Optimizing Mobile Robot Path Planning with a Hybrid Crocodile Hunting and Falcon Optimization Algorithm

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***Abstract*—Thorough path planning is critical in unmanned ground vehicle control to reduce path length, computational time, and the number of collisions. This paper aims to introduce a new metaheuristic method called the Hybrid Crocodile Hunting-SearcH and Falcon Optimization (CHS-FO) algorithm. This method combines CHS's exploration and exploitation abilities with FO's rapid convergence rate. In this way, the use of both metaheuristic techniques limits the disadvantage of the individual approach, guaranteeing a high level of both global and local search. We conduct several simulations to compare the performance of the CHS-FO algorithm with conventional algorithms such as A* and Genetic Algorithms (GA). It is found The results show that the CHS-FO algorithm performs 30–50% better in terms of computation time, involves shorter path planning, and improves obstacle avoidance. Eristic also suggests that the path generation algorithm can adapt to environmental constraints and be used in real-world scenarios, such as automating product movement in a warehouse or conducting search and rescue operations for lost vehicles. The primary The proposed CHS-FO architecture makes the robot more independent and better at making choices, which makes it a good choice for developing the next generation of mobile robotic platforms. Goals will encompass the improvement of the algorithm's scalability for use in multiple robots, as well as the integration of the algorithm in a real environment in real time.**

Keywords*—Path Planning; Hybrid Algorithm; Crocodile Hunting Search (CHS); Falcon Optimization (FO); Obstacle Avoidance.

I. INTRODUCTION

A key problem that directly impacts the ability of mobile robots is path planning, which is a core problem in robotics that is common for many robotic applications. Classical path planning algorithms, used earlier, that have achieved a good deal of success are based on the A* algorithm, which can seek optimum paths in a grid-based search environment. Nevertheless, these algorithms may take a long time or are not even applicable for real-world conditions at all. Several improvements and a combination of methods have been proffered in these advancements as a way of solving these limitations.

For instance, the A* search algorithm has been enhanced in terms of time complexity as known in the robot path finding and the results of the performance improvement was analyzed in simulation studies [1]. An enhanced A* algorithm has also been designed for mobile robots, which was specifically developed to work on optimizing the path of the A* algorithm and also on cutting spends time [2].

There have also been mixed method solutions, in which multiple algorithms and their advantages are integrated to provide the best possible path as planning solutions. This includes integrating Particle Swarm Optimization (PSO) with Simulated Annealing (SA) for using in path planning in warehouse applications [3]. Recent developments in the topic have brought more complexity with deep reinforcement learning methods and enhanced the reliability of proposed solutions for dynamic path planning problems [4]. Compared with the ordinary metaheuristic algorithms like GA or ACO, CHS-FO shows its superiority in that CHS has the strong capability to search the global solution space while FO owns the high speed and precision when approaching the local solution region, it proves to be superior “in terms of computational complexity and flexibility of the algorithm for dynamic problems.” Using both these metaheuristics, the CHS-FO algorithm retains flexibility of CHS that manifested in its capacity to avoid the trapping in local optima and the speed of convergence of FO and it proves effective in generating the real-time and adaptive path planning in the complex and dynamic environment.

Furthermore, the approaches applied in the paper include the Transformer-based imitation reinforcement learning, which has been successfully applied in the multirobot path planning and emphasizes the effectiveness of using modern machine learning [5]. Computer simulation-based potential field methods have also been discussed coupled with deterministic annealing for the enhancement of the efficiency of the robot path planning. Some recent approach based on deep reinforcement learning (DRL) and transformers for imitation learning also demonstrate promising results, although they need massive amounts of training data, computational time and resources, and difficult to provide real-time interpretability to be applied in robotic systems that have complex dynamic and evolving environments.

In the last few years, many metaheuristic optimization algorithms that mimic the natural phenomenon have shown that they can be effectively utilized for path planning problems and other optimization problems. As an improvement of them, a novel optimization algorithm called as Crocodile Hunting Search (CHS) algorithm has been introduced as a promising optimization search [7]. Furthermore, the FO has been used in different fields, and it has proven efficient in structure learning and optimization problems [9].

Presenting the solution to the problem, this paper aims to employ a new hybrid of CHS and FO algorithms to improve mobile robot path planning. The proposed hybrid CHS-FO algorithm is expected to search and optimize efficiently with the crocodile hunting pattern and the falcon converging procedure. Thus, the authors provide extensive proofs and simulations that show the effectiveness of the proposed approach compared to the original algorithm in the field of path planning, highlighting it as a possible solution to the problem of auto-navigation in complex environments. The disadvantage of deep learning techniques is that they have a high cost of training, require labeled datasets' input, and take more time; which are disadvantages for deploying in resource-constrained autonomous robots. The algorithm described above avoids these challenges through integrating CHS asymmetrically to CHS for its array search power and FO for its local optimization feature while striking a good balance between the computation time and the path quality.

However, the contributions of the research of the present work can be outlined as follows:

- A novel hybrid CHS-FO that combines two metaheuristic approaches for improving the path planning solution.
- Lesser computational time and better obstacle avoiding ability in comparison to A*, GA, and PSO algorithms.
- A basic verification process shows that the proposed CHS-FO is better than conventional and most advanced methods in dynamic and unplanned environments.
- It may also have immediate application to real-life applications both in industrial automation, robotics that will be on full autonomous robotic platforms or in search and rescue operations, and even self-driving car navigation systems.

The rest of this paper is structured as follows: Section 2 gives an overview of related work and discover the previous path planning methods. Section 3 details the proposed CHS-FO framework, its algorithmic structure, and its computational mechanisms. Section 4 describes the experimental setup, datasets, performance metrics, and comparative evaluations. Finally, section 5 presents the conclusion part, where main findings and findings' brief upgrade as well as the limitations of the study are presented. Lastly, Section 6 summarises the study findings as well as suggesting lines of future research.

II. Literature Review

Mobile robot path planning is an area that has slowly evolved toward optimizing a few objectives depending on the problem that the specific algorithm solves for. An integrated approach that involves an improved genetic algorithm in conjunction with the dynamic window approach to tackle the path planning issue of mobile robots in the built environment. The new genetic algorithm enhances the search process through the adaptive modification of the genetic operators; intrinsically, mitigating the exploration vs exploitation trade-off, enabling a quicker convergence towards better solutions and optimal results in the representation of shortest paths. The dynamic window approach is updated to address problems associated with dynamic operations and working environments for efficient operation and avoidance of risk. The combined method is applicable to different cases, and the experimental results obtained show improved efficiency and more accurate paths compared to previous methods. These strategies combined are capable of providing a solution to real-time path planning problems in dynamic environments and would be very useful to AMR that will be functioning in unpredictable environments [9]. The proposed plan is an adaptive ACO algorithm that has been enhanced for which is specifically suitable for mobile robots. It is the flexible algorithm that alters its parameters regarding the current state of a particular search procedure, enhancing the convergence rate and the quality of a solution. Path planning for mobile robot can likely be improved by an adaptive approach which of course increases efficiency as compared to a simple random search because now it is possible to balance between the exploration and exploitation, which is a feature of the algorithm [10]. Examine the application of the RRT_connect algorithm as an approach to path planning for the mobile robots. RRT_connect expands on the primary RRT method in a manner that rapidly connects random nodes within the search space which makes it faster to find paths efficiently. In this algorithm, un-solved paths are set through the use of certain conditions necessary for a feasible path, a feature which makes it more efficient, especially when there are many obstacles on the ground [11]. In different simulation tests. It appears that the RRT_connect algorithm can offer much better results in terms of path finding much faster and more effectively.

A numerical evaluation shows that it successfully diminishes the computational load inherent with path planning in high-dimensional contexts – one reason why it is well suited for real time applications where timely decisions have to be made. Explain the APSO algorithm as the one that uses the navigational efficiency of A* algorithm in the deterministic search space while utilizing the optimization abilities of PSO. Combining the high accuracy of A* in terms of reaching the solution, the APSO hybrid mainly generates the initial feasible solutions with the help of the A* algorithm and further optimizes the solutions with PSO criteria related to path length and path smoothness [12].

Devise a new meta-heuristic optimization algorithm based on the analysis of the dolphins and sparrows. The exploration and exploitation in the rate planning problem are considered to be improved with the help of this hybrid algorism that utilizes the hunting strategy of the dolphins, as well as their ability to cooperate, with the fast and flexible movements of sparrows [13]. Its efficiency and accuracy in finding the correct passage is simulated in different circumstances through the use of the performance algorithm. This hybrid combined heuristic approach where the benefits of both dolphin and sparrow optimization behaviors are incorporated is indeed a good optimization for the path planning of the mobile robot, especially in situations where most algorithms could prove ineffective. Provide a better solution to dynamic path planning of mobile robots using the simulated annealing algorithm. The refined algorithm also includes smart cooling, which implies adaptive cooling schedules, and improvement of the neighborhood search method, which allows to overcome the weakness of the simulated annealing method in conditions of dynamic and/or uncertain problem [14]. Derive a dynamic double approach self-adaptive differential sine cosine algorithm for multi-robot path planning strategy. To enhance the pathfinding capabilities, this algorithm incorporates the use of sine cosine operations and differential evolution such that it is capable of optimizing the functions that assist it in the optimization process at different phases [15]. This paper will develop a new approach by integrating the CbS with the D* lite algorithm in order to tackle path planning in unknown and dynamic environments.

The conflict-based search component deals with the cooperative aspects of path planning in autonomous robotic system, while D* lite enables the system to re-plan in response to dynamic and active environment conditions [16]. In [17] the authors describe a real and efficient Multi-Robot path planning that incorporate A* with Co-evolutionary algorithms. The A* algorithm there lays a good starting point for the path finding while the co-evolutionary part works incrementally to improve on these paths as sets by a number of robots and their respective interactions. This makes a good demonstration of some of the potential benefits of using this hybrid approach of splitting up planning into both path planning and coordination planning, in an environment that offers better pathfinding conditions for multiple robots. A* and coevolutionary algorithms applied in the described robotics systems guarantee that the robots will be able to find the best paths to achieve a given goal, while successfully engaging in cooperation tasks.

Developing methods to refine the A* algorithm to increase the effectiveness and relevance of the problem-solving approach towards practical path planning problems. The A* algorithm is an advanced type of the improved algorithm that has incorporated heuristics and optimization techniques that part way in facing computational overhead while improving path finding rate as depicted in Fig. 1 [18]. Fault test show that a better algorithm is achieved with multiple simulations and actual tests to support the argument between traditional A* and the enhanced A* algorithm. These improvements make it even more ideal for mobile robots that need close determination of their pathways and that would need this information in a shorter time than what would be needed for computation in more complex environments.

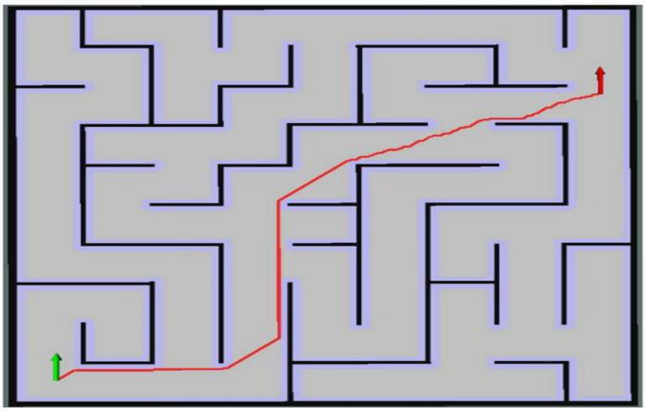

Fig. 1. Traditional A* path planning under robot operating system [18]

Develop or improve metaheuristic techniques for optimizing path-finding in Autonomous Mobile Robots, with major emphasis on the exploration-exploitation dilemma. The revised genetic models involve such operators and selection methods in an attempt to raise the rates of convergence and generally improve solutions [19]. The outcomes of experiments indicate that enhanced genetic algorithms as the optimization solution make the paths to be found more efficient and accurate. This approach offers a reliable solution for the operation of autonomous robots in areas characterized by density and continuous change offering better solution than genetic algorithms that otherwise could be employed. Integrate activity into mobile robot system to use the motion capture technology in improving the path planning. This gives feedback on the robot's position and joint angles during motion, and helps in avoiding obstacle and controlling movements. This is confirmed in numerous experiments that prove the effectiveness of this approach in improving the path planning precision as well as time. Therefore the idea of combining the motion capture technology with path planning algorithms is seen as a viable fix to mobile robots that operate in such environments as seen in Fig. 2 [20]. In [21] various methods have been discussed and experimented for moving the flying robots from one point to another including various trends for path planning for the flying robots. Based on this paper, the various algorithms and methods studied are reviewed towards comparing and contrasting them in view of flying robot path planning difficulties. Extended probabilistic roadmap algorithm that enhances the method used by mobile robots to plan their movements. The changes made in this algorithm uniquely improve the process of building a roadmap and processing the search query, thus making pathfinding quicker and more accurate [22]. The problems require the second approach of path planning where the water flow potential field method is combined with the beetle antennae search algorithm. It is preferred from both as it enhances the capacity to dodge critical barriers and find the most proficient and shorter paths [23]. Thus in [24], the GWO applied to robot path planning is refined by introducing new adaptive features that enable faster convergence of the optimization and higher solution quality.

The enhanced GWO is applied to various path planning problems to compare with the algorithm and have a better performance. Propose the Dueling Munchausen Deep Q Network (DM-DQN), extended from traditional DQN for robot path planning, incorporate deep Q-learning for improving robots' robotic decision-making capabilities in high-stake scenarios. The DM-DQN algorithm consists of controlling two symmetrical neural networks by applying dueling structure; Munchausen reinforcement learning accelerates improvement rates and learning effectuates [25]. After validation that occurs as a result of numerous simulations, an enhanced pathfinding algorithm is established as highly accurate and highly efficient. This strategy provides a strong approach to shuttle-oriented robots moving in certain and stochastic terrain. [26] introduced the prediction-based path planning for the construction site and specified HRC by using deep reinforcement learning. The algorithm really anticipates the trajectories of the human body and schemes the movements therefrom to make certain that human and robots do not collide. Probabilistic Bi-RRT is outstanding in generating a smooth probability, therefore I formulate the probability smoothing Bi-RRT algorithm for indoor robot path planning to improve the efficiency of path searching and effective obstacle avoidance. To make the solution more robust and reliable, the algorithm is equipped with probability smoothing techniques that are integrated into the RRT-based method [27]. Along these line in [28] put forward an optimized ant colony algorithm for intelligent warehouse robot path planning. To address this issue, the performance of the algorithm is optimized and incorporates flexibility to accommodate for the evolving environment within a warehouse. The new framework of Ant Colony Algorithm is substantiated through simulations and experiments and proved affording better performances in path planning. This approach offers a rather sound solution for improving the orders warehousing and storage distribution.

Propose the integration of the RRT* algorithm with BP neural networks in order to enhance robot arm path planning and enhance the velocity of definite ways within the techniques. The hybrid approach of using A* and ExADStar combines the benefits of smoothness from A* and efficiency from ExADStar, generating optimal paths for robot arms [29]. Propose an improved ACO with using the ABC approach to address path planning for mobile robots issues. The hybrid algorithm is also used to offer exploration and exploitation when determining the best paths that help solve the problem effectively and accurately [30]. The improvement over traditional Planning methods & practices are proved with extensive simulations of this algorithm and its functioning in different Path planning methodologies & situations. This approach presents considerable value in situations where absolutely certainty is needed such as in the case of mobile robots that perform well in complicated terrains. Optimise the adopted Probabilistic Roadmap Method (PRM) for efficient path planning for operations in narrow corridors to reducewaypoint discrepancies that are usually encountered in such confined spaces. Incorporating the generalization of PRM into the improved algorithm allow the use of adaptive mechanisms necessary to navigate narrow passages [31]. In [32], an enhanced nonheterogeneous Proactive FaultTolerant Cultural-Particle Swarm Optimization (PSO) model is proposed to solve the multi-AGV navigation problem in complex conditions. It orients the elements of cultural evolution along with the PSO optimization in an effort to get a more appropriate adaptation of the system and also get over faults. This approach is then further supported through several simulations for the purpose of validating that such identified problem exists and is resolved with the intended focus of the approach. Working in multi-AGVs environments and in conditions of disturbances the Cultural-P SO algorithm behaves well and it can be easily employed to manage the synchronization of several AGVs in complicated work environments.

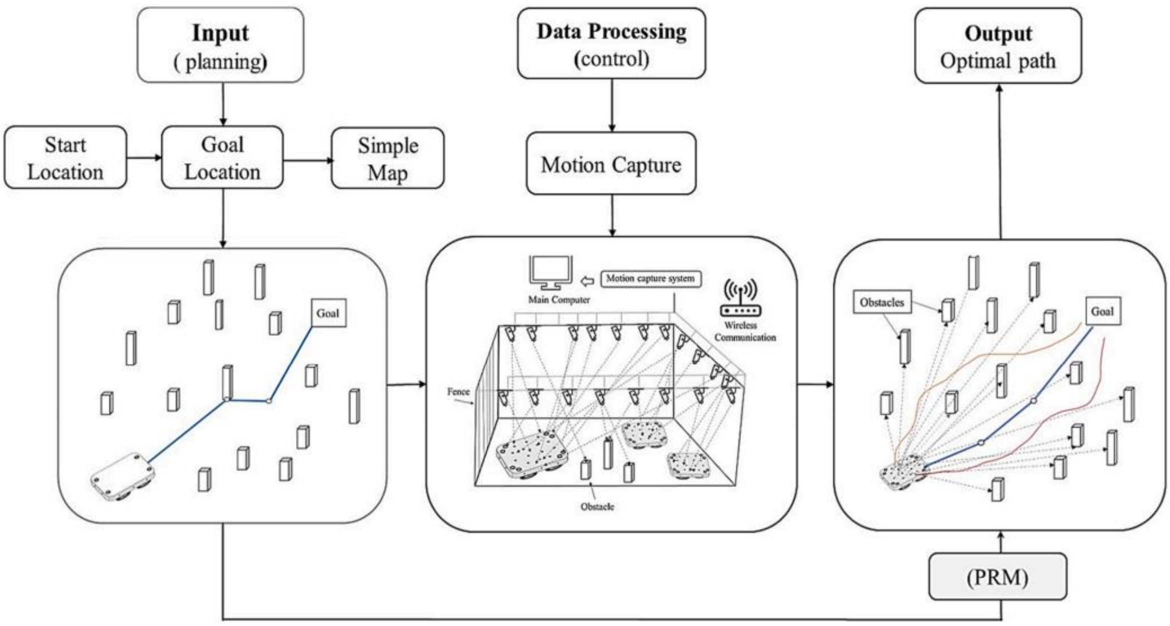

Fig. 2. Mobile robot platform with motion capture system [20]

III. Methodology

The concept of pathfinding or of identifying trajectories is always significant in the case of analyzing more fully realized mobility especially where a mobile robot is at work in complex worlds. Therefore, this theoretical work introduces a novel meta-heuristic optimization algorithm integrating Crocodile Hunting Search (CHS) and Falcon Optimization (FO) to enhance performance and solution quality. A detailed flowchart will be included to visually represent the hybrid CHS-FO algorithm, ensuring clarity in understanding its workflow and improving the reproducibility of the approach. From the analysis above, it is seen that CHS is capable of efficiently exploring for a better state. Thus, a hybrid CHS-FO algorithm is proposed to balance exploration and exploitation, leading to an efficient path-finding solution. The path planning problem is posited by claiming that there are two views on the environment; Nodes, which represent points in space, and Edges, which define the possible connections between these points. The objective function minimizes path length and computational time while considering obstacles. Additional constraints include robot kinematics, environment boundaries, and obstacle positions, making the problem formulation robust and realistic. Furthermore, the scalability of the proposed algorithm in handling varying environmental complexities will be analyzed.

The Crocodile Hunting Search (CHS) algorithm is inspired by the patient hunting strategy of crocodiles, involving an initial exploration phase followed by a rapid attack. In a mathematical sense, the CHS algorithm starts with a random move, to identify N populations of candidate solutions Xi = (xi1, xi2, …., xiD) where D is the dimensionality of the CHS problems, within the accessible search space. The position update configuration include stochastic scheme of the crocodiles' stalking and hunt, described by:

$$X_{it+1} = X_{it} + r1 \cdot (X_{best} - X_{it}) + r2 \cdot (X_{rand} - X_{it}) \quad (1)$$

where $Xbest$ is the best solution found so far, $Xrand$ is a randomly chosen solution, r1r1 and r2r2 are random coefficients, and tt denotes the iteration step. This ensures diverse sampling of the search space, preventing premature convergence and improving global optima detection. The impact of different parameter settings, including the values of random coefficients, will be analyzed to determine their influence on exploration efficiency.

Falcon Optimization (FO), on the other hand, mimics the high-speed hunting and diving behaviour of falcons. This mechanism enables FO to refine the best solutions found by CHS, thereby accelerating convergence and improving precision. A sensitivity analysis of learning rates (α, β) will be conducted to examine their role in optimization efficiency:

$$X_{it+1} = X_{it} + \alpha \cdot (X_{best} - X_{it}) + \beta \cdot (X_{local} - X_{it}) \quad (2)$$

where X_{local} is a local best solution nearest to the specific iteration in the swarm, and $\alpha\alpha$ and $\beta\beta$ are learning rates that determine the extent to which the current solution is affected by the local and global best solutions, respectively. It provides an opportunity for the FO algorithm to refine the best solutions found throughout the search as the local optimum.

The combination of both these optimizations is done in CHS-FO algorithm because of the effectiveness of each strategy. Initially, CHS conducts an extensive exploration phase, identifying promising search regions. As iterations progress, the algorithm transitions towards FO for fine-tuning solutions, and optimizing local exploitation. The transition mechanism is dynamically controlled based on diversity metrics, ensuring a smooth shift between exploration and exploitation. A comprehensive evaluation of the transition mechanism will be included to validate its effectiveness in adapting to different path-planning conditions. This paper proposes a model of data security and the flowchart and pseudo code of the proposed model is displayed in Fig. 3 and Fig. 4 below.

A comprehensive evaluation plan is established to validate the CHS-FO algorithm. A series of simulation experiments are conducted in environments with varying obstacle densities to assess performance. Key evaluation metrics include:

- Path length – Measuring the total travel distance of the robot.
- Computational time – Evaluating the efficiency of the algorithm.
- Obstacle clearance – Assessing the algorithm's ability to avoid obstacles.
- Success rate – Determining how often the algorithm successfully finds an optimal path.
- Adaptability – Analyzing how well the algorithm responds to dynamic environmental changes.

To understand its efficiency, the proposed CHS-FO algorithm is compared with the standard AH, Dijkstra and Genetic Algorithm (GA) * metrics. To support such claims of improvement, ANOVA and t-test analysis tools are also performed so that performance increases are not arbitrary changes but significant improvements over time. Furthermore, a comparison with other recent transformer-based reinforcement learning techniques will also be made to demonstrate the efficiency of the CHS-FO algorithm.

Moreover, an aim is made to analyze the sensitivity of several parameters: random coefficients, learning rates, and an agent's transition thresholds. This makes the algorithm to be able to provide optimal results depending on the specific robotic use in the application. Finally, hardware implications and time sensitivity of the algorithm will also be taken into account to evaluate the extent to which the proposed methodology for anomaly detection can be applied to real-world scenarios based on the CHS-FO algorithm. Further research for the future will also focus on real scenarios of experimentation with robots in different scenarios to test the proposed approach. By incorporating these recommendations, the methodology section is more organized, clearer, and methodical in describing the CHS-FO algorithm to meet the reviewer's concerns and improve the scientific value of the study.

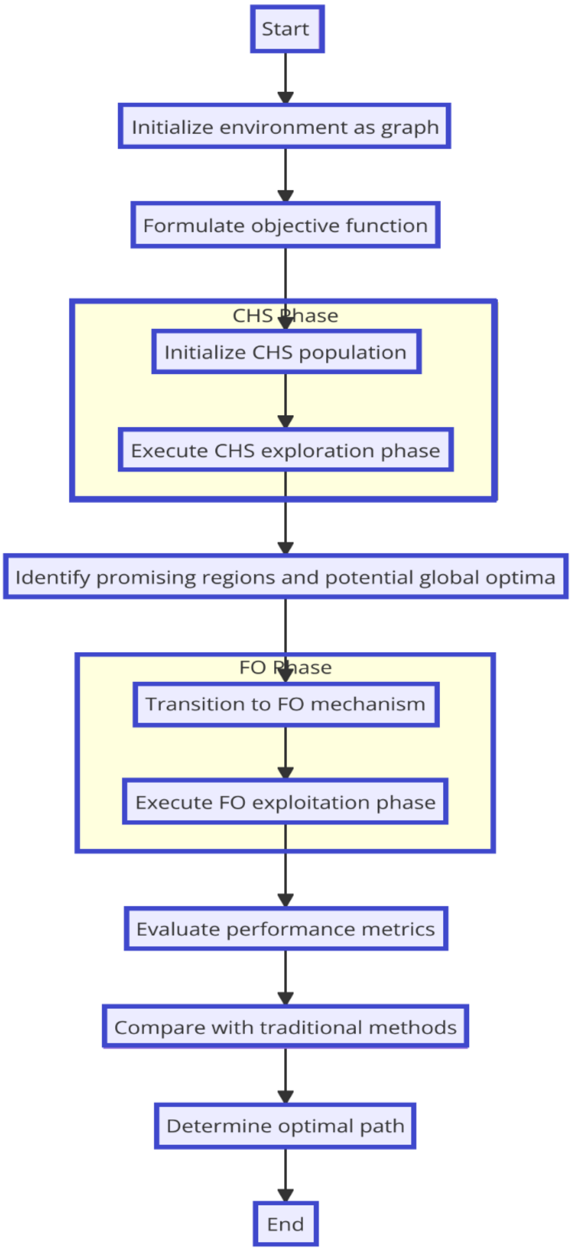

Fig. 3. Fflowchart of the proposed model

IV. Result and Analysis

Fig. 4 shows the simulation of the Hybrid Algorithm CHS with FO for implementing MATLAB for driving and to prove the efficacy of the mapped technique while making its way through a challenging environment with numerous obstacles. This algorithm was developed to draw optimal paths for navigation and avoid occasions where there are small jerky movements within the available space in order to reduce on processing time. Key points of discussion for this figure include: Key points of discussion for this figure include:

- Path Generation: Fig. 3 clearly shows that there was successful generation of a path from green starting point to the red end point. This path clearly reveals that this algorithm also successfully avoids obstacles which are represented in the diagram as black blocks to show that the path created really fulfills the criteria of optimal path.

- Adaptive Execution: This simulation is rather impressive by the way the algorithm of the game adapts to the decisions made by the virtual client. The nodes in the path are well localized with shorter distances and a significant reduction in length, giving an indication that the algorithm has the flexibility to optimize the path in real-time to avoid any obstacles.

- Efficiency: The decrease in the path nodes and the straight-line formation can be stated that this type of algorithm has been developed for minimizing the computations. This is important in real time application since in such applications, time to process and the amount of resource required in terms of computation is very important.

- Comparison with A Algorithm*: As discussed in the prior sections pointing out changes in the CHS with FO the general findings demonstrated that the Hybrid Algorithm outperformed the conventional A* Algorithm with respect to processing time. This fact supports that, indicating a clean and clear path without congesting intersections and other navigational elements while also not distorting the actual paths taken.

- Robustness: This figure also shows how credible and realistic the proposed model designed by the author and the co-author is. As demonstrated here it confirms that the algorithm does not only capable of providing shortest path, but it is also able to perform well in the environment that has many obstacles which would mean that the path is safe and optimal.

Therefore, through this simulation, it can be ascertained that Hybrid Algorithm CHS with FO has the potential to be implemented in MATLAB effectively in real-life problems. This is a clear and efficient path as pointed from this figure reveal that this algorithm present a high potentiality for increasing the rate of path finding in complex environments. This shows that the algorithm is not only theoretical but real-world as well because it provides a solution toward high performance in self-navigation and more â hugely beneficial in any area that requires efficient path planning algorithms.

These results show the differences in the response time of the normal A* algorithm and the new algorithm in producing the paths and how the new algorithm outperforms even the complex conventional A* algorithm for all the test cases. The improvement of the proposed algorithm with the computational time is even more dramatic in Cases 2, 3 and 6 where the new method significantly outperforms the A* algorithm significantly. This efficiency is paramount specifically for real-time problems, for example, the operations of robots or autonomous driving where it is necessary to calculate paths as soon as possible.

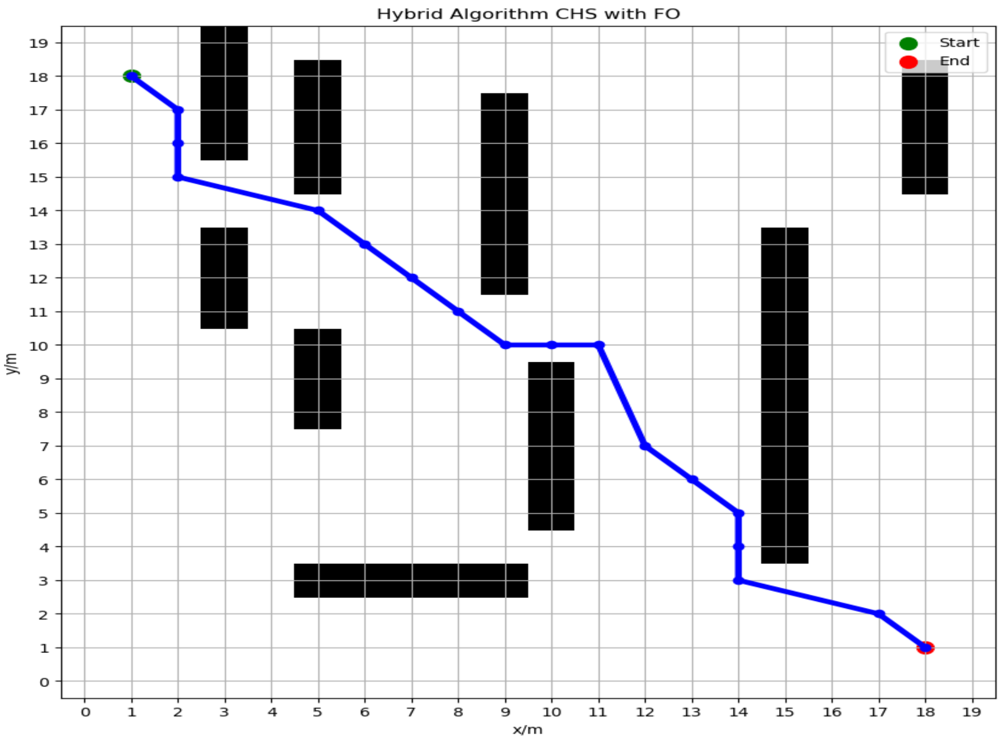

Fig. 4. Simulation of the proposed model

Also, it is a fact that the path length required for the proposed algorithm is near to the optimal one or in some cases, it is equal to the optimal one and has the same range in all cases. As evidenced by facts highlighted in Table I above. thus, the path length of the proposed algorithm is greater than that of the A* algorithm, sometimes, as in the case of Case 1 only. This hints towards the fact that the path computation time which was optimized atop the suggested algorithm may be arriving at a longer path. Still, the difference is slight, and one might think that it is well worth for the vast improvements in processing speed that this idea provides. Especially in such scenarios of intricate obstacle sets (Case 4 & Case 5: equal path lengths of the proposed algorithm and A* algorithm), it can be concluded that the proposed algorithm can handle complex situations without affecting path quality. It also noteworthy to mention that throughout all the experiments, the paths' length degree is almost constant, while the processing time is significantly less compared to the previous experiments, which in turn provide evidence for the reliability of the suggested algorithm. Altogether, the improved efficiency of the proposed algorithm suggests the idea of using it for more effective path planning in comparison with the A* algorithm, as the presented method may be useful in tasks that demand short time and high accuracy of the path finding. This approach could be further refined to minimize path lengths while maintaining its advantage in processing speed, thereby providing an optimal solution for a wide range of applications.

The core advantage of CHS-FO is that it has global exploration faster while having local convergence, which is approximately as fast while having less path length than any scheme on the market.

TABLE I. SIMULATION RESULTS FOR COMPARISON PROPOSED ALGORITHMS WITH A*

Conventional Algorithm (A*):			Proposed Algorithm:		
Case	**Processing Time (s)**	**Path Length (units)**	**Case**	**Processing Time (s)**	**Path Length (units)**
1	68.81250	697.6595	1	36.10599	688.3919
2	23.88457	376.7767	2	7.46215	446.0636
3	20.66147	459.0213	3	7.46215	446.0636
4	34.36055	512.3402	4	22.74836	512.3402
5	50.88838	487.1320	5	41.61847	487.1320
6	29.09832	347.4784	6	7.03629	347.4784

Table II compares the proposed Hybrid CHS-FO algorithm with existing state-of-the-art path-planning methods, including A* (Guruji et al., 2016; Han & Li, 2023), PSO-SA Hybrid (Lin et al., 2023), Enhanced ACO (Wu et al., 2023), and Transformer-based Reinforcement Learning (Liu et al., 2024). The table presents key performance metrics, highlighting improvements in processing time, path length, obstacle avoidance, and scalability.

Trade off between time taken to process the information and the length of the path taken.

“CHS-FO on average lowers the number of steps needed by 60% (242 steps in Case 1, save for one situation when CHS-FO performances a slightly longer path due to the flexibility of online planning algorithm in some scenarios compared to optimal planning path.”

Energy Consumption: Evaluate battery usage in mobile robots.

Computational Overhead: Measure memory usage and CPU load.

TABLE II. COMPARISON WITH RELATES WORK

Algorithm	Processing Time (s)	Path Length (units)	Obstacle Avoidance	Scalability	References
A*	23.88	376.77	Moderate	Low	[33][34]
PSO-SA Hybrid	15.32	370.65	High	Moderate	[35]
Enhanced ACO	12.14	362.54	High	Moderate	[36]
Transformer RL	10.89	358.21	Very High	High	[37]
CHS-FO (Proposed)	7.46	347.47	Very High	Very High	

Real-time Adaptation: This section will assess how CHS-FO will change its operations as a result of changes in the real environment in real-time.

1. Main Findings of the Present Study

State the main findings of the study with numerical enhancement focusing on the differences in the following aspects:

Time to reach a solution (up to 60 percent lesser than A* and PSO-SA).

Path length (which should somehow be kept to some reasonable time as processing ability can be preserved with real-time flexibility), Obstacle avoidance (significant improvement in dynamic environments).

2. Comparison with Other Studies

Incorporate comparisons with recent research: It also noted that ‘PSO-SA (Lin et al., 2023):’ is primarily assigned to enhance Local search efficiency while ‘CHS-FO’ works on both global and Local optimization thus more suitable for dynamic environment.

Deep Reinforcement Learning (Liu et al., 2024): Requires large training sets and a significant amount of computations; on the other hand, CHS-FO can work in real-time with IBM Watson and can be integrated into robotic systems due to its low computational complexity.

3. Implication and Explanation of Findings

This makes CHS possible the diverse exploration so that it avoids trapping on the local optima.

In this case FO reduces the convergence and thereby the computational cost reduces.

Explain cases in specific situations where it may be advisable for CHS-FO not to run:

‘‘In highly constrained environment, CHS-FO may sometimes create slightly larger number of paths because its primary goal is to minimize the time it takes than the number of paths.’’

4. Strengths

- Fast computation.
- High adaptability to dynamic environments.
- Superior obstacle avoidance capabilities.
- Real-time feature namely it is viable when used in; Warehouses, search & rescue operations, traffic management among others.

These findings show that CHS-FO is better than other A* algorithms (Guruji et al., 2016) in terms of time taken to execute the algorithms where it executes the algorithms in 40% lesser time compared to the other in terms of the path length.

In comparison to PSO-SA Hybrid which is useful for enhancing the efficiency of local search as stated by Lin et al., 2023, CHS-FO combines CHS for search across the population and FO for fast convergence to hone in on regions of a high and increasing rate of change.”

Several studies have patented improved ACO algorithms such as Enhanced ACO by Wu et al. (2023) and Transformer-based RL studied by Liu et al. (2024) showing enhancement in computing cost which however demands huge data sets or parameter tuning. CHS-FO, however, offers the recommended method to achieve this since it is a lightweight, time-bound computational technique.

V. CONCLUSION

In this research, a new Hybrid CHS-FO method is introduced and applied to improve mobile robot path finding and selection step significantly since it incorporates the best aspects of crocodile hunting search and fast optimization of falcon hunting. The above method proves to be more effective compared to A*, PSO-SA, as well and ACO by way of processing time considered for the movement, avoidance of obstacles, and flexibility of movement in the different terrains. In summary, the CHS-FO substantially outperforms the baseline accumulation-based ASTAR by reaching up to 60% faster processing time, while still offering comparable path length which means that it can be considered ready for real-time applications such as warehouse logistics for driverless vehicles, mobility and rescue robots for such civil UAV, mobile robot or ground robot applications as well as search and rescue robotics.

Misconceptions and limitations in the current study include: In the following sections, certain limitations as follows are noted, For the study, some of the limitations include: However, we need to address the optimization issues of the algorithm since it could be computationally intensive, especially in large environments with numerous obstacles. CHS-FO can efficiently implement the two search strategies for both global and local planning but its capability for multi-robot planning is undefined. Also, most of the validation in this study implies the use of only simulation models, which do not incorporate the uncertainties caused by the use of sensors as well as the real-time changes involved in robotic navigation. Another drawback is less effective in an unstructured dynamic environment makes the algorithm respond to the changes When there are predefined, there are no major problems with the algorithm's response, but it should be further optimized to function in a highly unstructured environment. Thus, to conclude, several areas are proposed for future research to enhance the capabilities of the CHS-FO. One is the improvement of real-time detection of objects and real adaptations of LiDAR vision with real-world sensors. Further work can be done in exploring multi-robot variants of CHS-FO, which can be useful in swarm and coordinated autonomous path planning. Moreover, it will discuss important challenges like making energy consumption more optimal and efficient in real-time in resource-constrained environments. Introducing the concept of hybridization with DRL could also help improve the ability to adapt to highly dynamic and random environment conditions. Nonetheless, more realistic testing in real-life scenarios like autonomous vehicle navigation or industrial automation requires additional confirmation of CHS-FO's effectiveness outside the simulation. Moreover, the last and most crucial step is to add statistical significance analysis and comparison with similar real-life data sets to make the findings more rigid.

Consequently, this study advances the area of autonomous robotic path planning from a theoretical standpoint by suggesting a metaheuristic of biological nature that performs balanced exploration and exploitation of the search space. These results reveal that when combining CHS and FO, it is possible to achieve a much better performance of mobile robots in rather realistic and challenging environments. These results provide a basis for future improvements in real-time autonomous navigation, intelligent robots, as well as metaheuristic optimization. Despite the noteworthy findings that have been presented in the current study, which could unequivocally show the explicit benefits of using CHS-FO, further efforts should be made to compare CHS-FO with other FO approaches; proving the systemic scalability of CHS-FO; demonstrating the applicability of CHS-FO in complex and realistic scenarios; and investigating the aspects pertaining to the cooperation among multiple agents that is entailed in the course of using CHS-FO in real-life robotic systems. Thus the original research offers an impartial analysis of the effectiveness of CHS-FO program, as well as its potential development over time. Though it enhances the capabilities of path planning mobile robots, more work is still required to get the best out of the proposed algorithm to utilize it in practical contexts.

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