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OPTIMIZATION OF DEFENDER DRONE SWARM BATTLE MANEUVER FOR GAINING AIR SUPERIORITY BY COMBINING ARTIFICIAL AND HUMAN INTELLIGENCE THROUGH HAND GESTURE CONTROL SYSTEM

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Abstract. *In a defensive military strategy, having air superiority brings many benefits. A drone swarm is one of the most effective approaches to gaining air superiority. Consequently, drone swarm battles may become the trend of military battles. Nowadays, some magnificent artificial intelligence approaches have emerged to effectively control the drone swarm movement autonomously as a tactical defense mechanism. However, artificial intelligence has weaknesses in a dynamic environment, like a military battle. We highlight that human intelligence is an unreplaceable factor for arranging a defense military strategy for gaining air superiority, even when using a drone swarm. Here, we propose the combination mechanism of artificial and human intelligence in conducting defender drone swarm movement. We develop an intelligent control system where a human can collaborate to arrange drone swarm maneuvers in real time. The system is built to optimize the defender drone swarm maneuver's effectiveness to minimize the damage to the area they guard. A human can dynamically change drone swarm maneuvers in our proposed system by performing some hand gestures movement. According to our experiment, human involvement in our framework increases the defender drone swarm group's effectiveness because a human can naturally control the drone maneuver using hand gestures.*
Keywords: Air superiority strategy, Drone swarm battle, Hand gesture controller, Intelligence combination, Maneuver optimization

1. **Introduction.** In today's military warfare between two opposing armies, the troops who have air superiority strategically possess a better chance of winning the battle. It occurs because having air superiority indicates that a group of soldiers may control a wider battle area [1]. Air superiority is obtained by an army when the army can control the battlefield's aerial situation without significant interference from the opponent's army

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air force. By having air superiority, an army may allow its military units to execute their job more effectively.

Because gaining air superiority is one of the most critical factors for winning military warfare, many technologies have been developed to support this necessity. One of them is drone swarm technology [2]. Drone swarm technology usage in war has become an emerging approach to winning a battle because it can obtain air superiority effectively without sacrificing human life as the pilot on board. Drone swarm performance is practically good as a military tool, especially when they use a GNSS (Global Navigation Satellite System), as described by [3].

From the defense military army point of view, the necessity of drone swarm technology is inevitable [4]. The defense military army should have adequate technology to protect an area from enemy attacks. The technology is needed to compensate for the enemy's advantage in initiative attack maneuvers [5]. The drone swarm technology is one alternative that can bolster the defense military army's performance. Because when using a drone swarm, a defense military army can efficiently conduct a routine patrol, investigate potential threats, or even immobilize the enemy's unit by using armed drones. By doing so, a defense military army can gain air superiority efficiently to outperform enemy units in a battle. Nowadays, the development of drone swarm technology and even strategy is outstanding. Some of them can be seen in [6-16]. According to them, we can see that using a drone swarm in the military is effective.

According to our references, most recent research on a drone swarm focuses on drone technology, communication security, and the movement coordination strategy. Although all this research brings essential knowledge related to a drone swarm, no study (to the best of the authors' concern) discusses the result of human and artificial intelligence collaboration in controlling a drone swarm, especially for the military. Compared to state-of-the-art studies, the main advantage of this study is that it brings analysis data related to the impacts of human involvement in controlling defense drown swarm maneuver that is being controlled by artificial intelligence.

There are two main methods to control drone swarm: human manual control and artificial intelligence systems to conduct adaptive autonomous drone movement. Both approaches have their pros and cons. When using a human-based drone pilot controller, human analysis capabilities toward an ongoing battle situation can become a valuable insight into navigating drone movement. Besides, humanitarian intervention is still an essential aspect of keeping drone swarm works as a defined and controlled weapon [17] because human policymakers ensure high moral responsibility, especially for armed drones [18,19]. However, because humans have a limitation in controlling multiple drones simultaneously in a battle environment, the human manual control system's usage may reduce the whole drone swarm's performance as a group.

On the other hand, artificial intelligence may produce an effective method to conduct drone swarm movements as a group. Many research types have been made related to smart drone maneuver strategy in a battle, for example, [20-22]. Nevertheless, as with other artificial intelligence characteristics, it cannot replace human insight toward a problem domain. In a dynamic environment such as warfare, human wisdom and perspective towards a battle situation are always needed to perform a decent battle result [23].

Based on the previous explanation, we analyze that artificial intelligence and human intelligence are critical for controlling drone swarm movement for the defense military army's sake. Accordingly, we design an integrated control system where a human can combine its intelligence with artificial intelligence to perform a high-quality drone swarm battle maneuver. We consider that the defense military army plays a vital role in securing a nation or an area. Thus, by implementing our proposed system, we try to increase a defense military army's battle outcome when protecting an area.

To effectively combine human intelligence and artificial intelligence in a drone swarm control system, the control system should interactively receive human input in real time while simultaneously performing the artificial intelligence analysis. We analyze that this can be effectively produced if humans can naturally interact with the artificial intelligence drone controller. We have explored some related research to support our statement.

Razzak and Islam developed an advanced battlefield communication system that accommodates strategic instruction from the command center to frontline troops under headquarters supervision [24]. Human-Computer Interaction (HCI) paradigm is used to evaluate the system. Razzak and Islam conclude that communication technology intervention is successfully and usably implemented primarily for a special operation, terrorist attack, and real war.

Tezza and Andujar reported that human-drone interaction is successfully implemented using several control modalities such as remote control, gesture, speech, touch, and brain-computer interface [25]. However, the existing communication system still handles the command center for a single troop separately and directly. It has not been designed for controlling swarm robots, especially unmanned drones. Currently, touchless gesture remotely becomes the most potential and robust control interface, especially with the COVID pandemic condition, to minimize any hand contact.

According to the previous research results, we design an intelligent touchless control system that can receive a human command by interpreting natural human movement, which is hand gestures. We develop the new Command, Control, Communications, and Intelligence (C3I) principle for controlling a defender drone swarm. The proposed system can potentially become an essential component of modern drone warfare [26]. In an emerging research topic like drone swarm battle, our proposed system brings some valuable insights into how good artificial and human intelligence collaboration is in controlling defender drone swarm.

In our proposed system, humans can share their knowledge, and then give some commands to the artificial intelligence drone controller using natural hand gestures without interacting with some complicated hardware or user interface. Our proposed system can more naturally collaborate human insight and artificial intelligence because humans can send commands by hand-sign/hand gesture. Our simulation result shows that the collaboration of human and artificial intelligence in controlling drone movement in military combat practically improves the performance of a drone swarm. In this paper, we organize the discussion as follows. In Section 2, we describe the research scope of this paper. Then, in Section 3, we explain how the proposed system works, while the experiment results are analyzed in Section 4. In Section 5, we emphasize the conclusion of our work.

2. Research Scope.

We develop a smart drone swarm control system that allows human intelligence and artificial intelligence to collaborate in determining a group of defender drone swarm movements. The movement is related to drone battle maneuvers in a war. We focus our research on designing an effective control system that increases defender drone swarm performance when guarding an area against an enemy's attacker units. Here, our research's primary goal is to enable the defender drone swarm to gain air superiority in a war as efficiently as possible.

Our research is conducted in a 3D simulation environment, where the defender drone swarm can move freely in the 3D axis. Because our research's main objective is to gain air superiority, we arrange the battle in our environment to be conducted solely between the defender drone swarm and the enemy's attacker drone swarm. In general, our research scope is drone swarm vs. drone swarm battle strategy, where we focus on developing an effective movement control system for the defender drone swarm side.

Here, we do not explain the artificial intelligence strategies used by the defender drone swarm in detail. We have previously explained these strategies in our publications [21,22]. This research aims to measure how effective human involvement is in deciding drone swarm maneuvers when combined with artificial intelligence analysis. This research analysis target is similar to the study in [27] when analyzing an automatic control system performance. As a part of our drone swarm control system, we develop an intelligent module that can interpret human hand gestures as commands. We use a sophisticated infrared camera sensor to retrieve human hand data and then apply a recognition algorithm to interpreting human gestures. This paper does not explain how the sensor works or the hand recognition algorithm used to understand human hand gestures. We focus our explanation on the effects of human intelligence and artificial intelligence combination for controlling defender drone swarm maneuvers.

Our research's novelty lies in its analysis of data related to the impacts of human involvement in controlling defense drown swarm maneuver that is being controlled by artificial intelligence. This aspect is relatively new from a computer science perspective because the current state-of-the-art drone swarm battle usually focuses on artificial intelligence's performance in controlling drone swarm movement. There is no comprehensive analysis of the impact of human intelligence's real-time involvement on the control system.

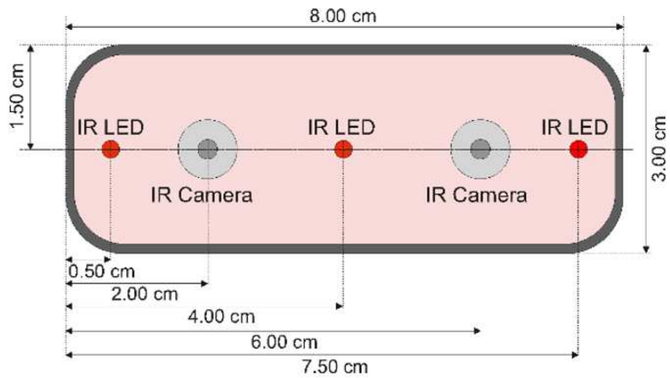
Focusing on our research scope, we emphasize that the analysis provided in this research contributes to the scientific research field. Please notice that we have developed our simulation environment for obtaining our research data in this paper. We have published some artificial intelligence algorithms related to the defender drone swarm maneuver, as provided in [21,22], and we have developed our hand gesture recognition system. Consequently, this paper's analysis data can be considered a novel aspect because it can enhance the scientific knowledge about how good the collaboration performance of human intelligence and artificial intelligence is in controlling the battle maneuver of the defender drone swarm.

3. **Proposed System.** Figure 1 illustrates the design of our control system. According to Figure 1, we arrange a combat room with a well-trained agent controlling the drone swarm's maneuver. We call the agent a Drone Swarm Pilot (DSP). As shown in Figure 1,

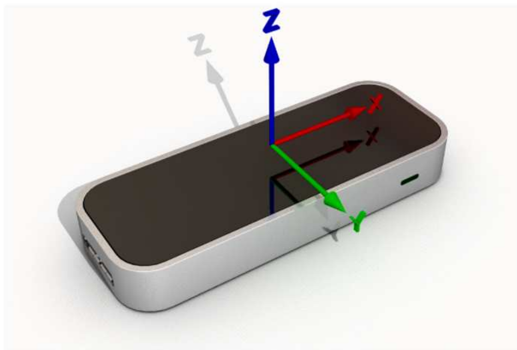
FIGURE 1. Proposed control system environment

a big screen is located in front of a DSP allowing the DSP to observe the aerial battle's current situation. The video displayed on the screen can come from any defender drone camera or even any long-range camera installed on the ground around the battle area. In default mode, the drone swarm moves autonomously using artificial intelligence defense maneuvers. However, when the DSP plans to change the drone swarm maneuver according to aerial battle dynamics conditions, the DSP can control the drone swarm movement as a group only using natural hand gestures.

We use Leap Motion Camera (https://www.ultraleap.com/) as the basis of our hand gesture sensor. Figure 2 [28] shows the device we use as a sensor. The sensor we use as a hand gesture sensor has two cameras and three infrared LEDs that enable the sensor to track DSP fingers' position accurately. We then interpret the finger data retrieved by the sensor as a hand gesture command. We built our own hand gesture interpretation algorithm. We successfully manage to detect the condition of each DSP finger, whether it is extended or bent. Besides, we also manage to detect DSP's hand palm position, whether it is facing up, front, or down. According to each finger position of all hands (right/left) and combining with each hand palm position, we then interpret them as a hand gesture command.



(a) Schematic view of the leap motion controller



(b) 3D model of the leap motion controller

FIGURE 2. Camera sensor used to retrieve hands and fingers data

Figures 3-5 illustrate how our proposed system works when interpreting some DSP hand gestures. As shown in Figures 3-5, our system has accurately interpreted the hand position, palm direction, and finger state. In Figures 3-5, the top-right and top-left fingers' status boxes indicate the fingers' condition in their corresponding hands. If the finger status box color is red, it means that the finger is being bent; meanwhile, if the finger status box color is green, it means that the finger is being extended. Please notice that the finger status box's abbreviations are Th: Thumb, Id: Index, Md: Middle, Rg: Ring, and Sm: Small. According to our hand gesture recognition system, practically, many variations of hand gestures can be interpreted by our proposed system depending on each hand's palm direction, and fingers state. Accordingly, our proposed system may be developed for many usages. This research focuses solely on our hand gesture recognition system for changing the defender drone swarm maneuver.

Figure 6 describes how our proposed system works. As described earlier, we design a control system where a human can combine its intelligence with artificial intelligence in controlling defender drone swarm maneuvers. In Figure 6, by default, artificial intelligence controls the drone swarm movement using some drone swarm movement algorithms. In our experiment, we use algorithms explained in [22] as the algorithms used by artificial

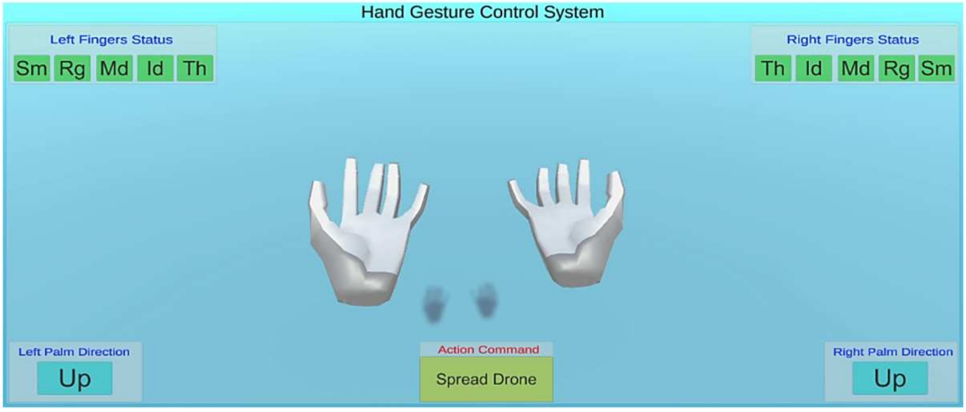


FIGURE 3. Gesture example for spreading drone swarm command

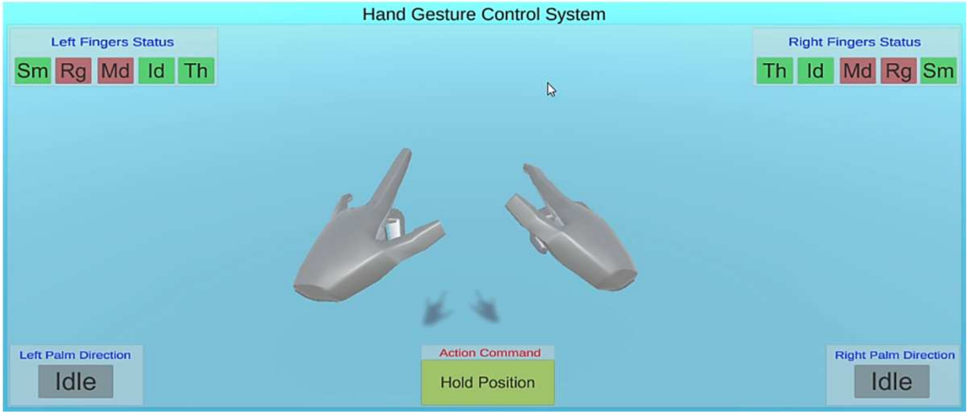


FIGURE 4. Gesture example for holding position command

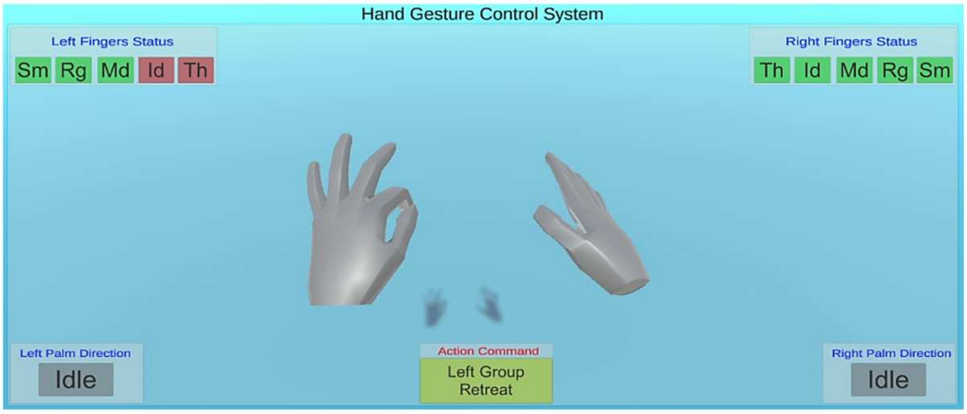


FIGURE 5. Gesture example for half group retreat command

intelligence because [22] has emphasized that they are standard algorithms in mobilizing a drone swarm. However, when a DSP gives some command to the system by using a hand gesture, the system recognizes the gesture, interprets it as a command, and then executes the command for collaborating human intelligence with an artificial intelligence drone swarm controller. Please highlight that this study focuses on measuring how effective human involvement is in deciding drone swarm maneuvers. We argue that human

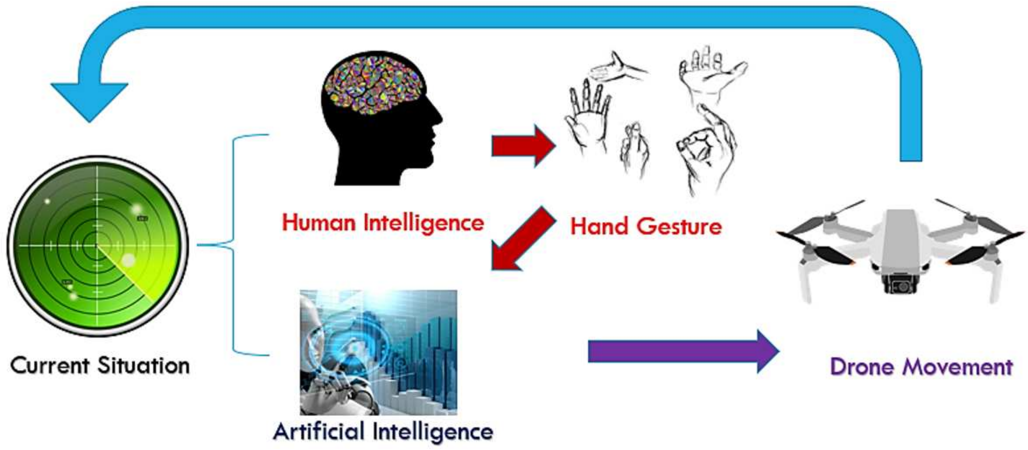


FIGURE 6. Proposed system workflow

involvement can increase the drone swarm maneuver performance when effectively configured. Thus, by designing the proposed system workflow provided in Figure 6, we analyze that we can obtain the best result of human intelligence collaboration with artificial intelligence in controlling drone swarm.

4. **Experiment Results and Analysis.** We have run some simulation experiments to measure the effectiveness of our proposed system. For this research, we develop a 3D simulation environment built with Unity (https://unity.com/). In our simulation, there are two groups of drone swarms combating each other. The first group is the attacker drone group, which invades an area guarded by the second group. The second group is the defender drone group which tries to capture or immobilize the attacker drone group before producing damage to the protected area.

From a computer-science perspective, the problem domain of our research problem is multiple-agents vs. multiple-agents optimization algorithm. In our simulation, there is only one target as the Center of Gravity (CoG). The attacker drone swarm tries to produce as much damage as possible toward the CoG; meanwhile, the defender drone swarm tries to minimize the damage retrieved by the CoG by capturing or immobilizing the attacker drone swarm as fast as possible. In our simulation, as also used in [21,22], we adapt the Cop and Robbers problem scenario [29], where the attacker drone cannot attack any defender drone swarm. In our simulation, the attacker drone swarm runs an *Electrostatic Force* maneuver [30]. This paper does not discuss the obstacle avoidance maneuver or the localization strategy used in the defender drone artificial intelligence algorithm. Some of the paper examples that discuss about them are shown in [31-33].

This research focuses on measuring how good human intelligence involvement is in the effectiveness of the defender drone maneuver. We use the experiment data provided in [22,30] as our comparison basis. The scenario used in this experiment compares the damage retrieved by CoG when being protected by 4 variants of the artificial intelligence algorithm and when being protected by our proposed system. The 4 variants are Waiting Defender (WD), Brute Force (BruteF), Switching Target (ST), and Social Spider Optimization (SSO), as described in [22]. In this experiment, our proposed system is designed to dynamically switch the drone swarm movement among the mentioned 4 variants according to DSP hand gestures. To do that, we count how many DSP fingers are extended; then, we convert it to the associated artificial intelligence variants: 1 for WD, 2 for BruteF, 3 for ST, and 4 for SSO.

In this experiment, to objectively measure the effect of human intelligence involvement in controlling the defender drone swarm maneuver, we do not design some complex hand gestures command maneuvers. Here, we limit the hand gesture input from DSP to switch drone swarm maneuvers among the 4 variants of the artificial intelligence algorithm. We realize that our hand gesture recognition system may recognize many hand gesture variants of DSP. Nevertheless, we decide to focus our research on analyzing the effect of human intelligence involvement in switching defender drone swarm artificial intelligence among the mentioned 4 defense algorithm variants. We interpret that if involving human intelligence to switch the maneuver may improve the defender drone performance, then human intelligence involvement in a more sophisticated hand gesture control system can surely improve the defender drone swarm's performance. Consequently, if enabling a DSP to switch drone swarm maneuvers using hand gesture commands can produce a better defender drone swarm performance, we can conclude that our proposed system is practically good for controlling a drone swarm.

Figure 7 shows how our simulation environment is. In our simulation environment, several defender drones (marked with yellow) are located around the CoG. The CoG is notated with a 3-color (red-black-white) dot in the center of a pink circle. The pink circle marks the damaged border of the CoG area. It means that any attacker drone (marked with blue color) located outside the pink circle cannot produce any damage to the CoG. Meanwhile, when the attacker drone is situated inside the pink circle, its produced damage towards the CoG gets higher when it gets closer to the CoG. When a defender drone immobilizes/captures any attacker drone, this situation is shown with a pink line to illustrate a shooting process. In the top-right corner of Figure 7, we provide a mini-map showing the drone battle area's whole situation. A DSP uses this mini-map to consider the hand gesture command he/she should give to the control system.

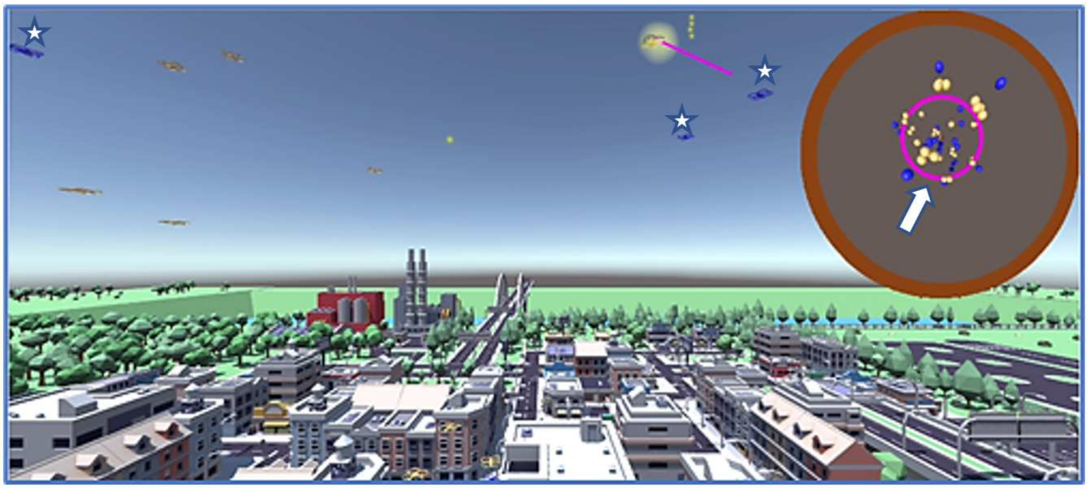


Figure 7. (color online) Simulation environment interface*

*Special Note: For readers who read this paper in black and white color format, please use this information. The drone with an additional star mark is originally printed in blue color. The other drones are printed in yellow color. The arrow on the top-right mini-map points to a pink circle that indicates the damaged border of CoG.

Every equation and configuration used in this research refers to [21,22,30], including the CoG damage calculation, the algorithm for the defender drone swarm, and even the attacker drone movement algorithm. We do not introduce any new equation in this research because this research is aimed to highlight how good the collaboration result of human intelligence and artificial intelligence is in managing the defender drone swarm maneuver.

Table 1 shows our experiment results. The CoG damage accumulation result in Table 1 is obtained by repeating the experiment 10 times for each case, and then the average value is written in Table 1. The lower the CoG damage value in Table 1 column, the better the related algorithm's performance is. Table 1 is relatively similar to the data provided in [30]. We use the same scenario provided in [30] as our data comparison. The only difference is located in the last column of the experiment data. The last column of Table 1 shows the damage accumulation retrieved by the CoG when our proposed control system controls the drone swarm.

Table 1. Experiment results for performance evaluation

Case	**Attacker**	**Def**	**WD**	**BruteF**	**ST**	**SSO**	**Prop**
1	4	4	0	161	83	87	0
2	8	8	1034	11196	3342	4974	1560
3	16	16	2957	5374	583	2149	393
4	32	32	6519	2983	361	251	243
5	64	64	1175	1418	339	179	177
6	128	64	6389	5977	2478	3249	2461
7	256	64	6645	15585	16662	15300	3684
8	32	64	2	68	147	17	2
9	16	64	1	37	36	8	2
10	16	32	3	155	123	29	3

Abbreviations:
Case = Case Number, Attacker = Number of Attackers, Def = Number of Defenders, WD = Waiting Defender Algorithm Performed by Defender Drone, BruteF = Brute Force Algorithm Performed by Defender Drone, SwitchT = Switching Target Communication Strategy Performed by Defender Drone, SSO = Social Spider Optimization Algorithm Performed by Defender with 65% Female Spider, Prop = Proposed System.

According to Table 1, we can analyze that, in general, our proposed system may reduce the damage retrieved by a CoG area. Figure 8 shows the graphical chart of our proposed system performance compared to other artificial intelligence algorithms in Table 1. As you can observe, our proposed system outperforms other artificial intelligence performances in case 3 – case 7. Meanwhile, our proposed system is outperformed by WD performance in case 2. Our proposed system performs relatively similar to the best artificial intelligence in case 1, case 8, case 9, and case 10.

According to our analysis, each artificial intelligence used in this experiment has its own superiority in each case. There is no "always best" algorithm for defender drone swarm artificial intelligence. Interestingly, when human intelligence is involved in controlling the defender drone swarm maneuver, the defender drone swarm performance is relatively improved. Case 3 – case 7 show that human intelligence involvement significantly reduces the CoG damage value. These results indicate that human intelligence can improve artificial intelligence's performance in controlling the defender drone swarm maneuvers. Human intelligence that can analyze patterns and adapt to real-time situations is proven beneficial in arranging defender drone maneuvers.

In each experiment, the default artificial intelligence used by the defender drone swarm is WD. After analyzing the drone battle situation, human intelligence decides what the defender drone swarm needs to do. Because of this situation, when the number of attackers

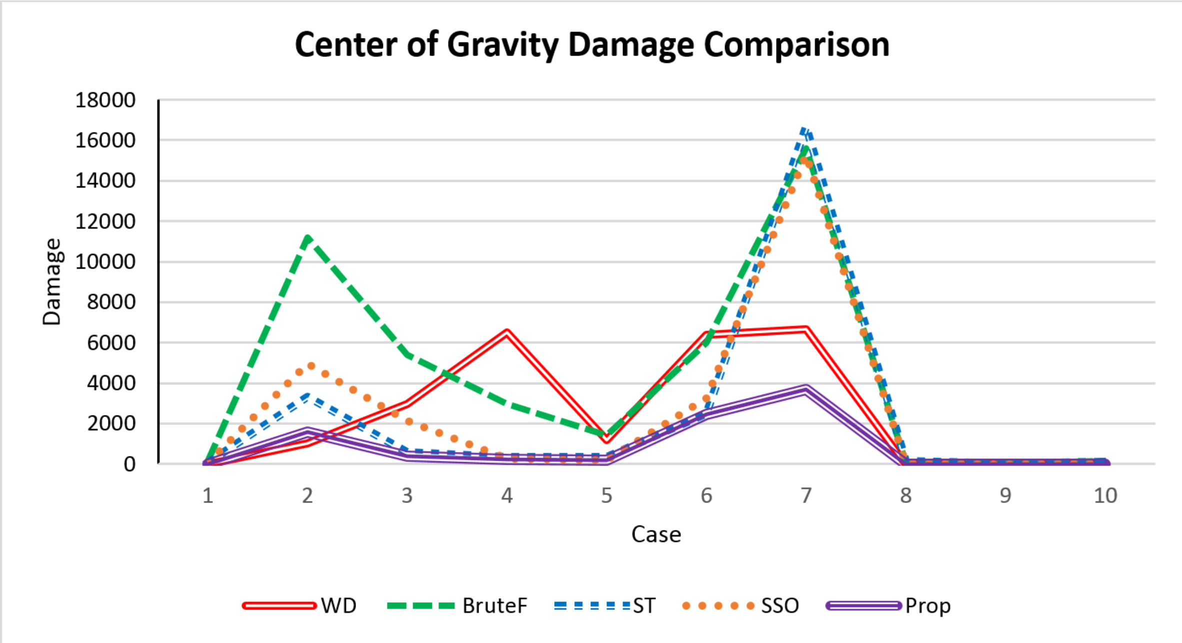


FIGURE 8. Center of gravity damage comparison chart

and defenders is still low, for example, in case 1, all the attacker drones are demolished by the WD algorithm before humans can interfere with the defender drone swarm movement. Consequently, the CoG damage value of case 1 is the same as the CoG damage value of the WD algorithm.

The most significant improvement provided by the proposed method occurs in case 7. It happens because the attacker number is relatively high. Because of this, human intelligence can thoroughly observe the attacker's behavior; thus, humans can produce significantly better performance than other artificial intelligence algorithms. In case 8 – case 10, the proposed system is relatively similar to WD performance because the defender drone number in these cases is somewhat higher than the attacker drone number. Consequently, the algorithm can damage many attacker drones before human intelligence is involved because the default artificial intelligence used in the proposed system is WD.

Our proposed system is only outperformed by WD in case 2. However, in this case, our proposed system beats BruteF, ST, and SSO performance. The analysis for this result is because the attacker and defender drones' numbers are relatively low. Human intelligence analysis to see the attacker pattern is not as good as the pattern analysis result of case 7. As a consequence, the proposed system cannot beat the performance of the best algorithm for case 2.

Please notice that Table 1 result is obtained from the experiment where the DSP involved is a well-trained person who knows the drone swarm battle characteristic. When our proposed system is tested on an ordinary person, the CoG damage may get worse than the CoG damage data in Table 1. This result indicates that the capability and intelligence of the DSP are vital aspects of our proposed system performance. The better the DSP experience in drone swarm battles, the better our proposed system's performance is.

5. **Conclusion.** We propose a hand gesture control system that allows a human to collaborate its intelligence with artificial intelligence in managing defender drone swarm maneuvers when combating with attacker drone swarm. This research aims to evaluate human involvement in helping artificial intelligence gain air superiority in the aerial battle

between drone swarms. We have tested the performance of our proposed system in a 3D simulation environment. In our experiment, we run 10 scenario cases with 10 repetitions for each case. We compare 4 artificial intelligence performances in each scenario with our proposed system. The experiment results show that our proposed system practically brings improvement to defender drone swarm performance.

As the proposed system's primary mission is to improve defender drone swarm performance in gaining air superiority, we can declare that our proposed system experimentally can support this mission's success. The drone battle experience of the human involved in our proposed system plays a crucial role in our proposed system's performance. The better the human experience in drone battle, the better our proposed system performance supports the defender drone swarm.

In general, we can analyze that although artificial intelligence may bring significant benefits for defender drone swarm performance in handling attacker drone swarm, human intelligence can still improve the artificial intelligence performance. We highlight that human intelligence cannot be totally replaced by artificial intelligence, especially in aerial warfare. By providing a system that allows humans to collaborate with artificial intelligence using natural hand gestures, we hope it can inspire other researchers to develop other systems that can naturally combine human and artificial intelligence. Combining human and artificial intelligence can bring enormous results to any system.

For the future follow-up of our study, we suggest that there should be further research to analyze the best hand gesture for DSP in controlling drone swarm by using leap motion. Currently, we have not studied the gesture movement alternatives for a DSP in commanding a drone swarm. We only provide one specific gesture for a particular command. In the future, if there are some studies related to this, the collaboration of human and artificial intelligence in controlling drone swarm movement is hoped to be improved. Furthermore, as an integral part, human and artificial intelligence collaboration can be more advanced when more research provides multiple collaborative approaches for DSP in controlling drone swarms with artificial intelligence, for example, by using hand gestures, voice commands, and even brain waves. If these collaborative approaches have been studied intensely, we believe the future of drone swarm control in the military will reach its highest potential in a short time.

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