controlling are the two main challenges along with object detection and recognition [xvi-xvii]. This paper mainly focused on intruder detection and recognition keeping in view the self-organized and decentralized behavior of PSO to control and communicate among swarm robots. On the basis of self-organized and decentralized behavior and with the help of global best of swarm robots is enabled to work as healthier Wireless Sensor heterogeneous Network to resolve the issues of communication and controlling among swarm robots [i], [xviii].

PSO swarm behavior implementation has crucial benefits to naval operations to sense location, ecological system monitoring and patrolling with surveillance [xix]. Life saving and rescue activities is performed with the help of sensor and camera as shown in Fig. 2, because sensors help in detecting objects to calculate the distance from swarm robots by using Arduino controller board in the Robot Operating System (ROS), and with the help of segmentation image processing matching algorithm of clustering the image taken with camera is tally with the stored images and after matching, the exact objects may be detected and recognized with the exact location. After calculating the exact location a life-saving boat will be launched to that position for rescue operation [xix], [iv]. New methods may be introduced to improve the searching performance, navigation and surveillance of swarm robots on sharing energy recharging station that is also a challenging point. The swarm robots used for long range communication behave like an Access Points to connect and communicate with other swarm robots to perform a specified task [xx], [vi]. The entire swarm connected efficiently and inexpensively in heterogeneous system manner to ensure unfailing and quick-communication with other swarm robots.

Though, it is difficult to implement but very impressive and scalable[xxi].

Evolution exists everywhere with the exclusive tests. In this article, we analyze that PSO plays an important role in Formation control of underwater swarm robots based on Assisting Mechanism Theory (AMT). This article enables formation stabilization of underwater swarm robots, obstacles and collision avoidance in between and outside the group. Indeed, implementation of natural behavior and evolution in artificial intelligence is a great challenge. On the basis of swarm optimization and evolution; development of advance swarm robots is an evolutionary step in enhancing the capabilities of ad-hoc and sensor wireless networks. Following four tasks are important in the controlling of swarm water drones,

1. Homing: Collecting swarm of water drones to a way point without any collision.
2. Clustering: Interaction of swarm of water drones with each other in finding and searching in a group.
3. Dispersion: To spread-out in a specified way from each other while still interact to communicate within the communication range.
4. Monitoring: where the drone must cover a pre-defined area to monitor the intruders and to detect them.

Brambilla in [xxi] proposed swarm robotics encouraged by the self-organized and decentralized behavior of meta-heuristic approach. European Union (EU) Funded Projects namely HANCAD and CORATAM, adopted new ways for communication on introducing heterogeneous system to overcome fundamental communication challenges to control swarm water-drones[xxi],[i].

II. Motivation

Meta-heuristics PSO technique is formulated to perform an important role to control the formation of underwater swarm robots on performing collective monitoring/ surveillance based on Assisting Mechanism Theory (AMT). This article makes it possible to form a stable robots with obstacles to avoid collisions between group and outside respectively. As PSO is decentralized and self-organizing behavior makes the swarm robots able to communicate, and also ensuring not only the location and detection of a single intruder but with multi-intruder detection capabilities as well.

III. Materials and Methods

Assisting Mechanism Theory (AMT) of UAVs relates to the study of swarm robots position, route searching and organization within a specified communication range following the self-organized and decentralized behavior of PSO. The availability of high level sensors to locate position and to avoid the obstacles is necessary. The main thing to focus on, is communication aspects of system design, the physical Mac-link address and the networking link-functions. The acoustic channels is effected by long propagations delay of sound signals, disturbance due to noise, Doppler's Spread and Error-Probability of AUV etc.

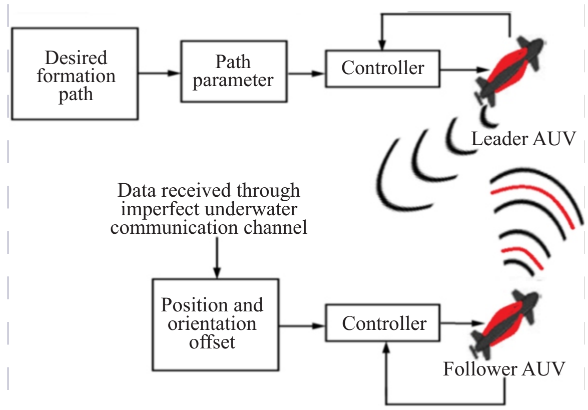

Fig. 4. Signal Control flow for Swarm-communication

In the swarm-robotics, each swarm particle may become team leader with high fitness value while others will follow their team leader shown in Fig. 4. The PSO strategy is fully based on randomness and all the particles are moving in random directions for their relative location and direction with velocity. Once a PSO particle reaches to its desired target it becomes the master particle (decentralized) and the information related to target path of master UAV is known to other swarm particles (UAVs) to follow their master. The factors that affect Assisting Mechanism Theory (AMT) of UAVs:

1. Feasibility of the Assisting Mechanism Theory (AMT) of UAVs strategies .
2. Avoidance of obstacles with the group and outside the PSO group.
3. Observation (vision) communication, when anything comes close in contact.
4. Switching of energy level status among group of UAVs.

Some explanation related to switching of energy level ensuring communication: Assisting Mechanism Theory (AMT) of UAVs helps to give specific shape to maintain formation control of UAVs[xxii]

Each swarm particle (UAV) i.e. 1,2 and 3 behaves like a gateway. They communicate in-between by sending their local best position information to the gateway and receive UAV's local position to compare with the global best to achieve global minima. Indication with arrows is given as under in below Fig. 5 [xxiiii].

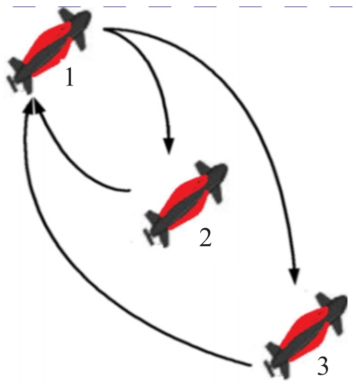

Fig. 5. Coordination to communicate among PSO Particles (AUVs)

In this way, any swarm robot needs to hold reference of their neighbor robot for maintaining communication and also for control formation, and is given in below Fig. 6.[xxiv].

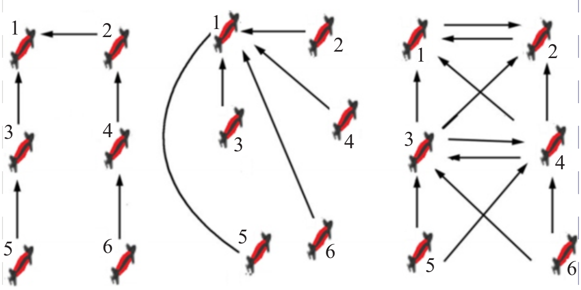

Fig. 6. PSO swarm robot's neighbors Reference formation Control and Coordination for communication

In accordance with the AUVs formation Control, reported various control-laws as given as under:The presentation of implemented cooperative control law for under actuated AUVs and robustness of the same law is discussed with communication delays in[xxv].

IV. Dynamic Model of Swarm Robot (Continuous System)

Dynamic model of a single swarm robot following PSO strategy contains PSO-reference generator, PID controller to control motion dynamics. By taking signals as inputs and thrust generated by the propeller as output. Because of the randomness of PSO, dynamic systems with non-linear and stochastic behavior make the swarm robot very difficult to control along XY coordinates, as shown in Fig. 7.

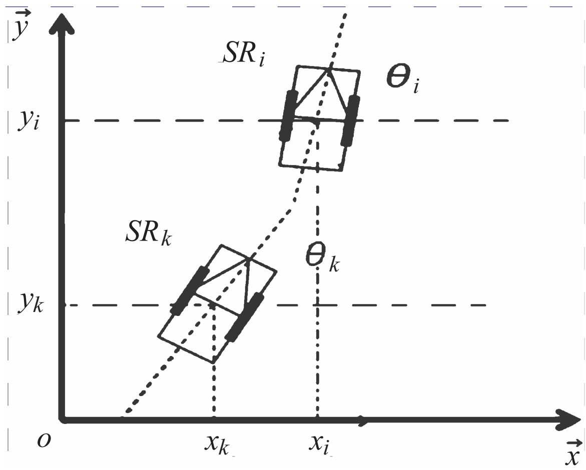

Fig. 7. dynamically driver swarm robot (SR) in 2D Plane

SR_k denotes Swarm robots of index k and i moving along XY plane, where $k = 1, 2, ..., n$, $i = 1, 2, ..., m$
With yaw angle θ_i and θ_k.

A dynamic system describes the time dependence of a point in a geometrical 2D-space (such case). Complete model is given in Fig. 8 below:-

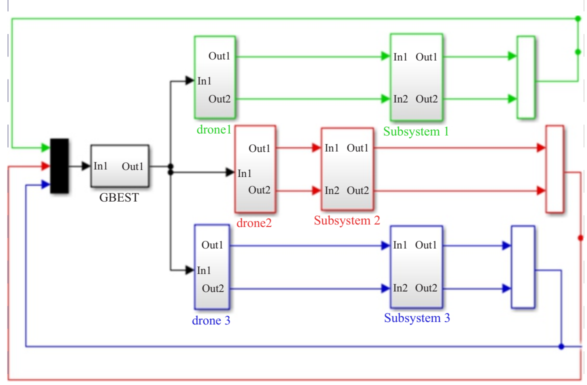

Fig. 8. Complete Multipurpose PSO robots Model

The dynamic state vectors, state variables, inputs, outputs and state equations are as follows:-

$$\dot{x}_1(t) = x_2(t) \tag{1}$$

$$\dot{x}_2(t) = \frac{b}{am} x_2(t) + \frac{\{u_1(t)+u_2(t)\}}{am} \cos \dot{x}_5(t) \tag{2}$$

$$\dot{x}_4(t) = \frac{b}{am} x_4(t) + \frac{\{u_1(t)+u_2(t)\}}{am} \sin x_5(t) \tag{3}$$

$$\dot{x}_5(t) = x_6(t) \tag{4}$$

$$\dot{x}_6(t) = \frac{b}{j} x_6(t) + \frac{1}{j}\{u_2(t) + u_1(t)\} \tag{5}$$

The state variables and state inputs in matrix form are given as under:-

$$x(t)=\begin{bmatrix}T(t)\\ \dot{T}(t)\\ y(t)\\ \dot{y}(t)\\ \omega(t)\\ \dot{\omega}(t)\end{bmatrix},\ u(t)=\begin{bmatrix}F_1\\ F_2\end{bmatrix},\ T1=\begin{bmatrix}T1_1\\ T1_2\end{bmatrix} \qquad (6)$$

In this case we have $T1$[redacted](t) i.e. $\{T(t),\dot{T}(t),y(t),\dot{y}(t),\omega(t),\dot{\omega}(t)\}$ the input $su(t)$. The output $T1_1$ is position of AUV along x-axis while $T1_2$ is the position of AUV along y-axis. Matrix form of the dynamic model is given by:-

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\\ \dot{x}_3\\ \dot{x}_4\\ \dot{x}_5\\ \dot{x}_6\end{bmatrix}=\begin{bmatrix}0&1&0&0&0&0\\ 0&\frac{b}{am}&0&0&0&0\\ 0&0&0&1&0&0\\ 0&0&0&\frac{b}{am}&0&0\\ 0&0&0&0&0&1\\ 0&0&0&0&0&\frac{b}{j}\end{bmatrix}\begin{bmatrix}r(t)\\ \dot{r}(t)\\ y(t)\\ \dot{y}(t)\\ \omega(t)\\ \dot{\omega}(t)\end{bmatrix}\begin{bmatrix}0&0\\ \frac{1}{m}\cos x_5(t)&\frac{1}{m}\cos x_5(t)\\ 0&0\\ \frac{1}{m}\cos x_5(t)&\frac{1}{m}\cos x_5(t)\\ 0&0\\ -\frac{1}{j}&-\frac{1}{j}\end{bmatrix}$$

The output (y) of the dynamic model of autonomous underwater swarm robots has two inputs (u) and 6 variables $x1, x2, x3, x4, x5$, and $x6$. Global best position of swarm robots is totally based on local best position of individual ones. Reference model of Global best Pg is given in Fig. 9 and PID section with dynamic model of a single swarm robot is shown in Fig. 10

$$y=\begin{bmatrix}r_1\\ \omega_2\end{bmatrix}=\begin{bmatrix}\sqrt{x_1^2(t)+x_2^2(t)}\\ \omega\end{bmatrix} \qquad (8)$$

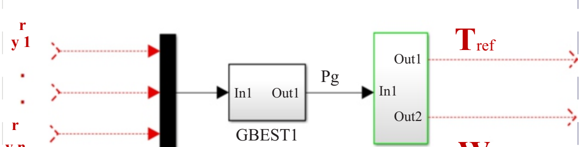

Fig. 9. Global best Pg of PSO reference Model

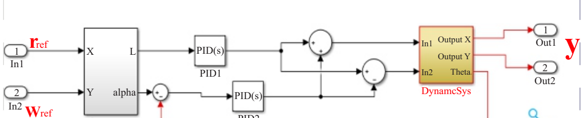

Fig. 10. PID Connection with Reference and Dynamic Model of a Single swarm robot

V. Object Detection and Recognition

During surveillance, sensors are responsible and have the capability to calculate and sense unwanted objects at a certain distance from swarm robots. First of all, radiations moving with certain speed (rate) from sensors hitting the object and bounce back (time/2) to the sensor calculate estimated distance of object from swarm robot minus noise or disturbance. The installed camera is responsible to capture the image of that detected object and after applying the segmentation algorithm of clustering with comparison to stored images decides whether the object is an intruder or otherwise. The direction is calculated on the basis of distance calculation and also through direction finding sensor namely Radio Direction Finder (RDF). Distance calculation equation is give as under:-

$$distance = rate * time \qquad (9)$$

rate is the speed of emitting sensor radiations, and *time* is the pinging time that is the sensor rays to hit object and back. By taking more than one measurements from different angles the location of object may be calculated as mentioned in Fig. 1 above. For the exact calculation of object's location a minimum three measurements is required, it means minimum 3 swarm robots is required for the same.

VI. PSO Reference Model

Swarm robots update its position with the following equation:-

$$x_j^i(t+1)=x_j^i(t)+v_j^i(t+1) \qquad (10)$$

velocity is the pre-requisite to update and locate swarm position on random basis with the following equation:-

$$v_j^i(t+1)=\omega v_j^i(t)+c_1r_1(t)(P_j^i(t)-x_j^i(t))+c_2r_2(t)(Pg_j(t)-x_j^i(t)) \qquad (11)$$

$x_j^i(t)$ is the current location of PSO i^{th} particle at time t, $x_j^i(t+1)$ represents the new position of the particle i in dimension j at time t.

$v_j^i(t)$ represents the current velocity of i^{th} particle with dimension j where $j = 1,2,..., n$ at time t where, i represents the index position of particle as $\{i = 1,2,3,..., n\}$, and n represents the number of swarm particles. $\{j = 1,2,3,..., m\}$, where m represents the dimensions of the problem.

ω:represents the weight of inertial value of {0,1}.

c_1, c_2:represent constants c_1 is cognitive component and c_2 is social component) also called acceleration coefficients.

r_1, r_2:represent random values in the range (0,1) are taken from regular distribution, and these values add random to the algorithm.

P^i_j (*t*), represent the local best position of each swarm particle *i* in time *t*,

Pg_j (*t*) represent the global best position of whole swarm in time *t*. Finally, each swarm particle is updating its position following the objective function criteria in the following manner, so that:-

$$P^i_j(t+1) = P^i_j(t)\ if\ f[x^i_j(t+1)] \geq f[P^i_j(t)] \quad (12)$$

$$x^i_j(t+1)\ \ if\ f[x^i_j(t+1) < f[P^i_j(t)]$$

Comparison of P^i_j *and* Pg_j

n:represents the number of elements in swarm. Discrete Time PSO Equations in matrix form,

$$x = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix},\ v = \begin{bmatrix} v_1 \\ v_2 \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} x^i_j(t+1) \\ v^i_j(t+1) \end{bmatrix} = \begin{bmatrix} 1 - c_1r_1 - c_2r_2 & \omega \\ 1 - c_1r_1 - c_2r_2 & \omega \end{bmatrix} \begin{bmatrix} x^i_j(t) \\ v^i_j(t) \end{bmatrix} + \begin{bmatrix} c_1r_1 & c_2r_2 \\ c_1r_1 & c_2r_2 \end{bmatrix} \begin{bmatrix} P^i_j & Pg_j \end{bmatrix} \quad (14)$$

$$r_{ref} = \sqrt{s_1(t)^2 + s_2(t)^2} \quad (15)$$

$$\omega_{ref} = \arctan\left(\frac{s_1(t)}{s_2(t)}\right) \quad (16)$$

Update Rule of PSO algorithm is given in below Algorithm I.

Algorithm 1: Initialize Population parameters
Result: Update Rule
Initialization:
While NOT True Termination criterion {
For i = 1 to population size
Calculate particle velocity according to (13)
Update particle position according to (12)

$\boldsymbol{if}\ f(x_i < f(P^i_j)$**then**
$P^i_j = x_i$
else
for P^i_j<$f(Pg)$;
$Pg = P^i_j$;
end
end

VII. PID Controller

PID controllers are widely used as part of the process control framework. PID controller adjustment is very important for optimal control [xxvi]. PID is the simplest controllers of all, in the sense that it has a 3 parameter set for tuning and to get optimal solution. The PID equation has given in (10) and block diagram of PSO with the connection of PID controller is given in Fig. 10, the estimated error say $e(i) = y_2(i) - y_1(i)$.

Initially, $y_2(i)$ is zero, $x_1(i)$ represents the Integrative State *I* of PID is $x_I = x_I(i) + e(i)$ Consider the transfer function of PID controller:-

$$u_i = k_I T_c x_I(i) + k_P\, e(i) - \frac{k_D}{T_c} x_2(i) \quad (17)$$

u_i is performed by setting the *I* (integral) i.e. k_I and *D* (derivative) i.e. k_D gains to zero.
k_P is proportional gain.

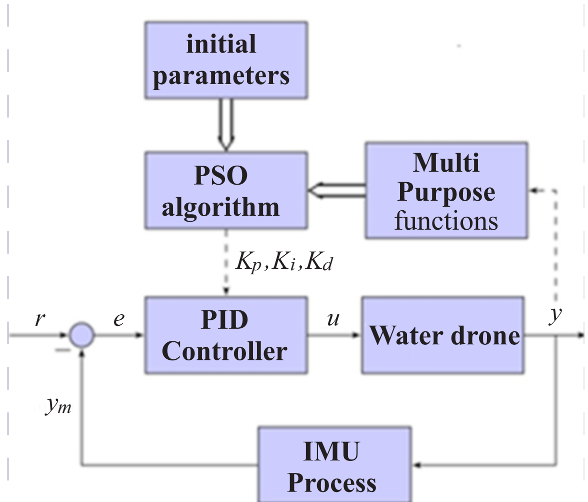

Fig. 11. Block diagram of PSO with the use of PID Controller

The sensor system consists of several motion sensors, which together form Inertial Measurement Unit (IMU) shown in Fig.11.

The controller parameters k_P, k_I, k_D, are chosen to satisfy prescribed criteria regarding the settling times T_s and the rise time T_r the overshot and the steady state error. In [xxvi] the effect of λwas analyzed to tuned the controller with the help of Integrated Model Control (IMC) and PSO. In that case PSO was found better and was more robust than other techniques on the basis of disturbance rejection as well. Table 4 shows improved PID gain on the basis of thrust produced in the propellers.

VIII. Results and Discussion

Allowing greater area to be searched, the swarm robots run on the solar-plate and wind-power with the help of two actuators following PSO methodology around its local best position. Thrust calculated for each ideal motor rpm from Momentum Theory Calculation on the basis of motor specification is given in Table I. The ideal motor speed in terms of rpm is 1/4 of its maximum speed.

TABLE I
IDEAL MOTOR RPM FROM MOMENTUM THEORY CALCULATIONS

Ideal Thrust (mass Kg)	Propeller	Diameter (m)	PC	PF	Ideal RPM
0.20225	6x4	0.1524	0.015	3.2	8324
	7x5	0.1778	0.042	3.2	5750
Air Density [Kg/m^2]	8x4	0.2032	0.06	3.2	4934
1.225	8x6	0.2032	0.106	3.2	4130
	8x8	0.2032	0.148	3.2	3721
Gravity [m/s^2]	9x4.5	0.2286	0.09	3.2	4189
	9x6	0.2286	0.129	3.2	3744
	9x7.5	0.2286	0.352	2.9	3036
	9x9	0.2286	0.448	2.9	2794
	10x5	0.254	0.144	3.2	3500
	10x7	0.254	0.223	3.2	3053
	10x10	0.254	0.68	2.9	2333
	11x5.5	0.2794	0.222	3.2	2967
	11x7	0.2794	0.301	3.2	2698
	11x8	0.2794	0.357	3.2	2558
	11x8.5	0.2794	0.383	3.2	2502
	11x10	0.2794	0.589	3.2	2188

For static thrust calculation, as estimated weight of swarm robot (boat) with DC motor and propellers is determined. The ideal speed of each motor in terms of rpm is given in Table II.

TABLE II
IDEAL MOTOR RPM FROM MOTOR SPECIFICATION

Motor	KV (rpm/v)	Max rpm	Ideal rpm
2822/14 Brushless 1450 Kv	1450	16095	4024
TURNIGY 2204-14T 19g out-runner	1450	16095	4024
TURNIGY 1811 Brushless Indoor motor 1500 Kv	1500	16095	4163
TURNIGY 2730 Brushless motor 1500 Kv	1500	16095	4163
Hobby King donkey ST2004-1550 KV Brushless Motor	1550	17205	4301
AP19 Brushless Motor	1580	17538	4385
C2024 Micro Brushless Out-runner 1600Kv (17g)	1600	17760	4440

To determine the ideal propeller speed in terms of rpm following equation is important,

$$rpm_{ideal} = \left(\frac{2}{\pi}\right)^{\frac{1}{2\omega}} \left(\frac{g^{\frac{3}{2}} m^{\frac{3}{2}}}{\alpha D \sqrt{\rho}}\right)^{1/\omega} \qquad (18)$$

D is diameter
ω is Power factor
α is Power coefficient
ρ is water-surface air density
m is mass and *g* is center of gravity.

Such activity of swarm robots leads towards reliability, energy power saver, fuel consumption with simple structure. On-board sensors are responsible to detect the objects and the android cameras and wifi are responsible for object recognition and communication among swarm robots respectively. In Fig. 2,complete intruder detection and recognition by using segmentation algorithm of clustering has been shown to match the captured image with the stored images in the database to differentiate between swarm-robots and intruder. Fig. 12 shows the surveillance of 5 swarm robots navigate 24 hours at Gwadar port to locate the exact object's location.

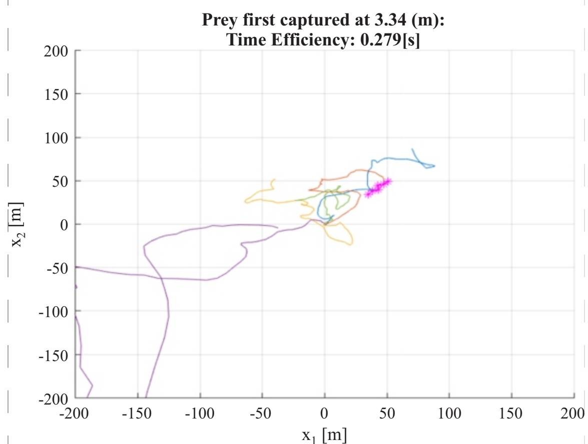

Fig. 12. Surveillance and Navigation of PSO

After locating the drowning object in the sea, a rescue boat may be brought for surveillance following the shortest Path Planned strategy to the exact location for rescue purposes shown in Fig.13.

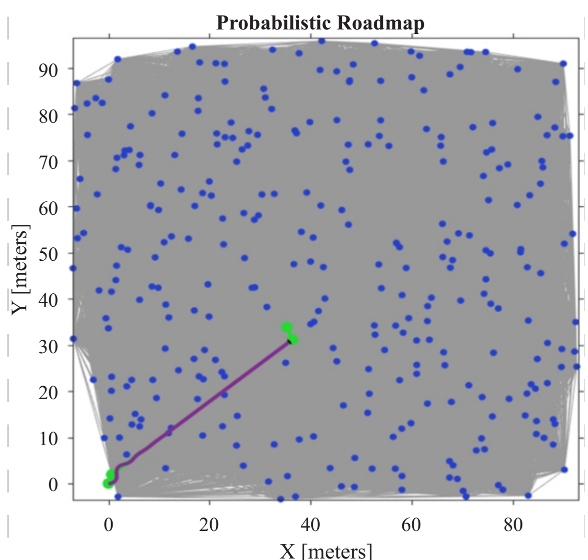

Fig. 13. rescue boat navigation after detecting the drowning object in sea

On the basis of performance, swarm robot runs on the solar and wind power instead of any fossil fuel. The fabrication and installation of this solar boat is very simple and reliable. Fuel consumption, capacity, complexity and reliability of solar energy driven boat is an innovative invention. Performance graph of PSO with comparison of Genetic Algorithm (GA) is given in Fig. 14, which shows the performance of PSO found better than GA on the basis of dynamic model of PSO with thrust produces in the propellers. The boat will be conducted by the energy processed from solar by minimizing environmental pollution and fuel cost.

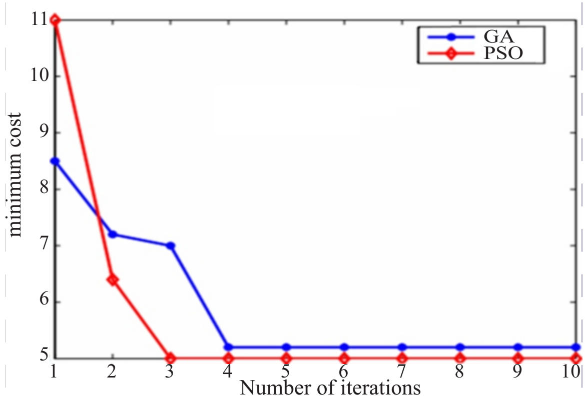

Fig. 14. Performance Comparison of minimum Cost graph of PSO with Genetic Algorithm (GA)

Proposed PSO control parameters for swarm robots velocity and position are given in Table III below:-

TABLE III
PSO CONTROL PARAMETERS DECLARATION

N = 5	Number of swarm robots
Ns = 100	Number of iterations
Ts = 1	Sample time
ω = 0.9	PSO inertia factor
C1 = 0.1, C2 = 0.14	Learning factors of PSO
Pg = 1e*ones(1,Ns);	Global best fitness initialization
Dimension = 2	XY coordinates

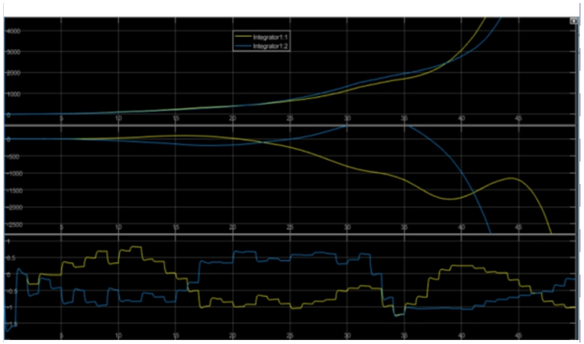

Fig. 15. PSO swarm robots position with Time Axis labels along XY Plane

Above Fig. 15 shows the simulation of a single drone velocity along XY axis with its angular acceleration while figure 16shows the plot signals as magnitude and phase of PSO speed and Fig. 17 shows the random movement of an intruder that crossing the limits and entering into the no-zone area.

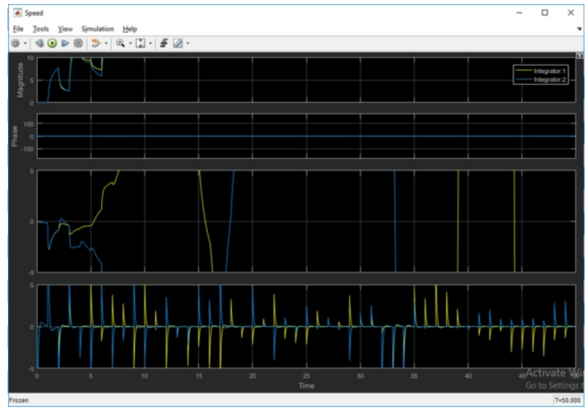

Fig. 16. Plot signals as magnitude and phase of PSO

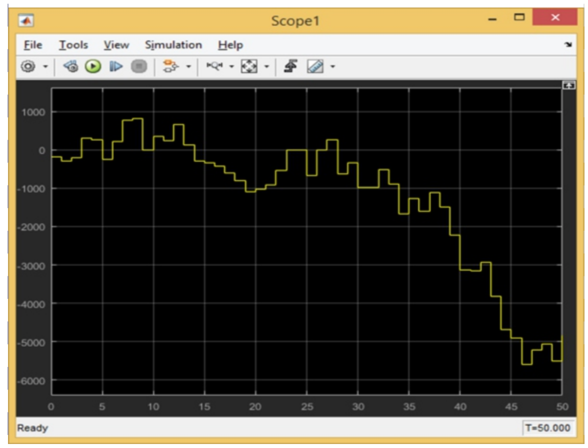

Fig. 17. Plot signals as magnitude and phase of PSO

Fig. 18 shows the surveillance of 5 swarm robots that are busy in searching for an intruder and finally detects indicating their position, iteration and Time efficiency details, even and if the intruder touches the sensing range of a swarm robot.

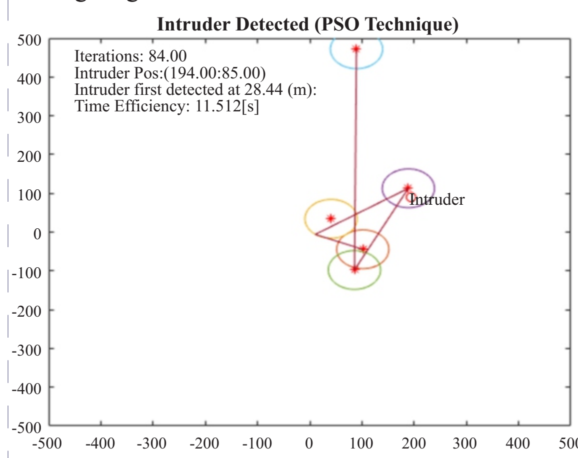

Fig. 18. Surveillance of 5 swarm robots with Intruder detection capability

Monte Carlo Simulations are done for modeling, the probability and totally random outcomes generated in the process is very tough-job to predict by the interference of PSO random variables i.e. $v_j^i(t+1)$, $x_j^i(t+1)$, $P_j^i(t+1)$, $Pg_j(t)$. The best solutions, mean and standard deviations obtained in 15 independent runs are given in the Fig.19. The outputs of PSO are compared with the results obtained by using Modified Cuckoo Search, BAT and ABC. It is observed from the results that PSO has produced better results than other compared algorithms with the exception that MCS has lowered STD Deviation value than PSO.

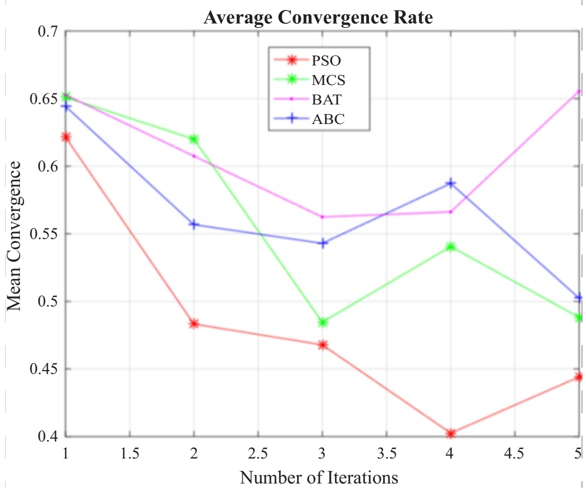

Fig. 19. Average time taken PSO graph with respect to other meta-heuristics

PID controller works on the error between the target output of the System and the desired output of the System. According to Ziegler Nichols equation,PID Controllers parameters measure Kp, Ki and Kd and is given below in Table 4, while Table 5 contains the XY and yaw values with the improved cost function values of PSO PID parameters.

TABLE IV
PID VARIABLES SHOWING IMPROVED TUNING

Symbol	Value	PID parameters	Value	Improved percent
K_1	0.26	33.004	K_P	12.37
K_2	0.122	29.947	K_I	8.70
K_3	0.501	7.776	K_D	12.10
Filter coefficient	10	1820.881		

TABLE V
PID VARIABLES

PSO PID Param	Xvalue	Yvalue	Yaw Value
K_P	41.26	41.26	25.09
K_I	38.122	38.122	45
K_D	15.005	15.005	5.42e-04
Time	0.501	7.776	KD
Improved Cost Function	0.20	0.20	0.30

PID controllers are designed in connection with embedding different meta-heuristic approaches. After introducing noise to the system, PID controller containing PSO approach is found with better performance than standard PID and others as shown in Fig. 20.

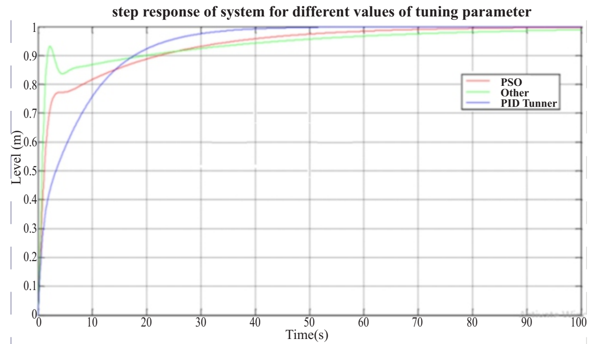

Fig. 20. PID controller works on the error between the target output of the system and the desired output of the system

By using Frequency Response (FRtool) and PID tuner of Matlab R2016a, Fig. 21 shows altitude, X and Y position and torque control step response with respect to proposed PSO.

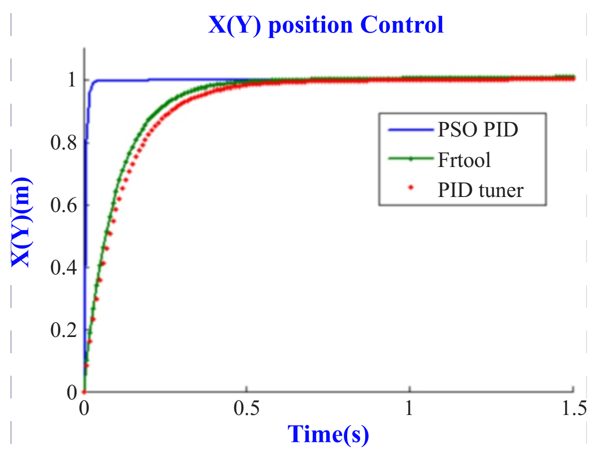

Fig. 21. step response of PSO by using Frequency Response (FRtool) and PID tuner

IX. CONCLUSIONS

On the basis of decentralized and self-organized behavior, swarm robots have the capability for an optimal solution to detect an intruder in the search space during surveillance. On the basis of target position, fitness function for each particle in swarm is calculated. After consecutive iterations of PSO algorithm, global best position of PSO particles is selected on the basis of particle's local best position and robot moves to its new calculated position to search the optimal target position. In real world scenario and in known-environment each and every swarm-robot is equipped with a limited sensing radius (vision circle) around it to sense an intruder whenever interacts with the vision circle. We analyzed all the functionalities in PSO swarm robots with the comparison of other meta-heuristic algorithms on the basis of convergence in Fig. 19, thrust production and tracking errors in Fig. 20 with the help of PID controllers and found the particle swarm optimization approach more convenient and target oriented to solve the optimization problem more accurately and efficiently.

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