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A novel algorithm for integrated control model using swarm robots for intruder detection and rescue schedules

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Abstract

Due to the development of computer controlled tools and expansion of integrated computing applications, more and more controller functions are turning to software implementations. A novel controlling algorithm is designed for continuous optimization tasks. However, they are used to thoroughly optimize and apply different areas. The most intelligent swarm algorithms have been designed for continuous optimization problems. However, they have been applied to discreet optimization and applications in different areas. This article gives experimental results on the control of swarm robots with the help of integrated control model (ICM), around its own axis. Such methodology is quite impressive in development of applications for surveillance, path planning, intruder and obstacle detection, model errors in communication to remove uncertainty. The ICM control design performance is based on comprehensive swarm robot model for the identification of actuators from testing data. The same ICM controllers are designed to be compared with the PID controllers in a variety of tests and collected feedback found 12.37%, 8.69% and 12.09% improved on the basis of thrust produced in the propellers for surveillance.

Keywords Swarm robots · Actuator · Controlling · Path planning · ICM

1 Introduction

Swarm knowledge is the property of a framework whereby the accumulation conduct of (unsophisticated) specialists cooperating locally with their condition causes lucid practical worldwide examples to rise [1, 2].

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Investment has been made and waterborne robots have been studied to facilitate research control and development of driverless/hydroplanes to work in a naval environment in real-world conditions [3, 4]. They focus on automated control systems (robots) with a high degree of software and hardware complexity [5, 6]. Automated systems have been tested in a variety of different circumstances for monitoring, searching and data mining with good sensing capabilities and with positive results/outcomes financially and commercially as given in [7]. The circumstances where such automated systems have been tested are Environmental updating and monitoring [8], Control systems boats [9], Archeology [10], Searching and Rescue operation robot, defense and geological [11] etc.

Robots are being continuously applied to different fields such as industrial and space projects with the capability to move and navigate in interior areas containing fixed and floating obstacles [12]. To attain decentralized, distributed and self-organized sensing capability swarm robots have been designed and controlled with the swarm techniques/behavior for the surveillance and navigation freely [1, 13, 14]. This paper is divided into different sections, Sect. 1 contains an introduction, Sect. 2 is relating work to the proposed research. Similarly, Sect. 3 contains proposed ICM, area 4 is about exploratory outcomes, while segment 5 is conclusions

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and about future work, segment 6 is an affirmation and segment 7 contains irreconcilable situation explanation and segment 8 are every one of the References referred to.

2 Related work

The present article is mainly focused on controlling of swarm robots work presented in the Project mentioned in [15, 16]. The aim of such project is to match and check the controlling performance, using swarm robots, surveillance, navigation, guidance, control communication and other strategies to be employed in naval defense system applications. Meta-heuristic swarm Optimization control algorithms play an important role in such type of developed applications [4]. Swarm robots were built and were a part of the project as a real world application with the introductory studies and simulations that were also carried out [17, 18]. Improvement of a solitary swarm robot actuator and distinguishing proof of model for control procedure was created by the blend of an established Hammerstein-Wiener structure [19, 20] with the LTI framework.

The meta-heuristic PSO algorithm is used in conjunction with the least-squares moving (MLS) in [21]. The PSO method is used to set parameters in the MLS method, which significantly affects the accuracy of the fit. However, its use in controlling the movement of wheeled mobile robots has not been extensively studied. The PSO-MLS method is used to simulate the movement control of a wheeled mobile robot [3, 22]. This method is based on the method of local approximation. The main advantage of this method is that the PSO method and the MLS method are used for local approximation of parameter optimization. Compared with the traditional least-squares (LS) method, the PSO-MLS technique is utilized to control the development of wheeled portable robots [23].

In order to control swarm robots with the PSO techniques to detect an object and to search for it, the swarm particle search target signal must be detected and the suitability of the turbulence caused by the inherent parallel processing performance of the spatial interweaving of the robot in the search medium is evaluated [24].

The platform of unmanned water swarm robots is getting significant importance in naval defense system and for war, on reducing human life risks in achieving important tasks [21, 25]. The same unmanned vehicles are responsible to detect motion of floating objects on the sea level or under the water with the help of sensors for combat and rescue operations in the form of fire control [1, 25, 26]. With the help of swarm robots, the possibility to identify the position and other properties related to the objects around in the group is ensured to know about the locality [27, 28]. The basic method used in [27] depends on the development of three controllers and the composition of an autonomous unmanned vehicle controller. Using technologies that identify offline systems and online parameter identification technologies [10, 29], every controller is consequently acclimated to acquire the coveted execution. The objectives of the controllers were, (I) position control drives the robot to the coveted move, pitch and yaw while keeping up a consistent ostensible push in the body outline. (ii) drift/hover controller to accomplish and keep up the required three-dimensional position and edge of revolution. (iii) three-dimensional tracking of the trajectory that controls the center of mass to follow the specified 3D path, preserving the specified, potentially changing the yaw edge along the route, setting the speed (and acceleration) profile along the path [21, 27, 30].

In addition, the difference in sampling frequency and communication delay of the sensor makes the asynchronous control of this group system practical. Therefore, in the case of target search, two kinds of asynchronous update principles are proposed, namely, loop-based and location-based evolutionary control strategies. In addition, it proposes to put forward the concept of time-varying so that the decision-making is at its best. Every autonomous-robot distinguishes the flag in fine-grained parallelism and contrasts the flag combination and the best flag in its populace attributes. Then update the speed and position of individual robots immediately. However, the general information in role roles is only updated asynchronously under different management principles. Simulation results show that the strategy based on the communication cycle has advantages over the position control strategy based on the evolution of search efficiency [31]. In systems consisting of several autonomous mobile robots that exhibit joint behavior, more and more are interested in research. Create mobile robot groups to explore issues such as building groups, resource conflicts and the origin of cooperation, learning and geometry issues.

To-date, there have been few applications of joint robots, and support theory is still in the development stage. Carry out a critical review of existing works and discuss open questions that emphasize the various theoretical problems that arise in the joint research of robots. They describe and guide early research and complements existing motives [31, 32]. By solving the synthesis of controllers for a group of robots, a desired two-dimensional geometric pattern is created, defined by a locally closed, simple closed flat curve to avoid collisions or to maintain specified relative distance limitations [3]. Controllers are decentralized because robots do not need to exchange or know information about each other's status. Instead, assuming that robots have sensors, they are allowed to receive information about the relative locations of neighbors within a certain range. The main method for determining the stability and convergence of some simple controller is a closed curve. Simulations were made to display the approach and methods with the display of the desired curves [33].

Many well balanced structures created by social insects are a result of self-organized behavior and may be changed with respect to time by changing the physical environment to its final state [32, 34]. One of the main factors of mediation is stigmergy, which causes specific changes in the behavior of the environment through the tangible impacts of nearby natural changes from past activities. A run of the mill assignment identified with the self-association of stigmergic is the conceptive arranging: numerous ants characterize their species keeping in mind the end goal to bunch objects at a similar improvement stage and separate them from objects at various phases of advancement.

The said work talked about crafted by stigmergy and self-association in a gathering of comparable physical robots including the assignment of bunching and arranging two unique sorts of flying plates. Using a set of rules of behavior is simpler than any classification algorithm proposed, and without spatial orientation or memory, the robot can accomplish effective bunching and arrange, hinting at all the self-association [21, 34]. It was contended that the achievement of this show basically relies upon the advancement of genuine material science. Utilizing just reenactments to think about stigmergy can't uncover its capacity as a developmental decision for aggregate living things.

One of the most serious issues for robots is the making of machines that can connect with circumstances continuously and capricious. One conceivable arrangement might be the utilization of a gathering of robots that work in a self-sorting out the way like crafted by settlements of ants. The viable detachment of the working system, particularly the connection of parallel activities and the exchange of data between colleagues, is a key segment of the immense ecological achievement of ants. The general rules that oversee the division of subterranean insect settlements permit the making of adaptable, solid and productive mechanical frameworks. Robots that utilization against heuristic calculations with decentralized control work more effectively than one robot, and keep up a larger amount of vitality for the populace. In any case, the advantages of gathering life are lessened in huge gatherings, in all likelihood because of inconsistencies amid sustaining. Curiously, a comparable connection between populace size and proficiency was recorded in social creepy crawlies. What's more, when nourishment is gathered, robots can select different robots in a subterranean insect way more proficiently than bunches without data, proposing that gatherings of dynamic robots can take after principles like those overseeing social bugs [27, 33–35].

In [31] extended PSO methodology has used in order to control the swarm robots for target search in the search environment. Due to the parallelism of the spatial dispersion of the robots detection combine the target signals for proper evaluation. The technique was great yet the parameters utilized were some way or another different from the others, as it was not identified with the physical idea of the issue. On the other hand, deals with the cooperative surveillance of swarm robots that was an excellent approach but due to the collision and deadlocks occurred in the proposed model was not so successful. In this paper, as PSO is self-organized and decentralized approach with the ICM approach removes the uncertainty factor in communication, intruder detection, castaway ship detection, surveillance and rescue operations in the search space that is a big flaw in [20, 21].

For controlling, motion trajectories and navigation with obstacle avoidance implemented PSO algorithm in [26], and ono finding trajectories, caring safety measures by keeping safe distance among the swarm robots to avoid collision and geo- fencing. The experiments validated with Parrot Bebop swarm robots [36].

3 Proposed ICM

Similarly, the group robot algorithm on one axis depth control was developed on the basis of the integrated control model (ICM) with the help of previous group robotic drives. The ICM includes advanced observers and control laws for measuring state values and providing active interference cancellation [1]. Based on these capabilities, ICM is very effective in eliminating interference, modeling errors and uncertainty in the presence of nonlinearities [6, 17]. The standard PID controller is compared with the current ICM controller test results. From the discussion above, it is established that the performance of ICM as a group robot is much better than that of conventional and standard PID controller methods in terms of accuracy and precision. Affected by nonlinearity and uncertainty [4, 18, 19].

On the basis of the above primary studies and activities following are the contributions with the proposed solution of the author with the description.

3.1 Development of a single swarm robot actuator model and identification of model for control strategy

Figure 1 shows the swarm robot actuator model consists of main elements i.e. 3-elements and composed of a dynamic speed controller (DSC), a motor and propeller.

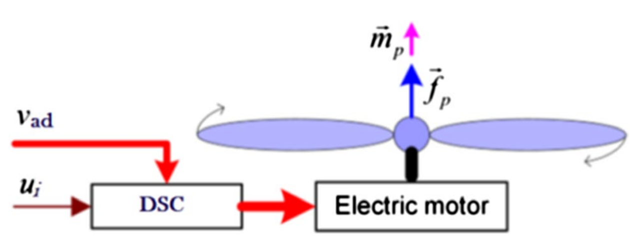

Fig. 1 Swarm robot actuator main components

The required mathematical form of actuator model is given below in Eq. (1):

$$\begin{aligned} z(t) &= g(u(t)) + K_v\left(v_{barmax} - v_{ad}(t)\right) \\ \dot{\omega}_p(t) &= -p\omega_p(t) + pz(t) \\ f_p(t) &= f(\omega_p(t)) \end{aligned} \tag{1}$$

f_p is the system output with respect to u_i and an additional input v_{ad}, z represents the signal intermingling LTI and Non-linear system blocks. ω_p is the thrust producer angular rate. Functions g() and f() represent LTI non-linear blocks. v_{barmax} indicates maximum battery charge status with the battery voltage K_v.

The spinning of propellers transferring a sum of vibrational energy converting later on into mechanical energy to water, generating a thrust and torque to push forward the swarm robot and the third center-propeller is responsible to bring the swarm robot up and down. The DSC controls the engine rakish increasing speed as per dynamic model containing precise rate reference. The actuator is essentially a dynamic framework with precise speeding up reference as Input and push created by propellers as Output. Due to randomize nature of PSO, such a dynamic system with non-linear and random behavior makes the control of swarm robots very challenging.

3.2 Development of swarm robot algorithm for movement control, based on ICM

According to ICM, as swarm robot contains two actuators with three propellers, used two propellers to move the swarm robot in a forward direction supported by dynamic model and other to bring the swarm robot to up and down in the water. Actuators rotating freely (torque generating) around one axis, letter 'd' denotes the gap between two propellers; 'J' represents rotation inertia. Simulation software 3D CAD/Matlab R2016a was used to extract the values of parameters as shown in the Table 1 below. Following is the swarm robot state equation:

$$\begin{aligned} \dot{\omega}_p(t) &= \frac{d}{J}\left(f_{p2}(t) - f_{p1}(t)\right). \\ \dot{\theta}(t) &= \omega_b \\ y(t) &= \dot{\theta}(t). \end{aligned} \tag{2}$$

From above state equation, f_{p1} and f_{p2} are input forces generating the thrust with the help of two actuators respectively. $\dot{\theta}(t)$ represent angular position while $\dot{\omega}_b(t)$ denotes angular acceleration with respect to time. f_p is the total thrust generated as the output of the actuator.

$$f_p = f_{p1} + f_{p2} \tag{3}$$

Table 1 Actuator model parameters [16]

Parameter	Symbol	Value
Actuator pole	p	16 rad/s
Discrete pole	β	0.27 rad
Inertia	J	0.032 Kg m^2
Arm length	d	0.25 m
Battery const.	K_v	40 rad/Vs
Control time unit	T_c	0.02 s
Maximum Battery volt.	v_{batmax}	12.6 v
Propeller coefficient 0	c_p1	0.0197 Ns/rad
Propeller coefficient 1	c_p0	-6.0771 N

3.3 Interconnection of multi swarm robots to communicate accordingly

According to the Particle swarm optimization (PSO) algorithm used as reference discrete model as shown in Fig. 2 with the connection of continuous dynamic model, 3 drones are connected in such a way that communication is established through global best value coming from each PSO swarm robots used as Reference generator.

3.4 Experimentation and simulation test results carried out

Swarm robot consists of two actuators comprising of dynamic speed controller (DSC), a motor and propeller as shown in Fig. 2, generates the thrust allow to push the swarm robot to navigate in continuous fission. The motor helps in propeller's rotation creating the thrust and torque which support the swarm robot to navigate freely in the water. Similarly, an algorithm for the swarm robots on single axial depth control, based on ICM with the help of the previous swarm robot actuator has been developed. ICM involves extended observer and a control law, used for measuring of state values and performing of active disturbance rejection respectively. On the basis of these mentioned capabilities, ICM is very efficient to remove the uncertainty in situations where relevant disturbances, modeling errors and non-linearity are there [5, 37]. Standard PID controller was compared with the present ICM controller test results, and it was found from the above discussion, that performance of ICM is far better than that of normal and standard PID controller methods in terms of accuracy and precision with disturbance rejection as swarm robot is affected by non-linearity and uncertainty [17, 29, 38]. PSO flow chart is given in given in Fig. 3 below.

The main functionality of DSC is to control the angular acceleration rate of the motor according to digital input reference. u is the input. v_{ad} also an input but an additional to

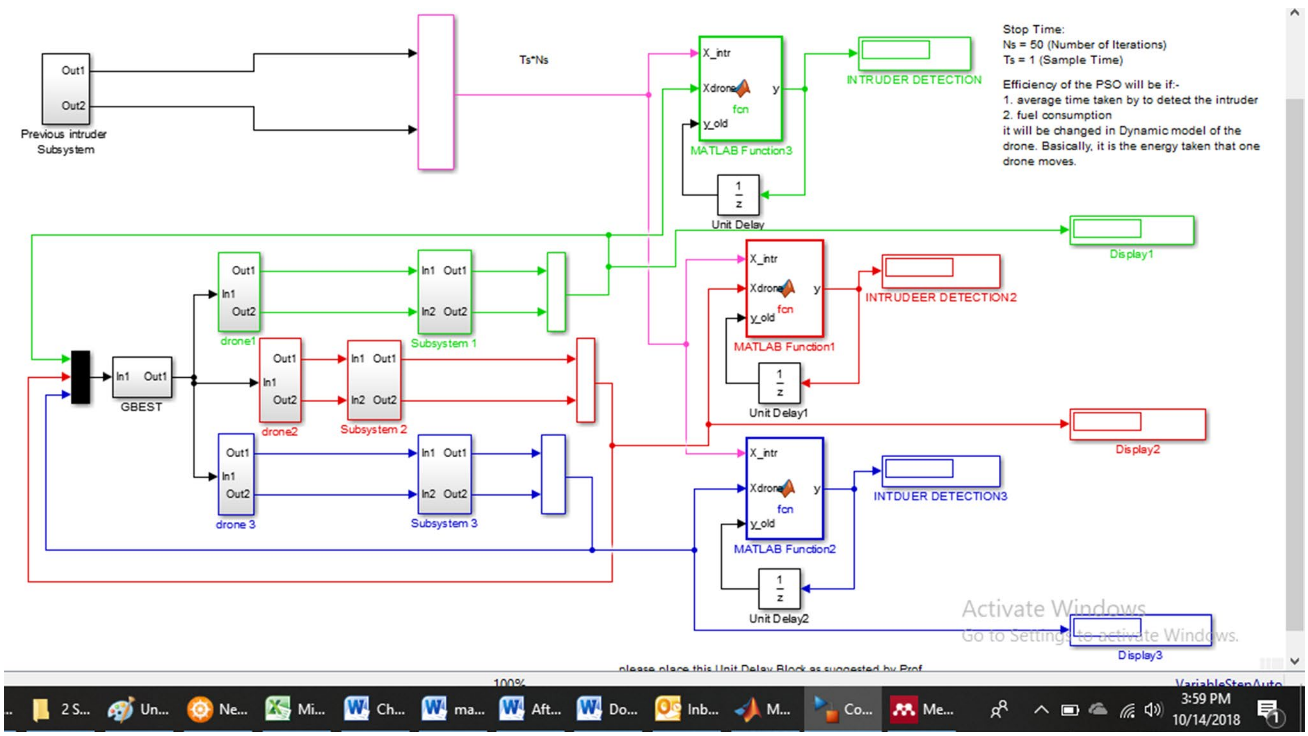

Fig. 2 A complete model of the multi-Swarm robot

check the battery effect. Following are the two actuator state equations with the thrust function:

$$\begin{aligned} z(t) &= g(u(t)) + k_v(v_{bmax} - v_{ad}(t)) \\ \dot{\omega}_p(t) &= -p\omega(t) + pz(t) \\ f_p(t) &= f(\omega_p(t)) \end{aligned} \tag{4}$$

From above equations, z(t) represent signal rate with respect to time (t). kv is the DC voltage. v_{ad} is the DC voltage is given as input, while v_{batmax} is the total DC voltage to produce thrust. ω_p is the thrust producer angular rate. $f_p(t)$ is the thrust with respect to time of the propellers.u(t) is the input with respect to time i.e. angular reference generator. $p\omega(t)$ represent angular acceleration with respect to time (t) and end-pole p.

4 Simulation results

First state equation represents LTI static non-linear, 2nd equation is dynamic LTI system and the 3rd one is again static non-linear. All above the three equations represent blocks in actuator model. z represents signal rate among the blocks. Functions g(.) and f(.) are non-linear proved and confirmed in [30], The model was approved utilizing as order input an arrangement of inclines with the pitch not quite the same as that used to produce the recognizable proof information. The approval results are delineated in Fig. 4.

The battery discharging capacity in Fig. 5, charge time and v_{batmax} is calculated from the manufacturer battery manual and is given as under in below Table 1:

For a balanced actuator, calculated the function (.), kV and p (actuator end-pole) from the input u, v_{ad} (DC voltage) and ω_p (angular acceleration) for the calculation to measure the value of z, consider the following equation:

$$\omega_{\underset{n\to\infty}{p\,(t)}} = g(\bar{u}) + k_v\left(v_{batmax} - v_{ad}(t)\right) \tag{5}$$

The sampling time during the collection of steady state condition was kept Ts = 0.025 s. v_{ad} is an extra input ω_p is the thrust producer angular rate. From the above equation $\omega_p(t) = z$ (t), the equation is given as under:

$$\omega_p(\mathcal{K}T_s) = g(\bar{u}) + \mathcal{K}_v(v_{bmax} - v_{ad}(\mathcal{K}T_s) + e(\mathcal{K}) \tag{6}$$

From above eq. $e(\mathcal{K})$ represent noise amount as distortion. Defining, $\Delta\omega_p(\mathcal{K}) = \omega_p(\mathcal{K}Ts) - \omega_p(Ts)$, $\Delta v_p(\mathcal{K}s) = v_b(\mathcal{K}Ts) - v_b(Ts)$, $\Delta e(\mathcal{K}) = e(\mathcal{K}) - e(1)$, we get as follows,

$$\begin{aligned} \Delta\omega_p(\mathcal{K}) &= \mathcal{K}v\Delta v_p(\mathcal{K}) + \Delta e(\mathcal{K}), \\ &\quad \mathcal{K} = 1, \ldots\ldots., \ldots .2000 \end{aligned} \tag{7}$$

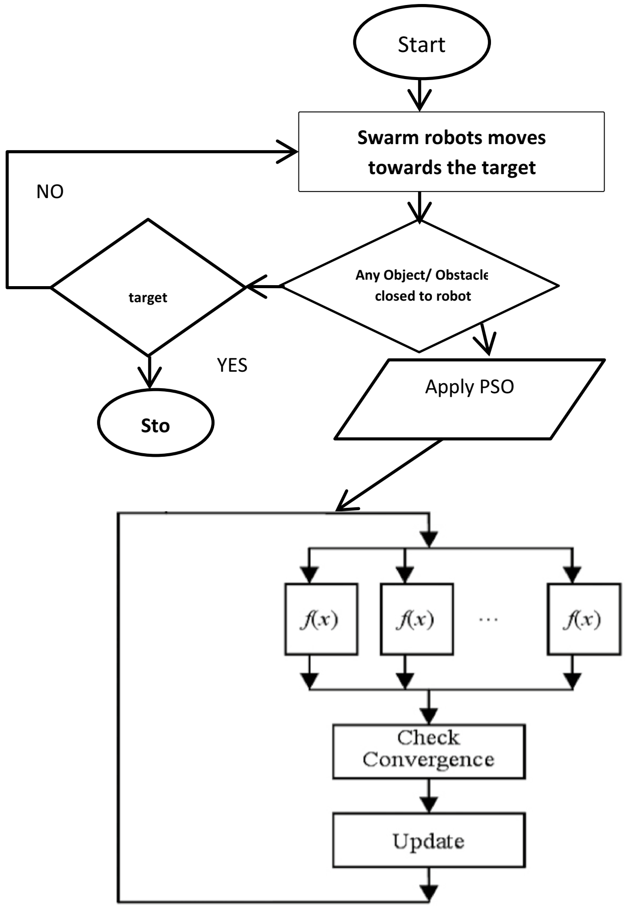

Fig. 3 PSO flow chart used as reference generator before the dynamic model

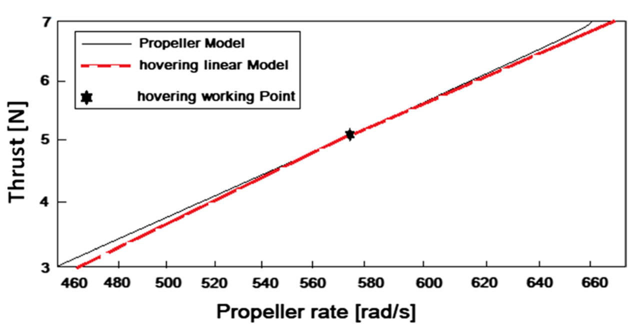

Fig. 4 Propeller thrust function [16]

Above Eq. (6) is used to calculate set of k_v estimated values with Std. least square method and the final estimated value was the mean of all values.

Below equation was used to identify the unknown function i.e. g (.) function:

$$g(u) = c_{g1}u^2 + c_{g2}u \tag{8}$$

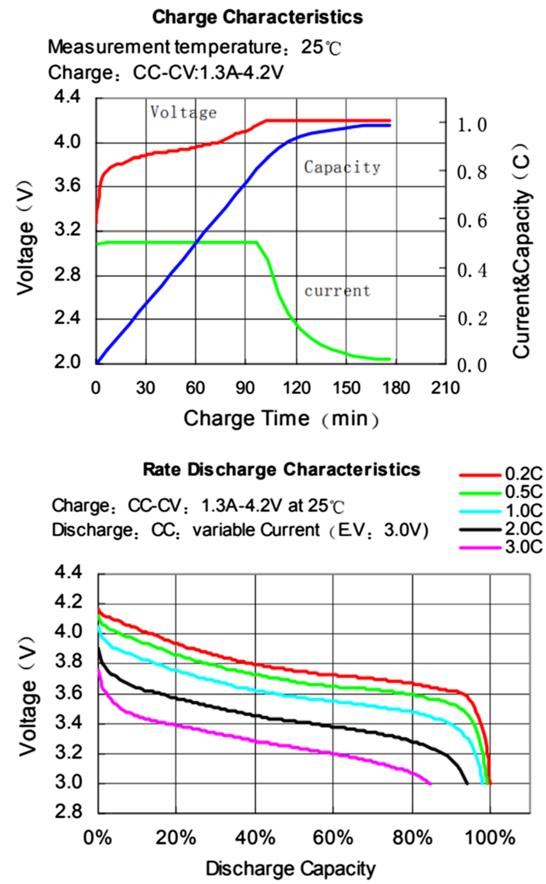

Fig. 5 Battery discharging capacity [28]

Table 2 stating battery discharging values

	Value
k_v	40 rad/s V
c_{g1}	446.9 rad/s
c_{g2}	1125.0 rad/s

for calculations of C_{g1} and C_{g2} a sequence of values for the actuator was experimentally checked as follows in Eq. (8):

$$\{\omega_p(kT_s), v_b(kT_s), u(kT_s)\}_{k=1}^{1000} \tag{9}$$

For the actuator to work in a steady state condition, combining Eqs. (4) and (8) we can write as:

$$y_g(\mathcal{K}) = c_{g1}u(\mathcal{K}T_s)^2 + c_{g2}u(\mathcal{K}T_s) + e_g(\mathcal{K}) \tag{10}$$

above equation measure the amount of noise and errors and the estimated values of c_{g1} and c_{g2} reported in above Table 2. Percentage wise simulation results are given in Fig. 6 below.

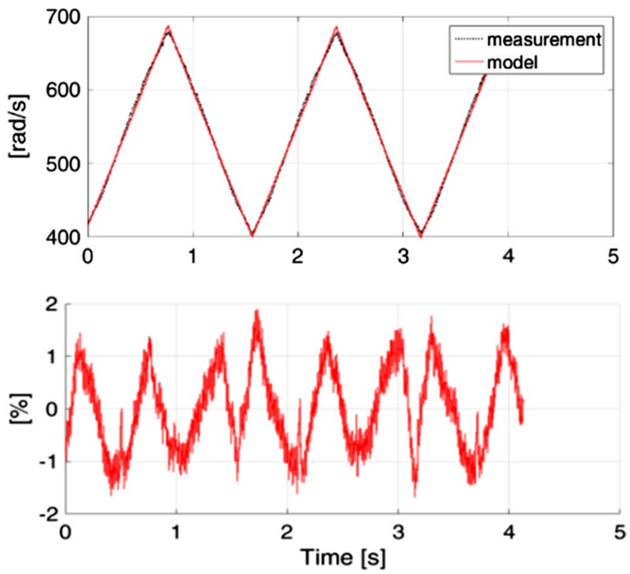

Fig. 6 Result shows error estimation of the Propeller angular rate measurement

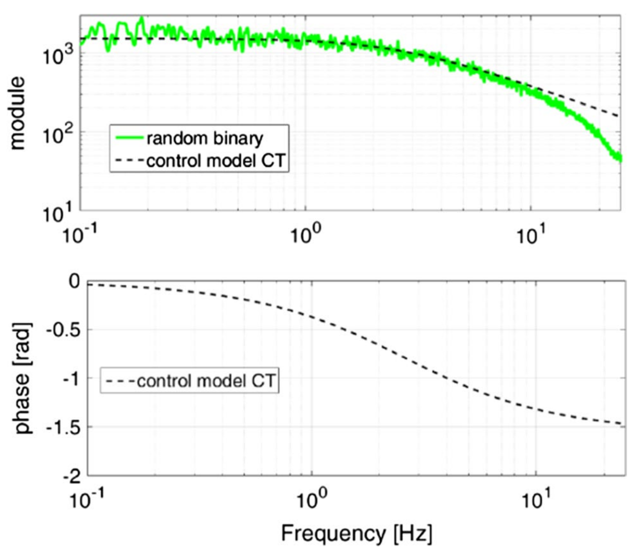

Fig. 7 Reference generator model and noise estimation

4.1 Control unit (CU)

CU is responsible to control the system output according to the digital inputs. The integrated control model (ICM) is composed of ra eference generator to control the position states and path planning according to the dynamic model. The dynamic model containing PID controller and Noise-Estimator which is responsible to predict disorders or noisy states and feedback as shown in below Fig. 7.

The main theme of the article is based on swarm robot controlling and calculation of error estimation. As, the reference generator is continuous model, while ICM is not a continuous time model representing control system internally. Dynamic model placed after reference generator is a part of ICM, coded into the CU with simple number of instructions running in a continuous fashion, leads to reduce the running time and more easy to debug. The thrust $f_{pj}(t)$ produced by two propellers of the swarm robot shows non-linearity of $f_{pn}(\omega_{pj})$ the speed of water surface wind.

$$f_{pj}(t) = \underbrace{f_{pn}(\omega_{pj})}_{Nominal} + \underbrace{e_{pj}(\omega_{pj}, v_{surfacewind}, t)}_{error\ component} \tag{11}$$

In above equation $f_{pn}(\omega_{pj})$ i.e. angular acceleration is directly proportional to the thrust in case of both the actuators without depending on surface-wind velocity i.e. $v_{surfacewind}$.

After merging Eqs. (1) and (11) we get the following dynamics:

$$\omega_b(t) = \frac{d}{j}(f_{pn}(\omega_{p1}) - f_{pn}(\omega_{p2})) + e_p\left(\omega_{p1}, \omega_{p2}, v_{surfacewind}, t\right) \tag{12}$$

From above Eq. (12) nominal thrust function $f_{pn}(\omega_{pj})$ is given as under:

$$f_{pn}(\omega_{pj}(t)) = c_{p1}\omega_{pj}(t) + c_{p0} \tag{13}$$

By combining Eq. (2) with on substituting Eqs. (11) and (12) we get,

$$\ddot{\omega}_b(t) = -p\dot{\omega}_b(t) + pb(g(u1) - g(u2)) \tag{14}$$

Input output state equations are given as under:

$$u_x(t) = g(u_1(t)) - g(u_2(t)) \tag{15}$$

$$\begin{aligned} \dot{\Theta}(t) &= \omega_b(t),\ \Theta(0) = \Theta_0 \\ \acute{\omega}_b(t) &= q_b(t), \acute{\omega}_b(0) = \acute{\omega}_{b0} \\ \acute{q}_b(t) &= -p\acute{\omega}_b(t) + pbu_x(t), q_b(t) = q_{b0} \\ y(t) &= \Theta(t) \end{aligned} \tag{16}$$

Euler forward discretization is important in obtaining ICM, where all the variables have the same unit. $\omega_b(i)$ is converted into y(i) on the basis of input as given below:

$$u^*(i) = T_c^2 bu_x(i) \tag{17}$$

Torque may be calculated from Eq. (16) and is conveyed in below Eq. (17):

$$u_p(i) = JT_c^{-2}u^*(i) \tag{18}$$

The state variables are given below:

$$
\begin{aligned}
&x.(i) = \left[x_c(i) \quad x_d(i)\right]^T \\
&x_{c1}(i) = \left[x_{c1}(i) \quad x_{c2}(i) \quad x_{c3}(i)\right]^T \\
&x_{d1}(i) = \left[x_{d1}(i) \quad x_{d2}(i)\right]^T
\end{aligned} \tag{19}
$$

The matrix form of state representation is as follows:

$$
\mathbf{x}(i+1) = \left[\begin{array}{c|c} A_c & H_c \\ \hline \mathbf{0} & A_d \end{array}\right] \left[\begin{array}{c} \mathbf{x}_c \\ \hline \mathbf{x}_d \end{array}\right](i) + \left[\begin{array}{c} B_c \\ \hline \mathbf{0} \end{array}\right] u^*(i) + \left[\begin{array}{c} G_c \\ \hline G_d \end{array}\right] \mathbf{w}(i) \tag{20}
$$

$$0y_m(i) = \left[C_c | C_{de}\right] x.(i)$$

$$0z_m(i) = \left[F_c | 0\right] x.(i)$$

The output in matrix form:

$$
1A_c = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1-\beta \end{bmatrix}, \quad 1B_c = \begin{bmatrix} 0 \\ 0 \\ \beta \end{bmatrix},
$$

$$
1F_c = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}, \quad 1C_c = \begin{bmatrix} 0 & 1 & 0 \end{bmatrix} \tag{21}
$$

According to Eq. (19) G_c and G_d are the sources for disturbance and A_d is the noise matrix while H_c is the indicator between noise and states connection.

$$
1A_d = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}, \quad 1H_c = \begin{bmatrix} 0 & 0 \\ 1 & 0 \\ 0 & 0 \end{bmatrix} \tag{22}
$$

Error in the model may be calculated as follows:

$$aE_m(i) = \bar{x}_{c2} - y(i) \tag{23}$$

By generating noise, states have to be predicted as shown in Table 2, with the blocked-diagram is given as under (Fig. 8).

State space equation is given as under:

$$
\left[\begin{array}{c} \hat{x}_{c2} \\ \hat{x}_3 \\ \hline \hat{x}_{d1} \\ \hat{x}_{d2} \end{array}\right](i+1) = \left[\begin{array}{cccc} 1-l_1 & 1 & 1 & 0 \\ -\beta l_0 & 1-\beta & 0 & 0 \\ \hline -l_2 & 0 & 1 & 1 \\ -l_3 & 0 & 0 & 1 \end{array}\right] \left[\begin{array}{c} \hat{x}_{c2} \\ \hat{x}_3 \\ \hline \hat{x}_{d1} \\ \hat{x}_{d2} \end{array}\right](i) + \left[\begin{array}{cc} 0 & l_1 \\ \beta & \beta l_0 \\ \hline 0 & l_2 \\ 0 & l_3 \end{array}\right] \begin{bmatrix} u^* \\ y \end{bmatrix}(i) \tag{24}
$$

The polynomial for above case is given as under:

$$
\begin{aligned}
p(\gamma) = {} & \gamma^4 + (\beta + l_1)\gamma^3 + (l_2 + \beta l_1 + \beta l_0)\gamma^2 + \\
& (l_3 + \beta l_2)\gamma + \beta l_3
\end{aligned} \tag{25}
$$

$\gamma = \lambda - 1$ is eigenvalue, important for disturbance gain.

$\gamma_k = \gamma_0\, 2^{-k\alpha}$, where $k = 0,1,2,3,4$, $\alpha \geq 0$ (the only param to be tuned).

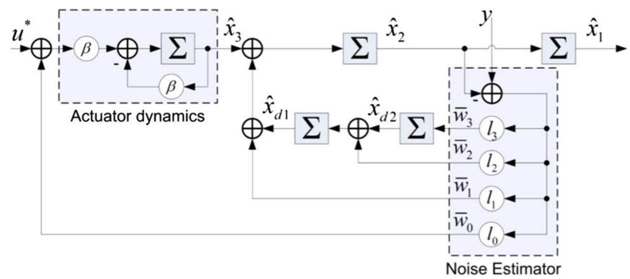

Fig. 8 State predictor blocked-diagram

Eigenvalues and noise estimator values are shown in Table 3 above.

Complete swarm robot control model is shown as an overview in Fig. 2. Figure 12 shows command reference υ(i), feedback and PID gain shown in Table 4, and dynamic model used for performance evaluation to control swarm robot to navigate freely in the naval environment (Fig. 9).

Multiple feedbacks collected from PID controller are as given below (Fig. 10).

PID command equation is given as under:

$$\upsilon(i) = k_P e(i) + k_I T_c x_I(i) - \frac{k_D}{T_c} x_2(i) \tag{26}$$

$e(i)$ is external disturbance in above equation.

On the basis of self-organized and decentralized behavior of PSO and by analyzing Table 1, swarm robots are not only supposed to control the viewpoint to 0 but also enhancing the performance of PSO swarm robots with comparison to other Meta heuristic algorithms, which are given as in below

Table 3 State predictor complementary eigenvalues and noise-estimator gains

Eigenvalues		Gain	
Letters	Prices	Letters	Prices
γ_0	0.278	l_0	−4.87e−17
γ_1	0.122	l_1	1.97e−1
γ_2	0.043	l_2	1.04e−2
γ_3	0.012	l_3	1.44e−3

Table 4 Performance

Symbol	Value	PID param	Value	Improved %age
K1	0.266	KP	2.20	12.37323
K2	0.122	KI	0.986	8.695652
K3	0.050	KD	0.575	12.09091
Filter coefficient (N)			1820.82	

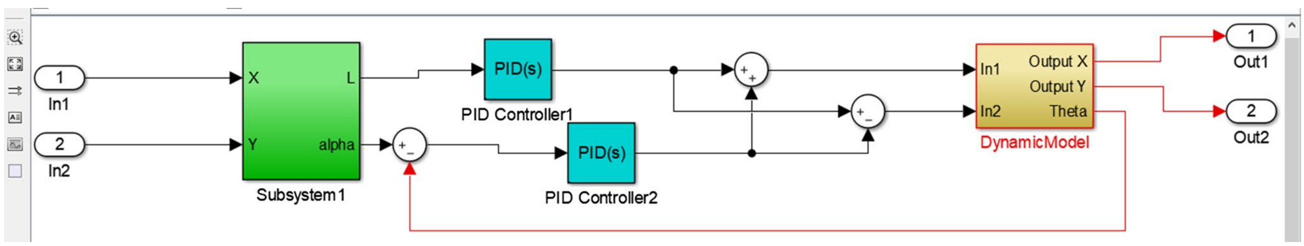

Fig. 9 Reference generator with PID controller

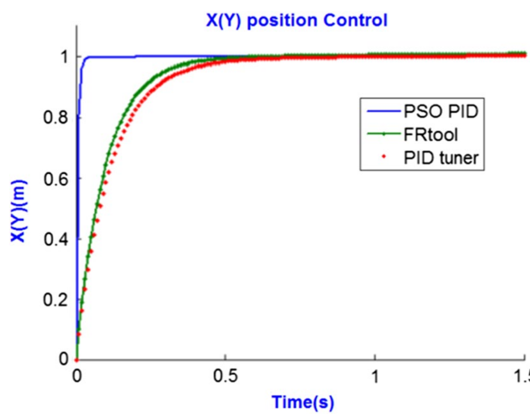

Fig. 10 PID tuning graph

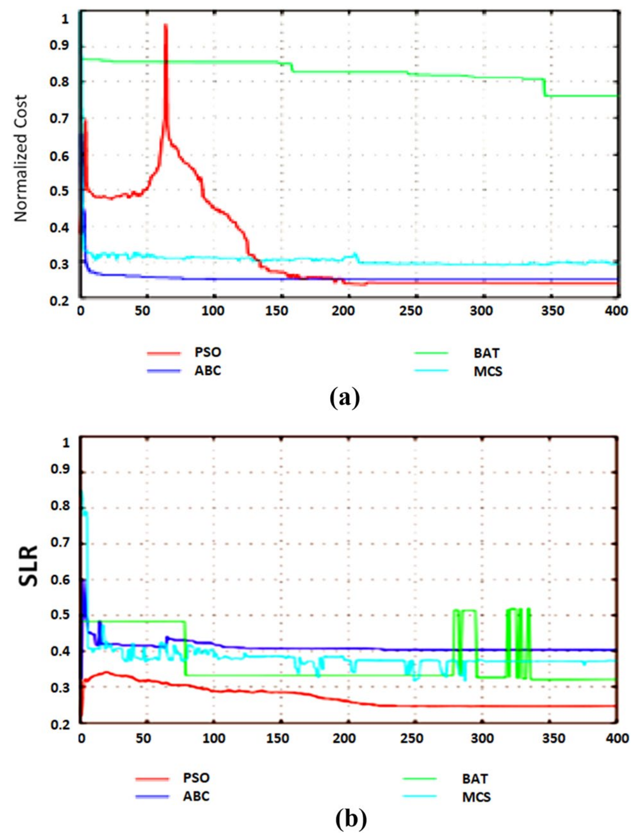

Fig. 11 Performance comparison of PSO with other Meta heuristic algorithms, **a** on the basis of Cost comparison. **b** Path finding on the basis of basis of straight line rate (SLR)

Fig. 11a show Cost comparison with respect to BAT algorithm, Artificial Bee Colony (ABC) and Modified Cuckoo Search Algorithm (MCS), While Fig. 11b Shows as the Particle Swarm Optimization is a randomized search algorithm to cover much search area and very fit for Path finding on the basis of straight line rate (SLR).

With the improvement of performance external noise (distortion) will be subject to decrease to its minimum. According to Table 4, the performance of ICM controller that has designed and compared with standard PID controllers in various tests and after collecting feedback found 12.37%, 8.69% and 12.09% improved on the basis of thrust produced in the propellers for surveillance, intruder detection and other rescue operations in naval defense systems.

The comparison graph in Fig. 12 of PSO that is a part of ICM, from experimental data by using Matlab R2016a demonstrates the execution of reference generator molecule swarm optimized approach. On the premise of average convergence rate with respect to other, the average convergence rate of PSO shows the minimum best of all other meta-heuristics approaches.

Figure 13 shows viewpoint error detection for PID and ICM, while, Fig. 14 shows the noise estimation graph with PID fluctuations with the subject to the torque impulse with small overshoot.

5 Conclusion and future work

Integrated control model (ICM) techniques may be applied to develop and control swarm robots with the functionality of intruder and obstacle detection, castaway ship detection, model errors to enhance communication and to minimize

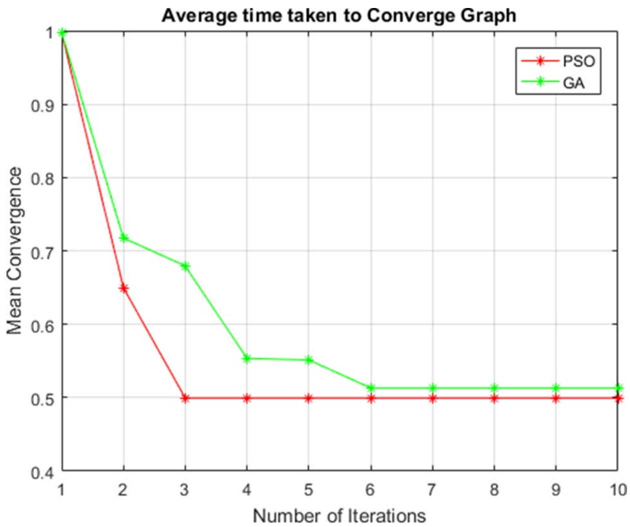

Fig. 12 PSO Comparison with other meta heuristics genetic algorithm (GA) on the basis of convergence

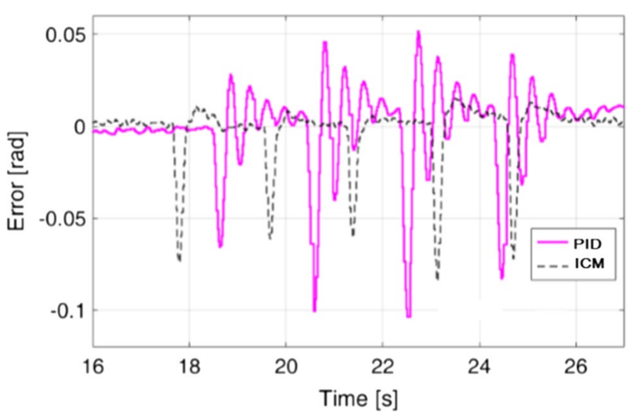

Fig. 13 Viewpoint error detection graph for PID and ICM

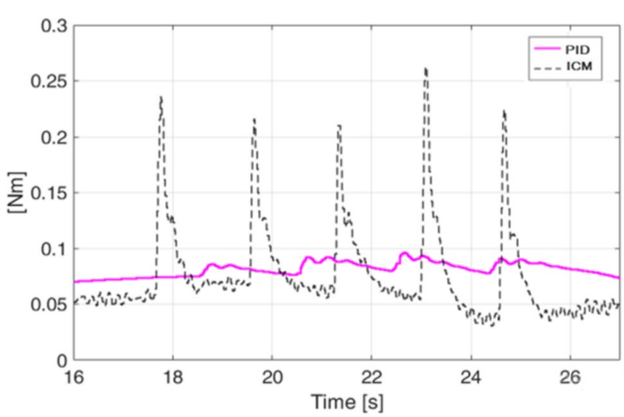

Fig. 14 Noise estimation graph

the uncertainty, surveillance and rescue operations in naval defense systems. Initial comparisons of ICM with PID controller has been made and collected improved feedback with 12.37%, 8.69% and 12.09% in respect of ICM on the basis of thrust produced in the propellers respectively. With the improved thrust, navigation and surveillance are made easy with the fuel consumption efficiency. Also compared PSO with other Meta-heuristic techniques gives better results on performance evaluation.

For future work, the formation of swarm-robots may be of interest to many real-world applications, especially deployment on appropriate hardware devices. In particular, in the context of the Economic Corridor Project (CPEC) at Gwadar port, the formation of smart water drones may also have an impact. In our ongoing research on computer vision, we will effectively participate in the future contribution of the offshore operations at Gwadar port in these projects. We will try our level best to keep our swarm-robots simpler and with the lowest deployment cost.

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