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Enhancing Assault Maneuvers in Simulated Scenarios of Multiple Invader Kamikaze Drones through the Utilization of a Modified Adaptive Elforce Algorithm

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Abstract

The development of autonomous drone technology has led in their widespread deployment, especially in combat scenarios. One instance of this is the utilization of kamikaze drones, as seen in the Ukraine war. Autonomous defense drones have been used to counter these invading kamikaze drones. This study focuses on simulating scenarios involving invader vs. defender drones, primarily exploring invader drone maneuver motions to maximize damage inflicted on chosen targets. The work we conducted presents an enhanced el-force algorithm that employs Coulomb's Law-based maneuver techniques to improve the effectiveness of multiple kamikaze invader drones when engaging target defended by defender drones. We aim to improve traditional el-force by addressing key challenges such as siege tendencies and unproductive conduct. In addition, we explore various attacking formations to determine the most effective formation. To evaluate the performance of our proposed algorithm, we conducted simulation in a dynamic 3D environment, employing damage inflicted as the evaluation metric. Through rigorous testing, we conclusively demonstrate that our proposed method combining with a circular formation, outperforms alternative attacking maneuvers and formations. Our findings provide insights into optimal maneuver movements and attacking formations, improving the effectiveness of invader drones in engaging and damaging designated targets.
Keywords: *drone, drone formation, kamikaze, el-force, 3d simulation, manuever*

1. Introduction

The utilization of autonomous drones in military operations has gained significant attention in recent years. With rapid advancements in drone technology, these unmanned vehicles offer numerous advantages, including their application in swarm attacks. The ongoing conflict between Russia and Ukraine has witnessed the deployment of swarm attacks, particularly kamikaze-style drone strikes, resulting in the destruction of formidable vehicles such as tanks and planes. Consequently, there is an urgent need for more effective methods to address this emerging threat. One promising approach involves using multiple drone technologies to form a cohesive group of defenders capable of autonomously intercepting, neutralizing, or immobilizing these kamikaze invader drones. Extensive studies have demonstrated the potential of swarm defense strategies in countering swarm attacks. Our own research findings [1,2] reinforce this notion, highlighting how a well-coordinated algorithm implemented among autonomous defender drones can effectively mitigate the damage caused by multiple attacker drones.

While defense has remained the major application, there are times when a swarm of drones for attack purposes is required. We believe that autonomous multiple invader drones are a suitable approach because most research in fighting swarm attacks have used autonomous defender drones and the limited number of available pilots in commanding drones may impede efficiency. A few research studies have looked into the area of drone combat strategy, as pointed out in [3-7], and potential use of drones in conflict, as mentioned in [3-10]. While many invader drones show potential for performing effective movements against targets, their effectiveness is dependent on the deployment of an efficient autonomous coordination algorithm and communication architecture, as demonstrated by the research described in [11-18]. Aside from that, [1,2, and 19] highlighted toward the fact that establishing such algorithms involves extensive communication and processing before initiating movement, which might be problematic when utilized in a dynamic situation such as a military battle. Given that complex algorithms could lead to delays in the movement of invasion drones.

To address this issue, [19] presents an invading maneuver algorithm based on adaptive electrostatic force law that can be performed via numerous invader drones without inter-drone communication to perform an optimal movement strategy based on current circumstances while inflicting substantial harm on its target. When compared to a straightforward maneuver, a typical maneuver that concentrates on advancing the invading drone toward the intended target while disregarding the existence of any defensive drone, the presented approaches [19] perform substantially better.

However, our investigation into the current adaptive electrostatic force research has revealed certain drawbacks. One notable issue is that the drones tend to cluster together, causing a siege effect, and can be pushed away from the intended formation in certain circumstances. This can significantly impact the effectiveness of the kamikaze swarm attack.

Therefore, our research not only focuses on developing an improved invading maneuver algorithm based on the adaptive electrostatic force law, but also aims to address these limitations and optimize the formation and movement of kamikaze drones in order to achieve maximum damage to the target area. By considering both the formation and the movement algorithm, we aim to overcome the challenges posed by the current shortcomings and enhance the overall effectiveness of kamikaze swarm drone attacks.

2. Research Scope

As our work are based on this research [19], we would conduct its surroundings in a manner comparable to that of its inventor. For this, we replicated our suggested technique in a 3D environment, where a group of invader drones using our proposed method would be task striking a target. The target will be protected by numerous drone defenders in this case. This sort of situation is well recognized as form of pursuit-evasion issue variation, for which several study types have been undertaken [1,2, and 19]. In figure 1, the problem domain of this research will be displayed. Several invading autonomous drones will try to fly towards a certain target whereas the defender drone will try

Fig. 1. Problem Domain

to guard its defended target by destroying the invading. Just like [1,2, and 19], on our simulation invader drones are unable to hit the defender drones and will only be focusing its movement towards the target area since it's the only way for invading drone to produce damage.

As stated in the introduction, our research focuses on implementing an algorithm that modifies the movement of the invader drone to achieve better results in the pursuit-evasion problem, which is why we will configure all invader and defender drones to have the same speed and detection range capabilities in this study. The defensive drone has three ranges which can been seen on figure 2, the most distant of which is the R3 range, which is a blind range in which no object can be identified. R2 is the range at which the defender can detect the presence of another drone, while R1 is the range at which the defense drone can destroy any invader. Defender drones cannot correctly eliminate any invader if their range exceeds R1, which is why R2 must travel towards the invader after discovering it.

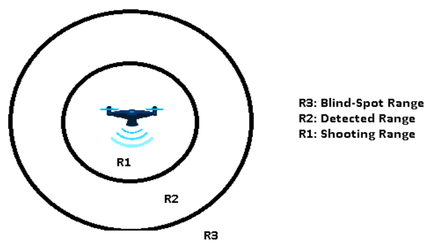

Fig. 2. Variety Region of Defender Drone

In the previous paragraph, invader drones are stated to be unable to assault or crash any defense, which is why the R1 Region is not utilized in this situation for the invader. However, the invader drone may still do harm to the target if it is close enough to it; the closer they are, the greater the damage to the region. In this experiment, each drone is assumed to have a collision-avoidance sensor and algorithm that allows them to maneuver close to each other, even bumping, without causing any effect to one another. Technical aspects such as how defender shoot, and sensor of each drone will be described in this simulation as we focus sole only on its algorithm effectiveness. For more information regarding sensors, obstacle-avoidance algorithms can be seen in such research [6,7,12,15, and 16]. Other than that, the reason we are not using any extra variables is to be appropriate to emulate its surroundings as similar as possible as our reference research.

The calculation of damage inflicted by an invader drone, upon reaching a certain distance from the target, is of interest. When an invader drone reaches a specific distance from the target, we calculate the damage inflicted. The invader drone's position is represented by the vector3 variable (xI), while the target's position is denoted as (xG). Upon the invader drone's destruction, we determine the range between its last position (xI) and the target position (xG). Based on this range, we calculate the damage, denoted as D, inflicted by the invader drone. If the range is equal to or closer than one unit, we set the damage to 100. For ranges greater than one unit, the damage is calculated by dividing 100 by the squared value of the range. It's important to note that this calculation applies only when the distance between the invader and target falls within or equals the designated range for target damage, referred to as rdamage. At the conclusion of the simulation, the accumulated damage from each invader is analyzed, serving as a performance measure for our algorithm. A higher damage value reflects improved algorithm performance. We have chosen a range of 10 units for rdamage, as Unity 3D environments do not have specific units of measurement. Therefore, all distances in the environment are referred to as 'units'."

Algorithm 1. Damage Calculation Each Invader Drone

```
Input: Vector 3D Position of xI and xG
Output: total damage of units.
range = distance(xI,xG)
if range <= rdamage:
    if range <= 1unit
        D = 100
    else:
        D = 100 / (range * range)
    end if
return D
```

In order to enhance the reader's understanding of the formula used to calculate damage inflicted by invader drones, we have created a practical example to illustrate its application. In this example, we consider a scenario where three invader drones are deployed, each at a different distance from the target. By examining the specific ranges and corresponding damage values, we aim to provide a clearer comprehension of how the formula functions in the simulation.

In this instance, three invader drones are destroyed at distances of 12 units, 5 units, and 0.5 units from the target, respectively. The distances between the invading drones and the intended target of their attack are represented by these range values. We can evaluate the differential effects that different ranges have on the total destructive capabilities by assessing the damage produced by each invading drone.

The damage dealt by the first invader drone (Invader 1) with a range of 12 units is assessed to be 0 according to its position beyond the range of the rdamage, which is 10 units from the target. The second invader drone (Invader 2), which has a range of 5 units, deals 4 damage. Finally, the third invader drone (Invader 3) has a range of 0.5 units and deals 104 damage. The three invaders dealt a total of 104 units of damage.

3. Proposed Method

In this section, we present our modified Adaptive El-Force algorithm for attacking maneuvers in multiple invader drone simulations. The algorithm incorporates the concept of El-Force based on Coulomb's Law to coordinate the movements of invader drones effectively.

3.1 Adaptive El-Force Algorithm

Adaptive El-Force [19] is an algorithm that replicates the interaction of charged particles by considering defensive drones and target regions as charged particles and is based on the notion of Columb's Law. Defender drones are classified as positively charged particles, whilst the target region is classified as negatively charged. Coulomb's Law is used to determine the El-Force, where F represents the El-Force, k is a constant number, q1 and q2 are the charges of the particles, and r is the distance between them. The charge's sign affects whether the El-Force is repulsive or appealing.

$$F\ Movement = \sum_{i=1}^{n} \frac{k*q1*q2}{r^2} \quad (1)$$

The El-Force concept is used in the simulation to synchronize the movements of the invader drones. Each invading drone calculates the El-Force result based on surrounding defender drones and the target area. This calculation is done using equation (1), where particle-i represents the target area or a drone defense system around an intruder drone. We utilize vector summation to get the overall force experienced by an invader drone since the El-Force resultant is a vector value. The exact magnitude of the El-Force is less important; what matters is the direction that the El-Force leads to.

Thus, we may simplify computations without materially changing the direction of movement by assuming certain variables, such as the charge values and constant values. In addition, the phrase "adaptive" refers to the target area's charge being increased over time if the invading drone fails to do damage within a given period. This is done because intruder drones have the drawback of avoiding many defense drones without causing harm to the target region. A kamikaze maneuver occurs when the invader drone prioritizes assaulting the target region even when there are defense drones present by increasing the charge's strengths and the attractive force that the target location exerts on the invader drone.

3.2 Modified Adaptive El-Force

The Modified Adaptive El-Force algorithm is an improvement on the standard Adaptive El-Force algorithm used in drone swarm assault simulations. It seeks to overcome the constraints of the original approach. The current Adaptive El-Force algorithm utilized in this simulation has a significant shortcoming. The El-Force may cause an invader drone that is close to the target region to be pushed farther away or even to leave the attack zone in certain circumstances. Due to the drones' potential to accidently stray from the intended target region, this behavior reduces the efficiency of the assault operations. The situation described in figure 4 demonstrates the set of circumstances. The image depicts three drones: two blue drones representing the defender drone and a pale white one representing the invader drone. A black arrow in he image indicates the direction in which the invader drone will move, based on the electromagnetic force exerted by the defenders and the target. In figure 4A, the invader drone is correctly aligned towards the target. figure 4B shows a similar alignment, but as the defender drone gets closer to invader, it causes the invader to experience a repulsive force that causes it to move farther away from the target. This effect is observed in figure 4C and 4D. Even though the conventional method includes an adaptive mechanism that enhances the attractive force towards the target, circumstances like these can arise when the target's attractive force is not strong enough to overcome the repulsive force from the defender.

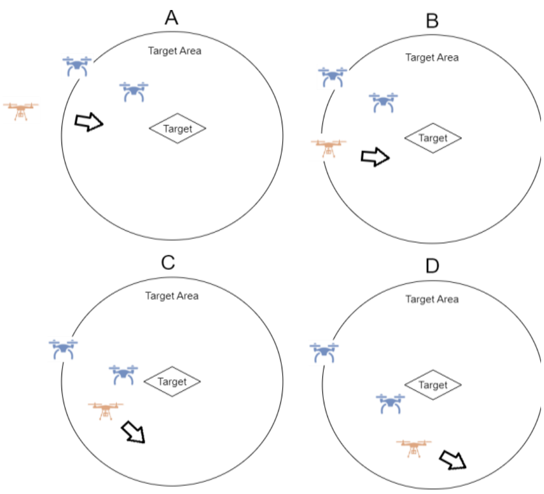

Fig. 4. Adaptive El-Force Drawback when nearing Target.

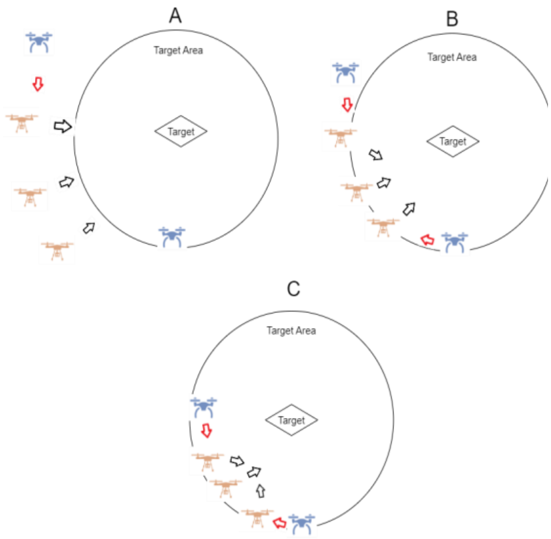

Fig. 5. Adaptive El-Force Drawback when nearing Target.

The attacking drones must also keep their distance from one another because this is a swarm attack in order to prevent siege and guarantee synchronized movement. However, the present method is unable to separate the invading drones from one another, which may result in stacking or unproductive swarm behavior. To explore this flaw, Figure 5 depicts a specific scenario in which three invader drones are moving toward a target guarded by two defender drones. The black arrow represents the attacking drone's direction, while the red arrow indicates the defense drone's direction. Figure 5A shows that one of the invader drones has been identified and begins to alter its location in order to move away from the defensive drones, mistakenly guiding them towards the other invader drones. The results of the prior situation are visible in figure 5B, as the three invader drones are unintentionally sieged and held down by the defense drones, where the final location of the Invader drone may be seen in figure 5C.

To overcome these limitations, we introduce modifications to the Adaptive El-Force algorithm, focusing on addressing the aforementioned drawbacks:

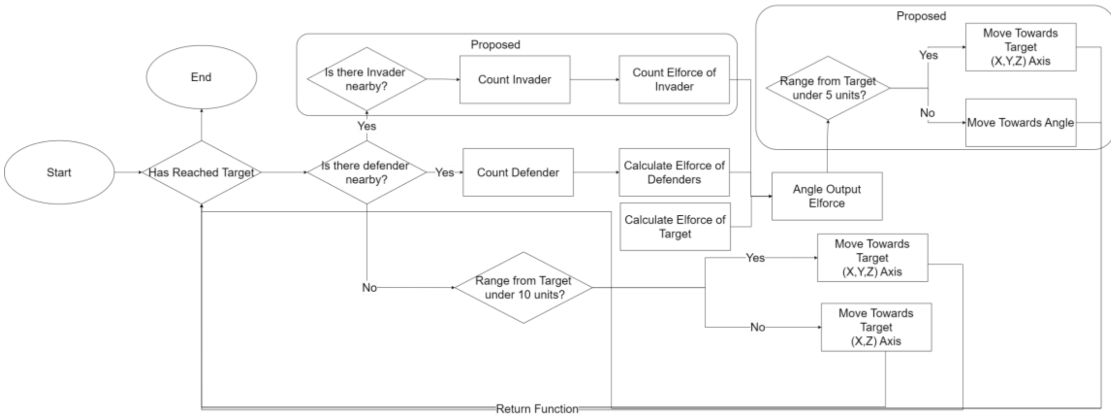

Fig. 6. Proposed Adaptive El-Force Algorithm Overview

a) Treating Detected Invader Drones as Positively Charged:

In our modification, each identified invader drone behaves as though nearby invader drones are also positively charged particles. They will incline to split from one another and maintain a specific distance by acting as repellent forces between invading drones. The drones may achieve better separation within the swarm thanks to this improvement, which encourages more efficient coordination and lowers the likelihood of collisions or clustering.

b) Removing Adaptive El-Force Effect when Close to the Target:

The elimination of the El-Force effect when an invading drone is sufficiently close to the target is another change we make. The drone is instructed to fly directly in the direction of the target rather than being affected by the repellent force. Invader drones may efficiently enhance their efficacy and deliver more powerful strikes without mistakenly being driven away from the target region by reducing the repelling force around the target. Proposed Algorithm Overview can be seen on figure 6.

4. Experiment

In our proposed method, invader drones calculate the El-Force resultant they experience from nearby defender drones and the target area, considering the modifications discussed above. The resulting El-Force directs the drones' movement, enabling greater swarm separation and enhanced assault zone targeting. We will test the improved El-Force algorithm in several invading drone scenarios to determine its efficiency. Metrics damage done to the target region will be the main emphasis of the evaluation. To verify its efficacy, we will compare the modified El-Force algorithm's performance to that of the original El-Force algorithm and other current methods.

4.1 Experiment Settings

4.1.1 Formation of Drone

In our experiment, a swarm of kamikaze invader drones is built to represent the attacking force. The formation of the invading drones [20] is crucial to the swarm's overall success. We consider different formation strategies to assess their impact on the attacking maneuvers. These formations can include geometric patterns such as a V-shape formation depicted on figure 7, a Triangle-shaped formation depicted on figure 8, and a circular formation which is depicted on figure 9. Each

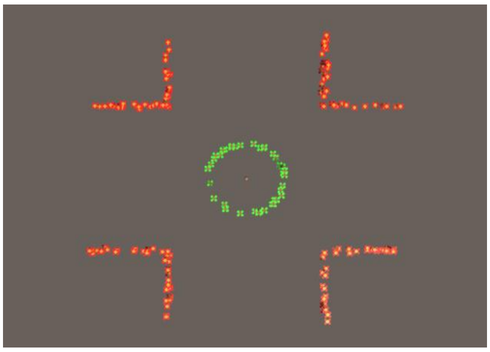

Fig. 7. Triangle Formation

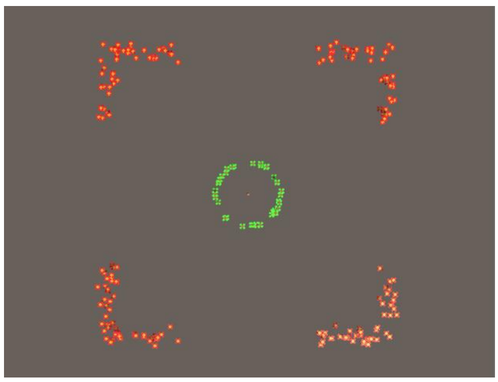

Fig. 8. V-Shaped Formation

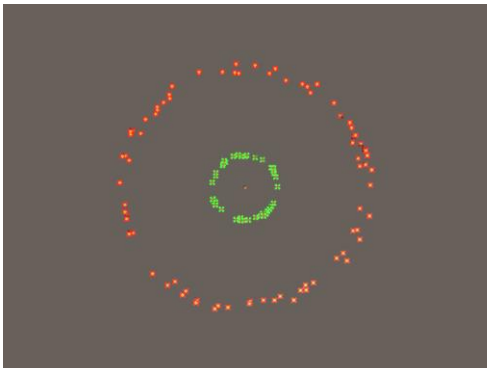

Fig. 9. Circle Formation

experiment starts with the invasion drone placements within the formation being started, and each experiment run involves various invasion drone instantiations inside the formation.

Figures 7 to 9 showcase strategically positioned defender drones around the target area, forming a defensive formation. Green dot figures represent these defenders, while red dots depict invader drones. The defender drones adopt a circular formation, specifically tailored for stationary target simulations [1, 2, and 19]. Positioned 10 units away from the target, at the target damage zone's edge, each defender drone safeguards the area. The initial height of the agents varies between -5 and +5 units compared to the target's height. The target is distinguished by a brown color, while the drones involved in the simulation are visualized differently.

At the beginning of every simulation the positions of the invader and defender in each experiment are randomized which can be seen in figure 7 to 9. Several rules are implied such as the invader's closest position to the target is always 40 and the number of invaders in each region north, south, east, and west are always equal.

4.1.2 Movement of Drone

Each agent's movement between the Defender and Invader follows a unique algorithm. Due to the fact that invaders begin at various heights, they will advance directly in the direction of the target while maintaining a constant height up until they are a certain distance away from it which is 5 units, at which point they will begin to shift latitude to the target's height, imitating references research [1,2]. Other than that, we would put into place two other tweaks related to the extra maneuvers invading drones may do when a defensive drone detects them. Those are the suggested approach and the conventional adaptive el-force.

To increase the defender's chances of success, we chose to use the Switch Target Communication [2], which is a maneuvering movement for defenders, instructing them to stand by at their position until an invading drone is detected on their R2 range. A defender will pursue the invader who has been detected, but if another defender who is not pursuing anyone is closer to the invader, the current chaser will switch tasks, the closer one will take over the pursuit, and the previous chaser starts searching for another invader. We define the maximum range of search space for each defender to avoid the scenario where defender drones are lured to travel too far from the target. We set the defender's maximum search range two times the damage. The illustration of the scenario in switch target is shown in figure 10.

4.1.3 Evaluation Metrics

We used the metric of "damage inflicted" as a measure of the impact caused by the invading drones on the target region to evaluate and compare the performance of the proposed improved El Force algorithm with existing methods. The distance between the invasion drones and the target area is used to calculate this measure. For example,

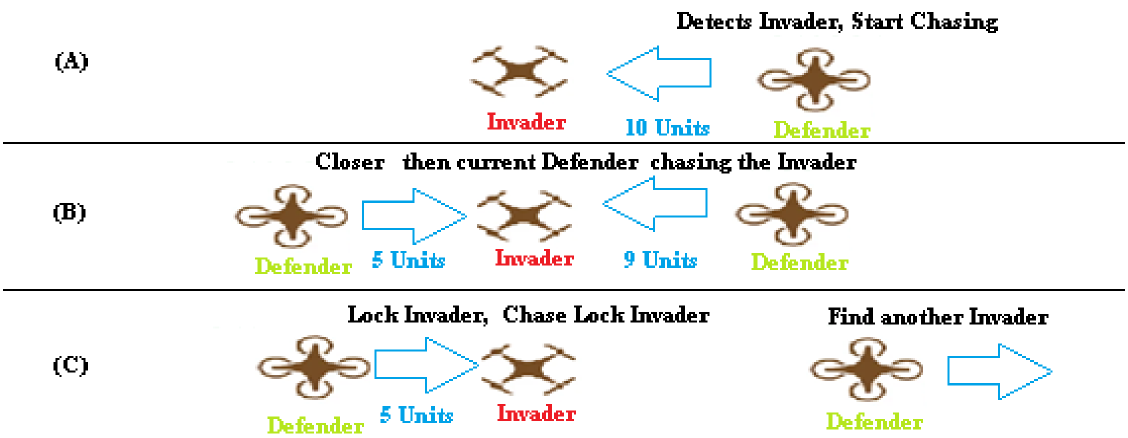

Fig. 10. Switching Target Illustration

Table. 2. Experiment Result

Case	Amount		Formation	Average Damage		
	Defender	Invader		Straightforward (SF)	Adaptive El-Force (EL)	Proposed (Prop)
1	40	40	V	0	102.04	112.80
2	40	80		0	128	183.07
3	40	160		0	227.8	404.82
4	40	200		10	313.04	562.07
5	40	40	Triangle	0	68.17	134.15
6	40	80		0	128.03	243.91
7	40	160		0	241.08	441.04
8	40	200		0	274.99	489.71
9	40	40	Circle	0	127.1	133.5
10	40	80		100	210.7	311.8
11	40	160		170	298	924
12	40	200		210	457.1	1687.27

if an invading drone is 5 units away from the target area, its damage output is 100 divided by distance to target area power by 2, yielding 4 as an integer value. This computation, however, can only be used if the invading drone has reached the minimum damage range of 10 units to Target. All invader drones that were destroyed where their positions fulfilled the requirement had their positions accounted for in the algorithm to finalize the damage output. The specific algorithm formula employed for this calculation is described in depth under the research scope of the study presented here and the pseudocode of the damage inflicted metric can be seen on Algorithm 1.

Several methods can be employed to assess the performance of a proposed algorithm in similar scenarios, such as measuring the success rate, evaluating the coordination among invader drones, and analyzing time efficiency. However, for the purpose of this study, we have chosen to focus solely on the "damage inflicted" method. This decision was made to emphasize the improvement in maneuverability and the potential for increased damage to the target.

Table 1. Variable used in Experiment.

No	Variable	Value
1	Invader and Defender Drones Movement Speed	1 unit per iteration
2	Defender' R1 Capture radius	2 units
3	Defender' R2 Detect radius	10 units
4	Invader detection radius to one another	2 units
5	Target damage range (r damage)	10 units
6	Maximum Distance of Defender from Target	20 units
7	Experiment Repetition	10 times
8	Minimal spawn distant of Invader to Target	40 units

By using the "damage inflicted" metric, we can gather more detailed information about the effectiveness of the algorithm. Assessing the coordination among invader drones would introduce complexities and potential delays in their movements, which goes against the objective of the modified El-Force algorithm. Our goal is to enable optimal movement strategies for invader drones without the need for inter-drone communication, while still inflicting significant harm on the target area. Furthermore, while time efficiency is crucial, it does not always correspond with the desired objective of inflicting maximum damage on the target. The time required to achieve the goal with the modified El-Force algorithm is expected to be longer than with the standard El-Force strategy.

In summary, by focusing on the "damage inflicted" metric and employing the modified El-Force algorithm, we hope to demonstrate the algorithm's ability to improve maneuverability and increase the potential for significant damage to the target area while keeping time efficiency as a Secondary consideration. A summary of variables used in experiment can be seen on table 1.

4.2 Experiment Result

In order to assess the full performance of comparison between our proposed method and the conventional way, we have undertaken a variety of invader and defender scenario. Due to its nature of having dynamic enviroment in the experiement, we tested each scenario ten times before calculating the average number of damage, as shown in Table 2.

We also divided Tabel 2 into several charts that is seen at figure 11,12, and 13 to which allows for easier reading and analyze different formation of invading drones. These numbers show that the proposed method outperforms the traditional approach.

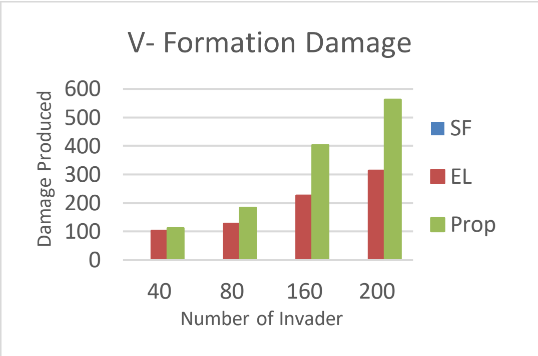

Fig. 11. Number of damages of each method in V formation

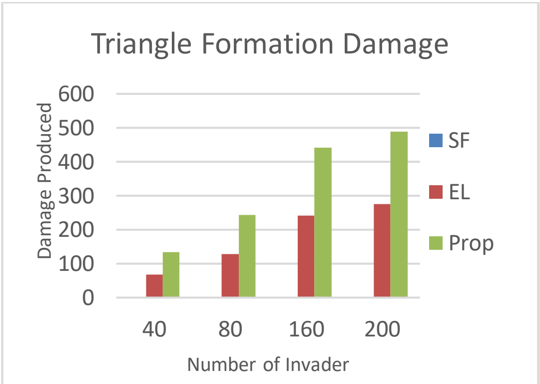

Fig. 12. Number of damages of each method in Triangle formation

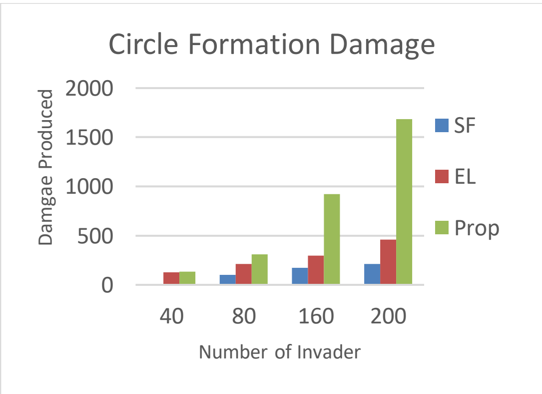

Fig. 13. Number of damages of each method in Circle formation

5. Result and Discussion

According to the results of our trials, the suggested method given in this research beats both the straightforward and the typical adaptive El Force algorithm in terms of producing damage to the targeted region. The damage produced by the simple method, in which the invader drones travel directly towards the target without any maneuvering, is the lowest of all approaches, which is consistent with predictions. On the other hand, the conventional adaptive El-Force algorithm, while exhibiting better damage output compared to the straightforward approach, still demonstrates certain drawbacks. It tends to result in siege between drones and pushes them further away from the target area or even outside the attack zone in certain circumstances. These limitations lead to lower damaged output compared to our proposed methods.

However, the conventional adaptive El-Force algorithm does showcase higher damage output than the straightforward approach due to its maneuvering capabilities, which allow it to evade defender and navigate more effectively. Additionally, we conducted an analysis of different invader drone formations, including the triangle, V-shaped, and circle formations, to determine their performance in this particular scenario. Table 2 displays the results, indicating that only the circle formation, when combined with the straightforward maneuvering approach, was able to generate damage, unlike the V-shaped and triangle formations.

Moreover, this superior performance of the circle formation was consistent across both the conventional adaptive El-Force algorithm and our proposed method, where it resulted in the highest damage output compared to other formations. These findings emphasize that, in this specific scenario, circle formation proves to be more effective than alternative formations. Further analysis, as illustrated in figure 9 and 10, reveals similar outcomes for the conventional adaptive El-Force algorithm, wherein the V-shaped formation achieved a higher success rate compared to the triangle formation in most invader scenarios.

This outcome aligns with the results obtained from our proposed method. Overall, these results demonstrate the superiority of our proposed method over the straightforward approach and the conventional adaptive El-Force algorithm. The circle formation, combined with the proposed method maneuvering approach, exhibits the highest damaged output, highlighting its effectiveness in this particular scenario.

6. Conclusion

Our studies show that the suggested method in this work beats the traditional adaptive El-Force algorithm and the straightforward approach in terms of producing damage to the targeted region. The straightforward strategy produces the least amount of damage, whereas the traditional adaptive El-Force algorithm produces more damage but has restrictions in terms of siege and driving drones further away from the target. In this case, the circular formation paired with the proposed Adaptive El-Force maneuvering strategy shows to be the most successful configuration with an inflicted damage of 1687,27. However, additional improvements to the Proposed Adaptive

El-Force approach can be produced to overcome any new problems that may be discovered. Future research will look at improving the attack and defense algorithms, including kinematics to boost realism, and looking into other areas to improve the overall performance and usefulness of the Proposed Adaptive El-Force approach in kamikaze swarm assault simulations. By addressing these aspects, we aim to advance the understanding and effectiveness of kamikaze swarm attack strategies in military scenarios.

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