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Motion Camouflage Guidance Strategies in an Aggressive Honey bee

Chakravarthi Jada*, Ashok Urlana, Pavan Baswani, Gouse Basha Shaik,
Sita Mounika Rayavarapu, Venkata Sai Rakesh Peteru, Santhi Sree Sandala

***Abstract*— The paper presents the conduction of the experiments and motion-camouflaged approach to determine how a bee chases and intercepts a moving target. The experimental setup is made ready, and the bee-target motion episodes are recorded for various target movements. The bee-target position tuples are generated at all-time instances, followed by the simulation of trajectories. The verification of motion camouflage strategies by the bee is carried out. Then a kinematic model with three phases is hypothesized and compared with motion-camouflaged data and it is found that both are interrelated. Then, switching between camouflage strategies is concluded. Concluding remarks on the future scope were discussed at the end. This research work is the first of its kind in observing the aggressive behavior in the bees and looking into their motion strategies.**

I. Introduction

Nature is a resource for many kinds of flora and fauna. Most of the creatures in the fauna have various lifestyles to feed, defend, and attack predators to sustain their lives. In general, most insects attack aggressively, individually or as a group. For instance, ants attack predators to protect their nests, mosquitoes attack for foraging food, and many more examples can be found in nature. In the view of attacking to protect their territory, the *Honeybee* is one of the eye-catching insects. There are around 7-12 species of honeybees in the world. In those, *Apis mellifera* (European Honeybee) is one of the most common species of bees which produces honey and has moderate aggressive behavior [2] as compared to other bee species such as *Apis dorsata, Apis cerana* etc.

A honey bee hive consists of a queen, a few drones, and many worker bees. The queen bee and drone bees are responsible for reproduction. It is well observed that the worker bees keep protecting the hive from birds, reptiles, and human beings etc. by attacking them aggressively as a solo or as a group. To determine the quantitative observations on the honeybee's aggression, [8] performed a behavioral study by introducing the honeybee queen into a cage that contains worker bees. The aggression was determined based on the percentage of queens rejected (dead, badly crippled, or being balled) in the period of observation. Indirect evidence says that the chemical pheromone (stress pheromone) released by the queen in the states mentioned above makes the worker bees more aggressive. The stress pheromone seemed very volatile and dissipated almost entirely on exposure to air for six minutes. The continuous aggression of worker bees depends upon the queen's continuous production of the stress pheromone.

In honey bees, the queen bee will mate with an average of 10 drones. It will lay eggs after 2-3 days of mating. During the queen's flight, the drone will track and fly over the queen and do the interception such that his thorax is above her abdomen to release their sperm[1]. With this observation and insight into the episodes of the drone track and docking with the queen bee, the idea of experimenting with aggressive bees chasing and attacking a target has emerged. Due to their moderate aggressive behavior[2], availability, and ease in conducting extreme experiments, the *Apis mellifera* bees were chosen to conduct the aggressive bee target tracking experiments.

For real-time experiments on bees, the beekeepers and state-of-the-art [1] mentioned various methods to make the Apis mellifera more aggressive. Among those, creating a disturbance at the hive, nectar death [2] situation, a continuous sprinkling of water, heat and humidity conditions makes bees aggressive. Various methods for making the bees aggressive were studied, and a possible approach for making the bees aggressive suits the requirements and resources. The experiments were planned to disturb and make the bees aggressive with a target and recorded both bee and target movements. Also, analyze them to find the pursuer behavior of the bees in the aggressive mode while chasing a target, which is both maneuvering and non-maneuvering. Finally, to use this pursuit behavior to design, and develop the guidance model, and test on artificial targets.

Previous studies have demonstrated motion camouflage in dragonflies (Hemianax papuensis), where these insects use this tactic to pursue prey without being detected. [11] revealed that dragonflies actively disguise themselves as stationary during flight, deceiving their prey's visual system. Similarly, the stick insect Extatosoma tiaratum was found to sway in the wind, using motion to blend in with moving vegetation, a behavior explored by [9]. Another study on cuttlefish (Sepia officinalis) demonstrated how these animals dynamically adjust their camouflage while moving between different environments[14].

To the best of our knowledge, in the state-of-the-art, no research study was performed on the aggressive behavior of honeybees and looking into their strategies.

*Corresponding author is from Rajiv Gandhi University of Knowledge Technologies - Nuzvid, India, cv@rguktn.ac.in

[1] https://www.youtube.com/watch?v=0WB0i1cSBWI
[2] https://tinyurl.com/BeesAggressiveMethods

II. Experiments with Aggressive Bees

A. Bee-hive and Testing Arena Setup

For restricted movement, the experiments are planned in a closed arena. The wooden bee-hive box size is 51 cm × 34 cm × 29 cm, painted with white color, reflecting the light and keeping the hive cool.

Initially, experiments were conducted to measure the maximum traversal distance of bees. With this observation, an aggression room was made with the dimensions 6 m × 4 m × 4 m. For better visualization of the bees, a room was constructed with a white background while experiments were conducted to maintain the intensity range between 200 and 250 candelas. The beehive was placed inside the room so that the beehive entrance and room entrance face each other which allows the aggravator (deemed a target for the bee) to move freely in front of the beehive. Fig. 1 shows the bee hive box and testing arena model setup.

The experiments were conducted in mid-summer 2018 in India, between May 15 and the end of June during early mornings and late evenings [5]. The average room temperature during the day was around 45°C. The bees were observed for natural aggression due to varying temperatures throughout the day. These manual observations were carried out for a week, showing bees were more aggressive in the mornings between 7 AM to 10 AM (IST) and less aggressive in the evenings between 4 PM to 6 PM (IST).

B. Aggravator Selection

After finding a suitable time to do the real-time experiments, different aggravators were used to identify which aggravator can make bees more aggressive. The trial experiments were initiated with the ball as an aggravator cum moving target after disturbing the hive from the top with the brood chamber opened. In the state-of-the-art [4][3], it is mentioned that bees could recognize dark colors more efficiently than other colors. So a blue color ball with a diameter of 12 cm was chosen as an aggravator. After trials, very few bees felt aggressive with this aggravator and attacked the target up to an average distance of one meter from the hive. To increase the area of the aggression region, a few more trails were made with the pink balloon. The basic assumption for this consideration is to burst the balloon once the bee hits it with its sting, which could indicate interception and force-hit. It did not happen practically because the bees did not feel much aggressiveness due to the balloon's less

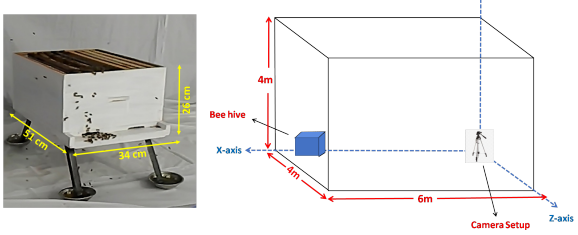


Fig. 1. a) Bee hive box b) Testing arena model setup



Fig. 2. (a). Experimental aggression region setup (b). Camera view of disturbed bees moving

rough surface. In this case, as well, the maximum average attacking distance was one meter; however, fewer bees were agitated compared to the ball aggravator. Later, trials were conducted with a blue brush where the number of bees that felt aggressive hugely increased and attacked the aggravator up to 5 meters from the hive. This aggressive movement is well suited to the experiments because the maximum length from the hive to the opposite diagonal is 8.24 meters. This brush was used with the help of a stick to carry out further experiments.

C. Camera Calibration

The core plan of the experiments is to check the chasing behavior of an aggressive bee to the movement of the target. A smartphone[3] (Samsung Galaxy S6 edge) camera is used to capture the bee-target movements, and it has a range of 120 fps (frames per second). A tripod has been used to set up the camera in the required direction and height from the ground to achieve better stability while capturing the whole episode. The selected tripod has a height range of (40 cm -109 cm). A selfie stick is utilized to hold the mobile at a proper covering position. The beehive is kept in the leftmost corner of the room. The camera is placed one meter from the base and 4.5 meters away from the beehive entrance. Fig. 2 shows a clear coverage of the experimental workspace and the aggressive region setup.

III. Bee-Target Motion Capturing Data Analysis

Recent studies [9][10] used computer vision algorithms to capture the honey bee's flying motion in nature. In contrast to that, in our experiments, the aggravator (brush connected to a stick) was treated as a target. The hive was disturbed on the top. The manual movement was given to the target to move away from the hive within the aggression region. Once the bees are aggressive, they come and chase the target. The whole episode was captured using the camera setup. To understand the bee behavior and for the sake of extensive analysis, various movements, viz. straight line, exponential, parabolic, circular, and random movement, were given to the aggravator. As the movements are manual, the trajectory shapes of the target are nearly accurate, for example in Fig.4 the target movement is near a straight line. Hence, the target's trajectory shape will help us classify the target movement. A total of 108 Bee-Target motion episodes were captured (Table. 1). Each episode had an average duration of 16 minutes. In each episode, the mathematical movements

[3]https://tinyurl.com/SamasungS6Edge

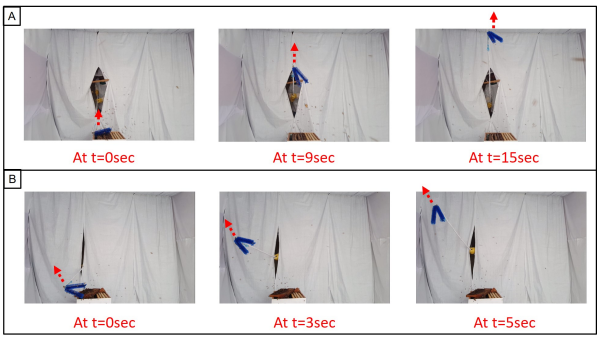


Fig. 3. A) Straight line B) Exponential movements of the Aggravator

of the target were repeated multiple times to obtain more bee-target trajectories. The mathematical movement and the number of captured episodes are listed in Table. 1. Fig. 3. A and B show the aggravator's straight line and exponential movement at various time intervals for each episode.

A. Target Movement and Bee Attack Identification

Each episode is converted into frames based on the captured camera Frames Per Second (FPS). Conversion of videos into frames was done using the MATLAB (Version 2024a) software tool. The entire analysis was performed in a 2D plane as the episodes were captured using a single camera. The (X, Y) coordinates (pixels) of the bee and target in the frames were stored in Excel using the cursor mode on each frame [15][16]. This procedure was repeated for all kinds of movements and all trails in each movement.

B. Movement Classification by Traversal Paths

The observance of episodes such as in Fig. 3. A, B, shows that in each episode, multiple bees are chasing, but only a few bees continue the chase and intercept with the target finally. The main aim of the present research work is to **observe the single bee tracking behavior**. Hence, in each episode, the bee that intercepted the target was identified and traced back its path to the initial point in the camera vicinity range. All these fully intercepted trails were identified and complete traversal paths of each trail (in terms of coordinates) of bee and target were plotted using the above-mentioned cursor method. On average, it is found that three bees have intercepted the target. However, around two bee paths have shown clear visibility and smoothness in their trajectories. This procedure is repeated for all the movements and the number of trajectories plotted are shown in Table 1. Fig. 4 shows the trajectories of the bee and target during chasing till the interception for two sample movements. Here the units for (X, Y) coordinates are in pixels. Hence, for this whole analysis any kinematic parameters such as velocity, angle, etc, shall be calculated in terms of pixels.

TABLE I

NUMBER OF EPISODES AND PLOTS; CAMOUFLAGE STRATEGIES: A - BEHIND, B - FRONT, C- INFINITY, D - INITIAL

S.No	Target Movement	#episodes	#trajectories	A	B	C	D
1	Straight line	24	43	29	22	28	5
2	Exponential	21	20	6	12	13	4
3	Parabola	19	21	13	1	12	1
4	Fixed target	20	17	13	2	2	0
5	Random	24	40	26	33	37	1

IV. EXTRACTION OF AGGRESSIVE BEE BEHAVIOR: APPROACHES AND PROGRESS

This research work aims to conduct experiments and apply various approaches to observe how a bee is chasing and intercepting the moving target. In this study, we analyzed the notion of single bee and target tracking. This chapter explains the important observations found in the trajectories and key conclusions drawn from these observations. Further, a phase-based hypothesis was formulated, and the validations for the hypothesis were explained in detail.

A. Active Motion Camouflage by Aggressive Bee

The observation of the majority of the data plots indicated that the aggressive bee seems to be a phase-changing pursuer by concealing its presence (also known as camouflaged). In general, many reptiles and amphibians use *camouflage* to hide from their enemies. The camouflage has its roots in the field of optic flow. In their idea of *active camouflage motion* [6] considered target as shadowee and pursuer as shadower. In this, the shadower will track the shadowee by hiding its motion. To do this, the shadower conceals motion by moving in such a way that the shadowee detects it as a stationary object. Several recent studies [11][12][13] identified the camouflage behavior in dragonflies and bats. However, this is the first work to detect the camouflage behavior in aggressive honeybees. Fig. 5 shows the various cases where the shadower fixes its stationary point viz. behind, front, at infinity, and initial w.r.t shadower's location. For our analysis purpose, we call these as strategies.

In the present study, the trajectory data has given a clue that, to conceal its motion, the aggressive bee applies one or more of the four strategies explained above. If the target is non-maneuvering the bee is applying a single camouflage strategy and if the target is maneuvering then the bee uses multiple camouflage strategies. Fig 6(a) shows the non-maneuvering target (linear movement) and bee implemented Fig 5(c) strategy and intercepted with the target. Fig 7 (a), (b) shows the maneuvering targets movements and we could observe that the bee has implemented multiple strategies. Fig 7(a) shows that the target moving in exponential pattern and the bee implemented the strategy sequence as Fig 5[(c)-(c)-(b)]. Fig 7(b) shows that the target moving in a random

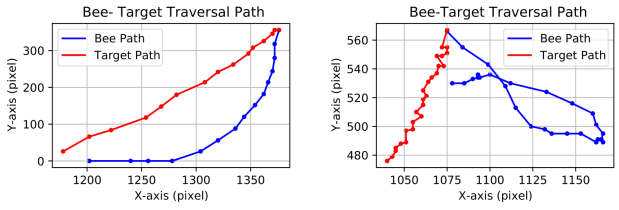


Fig. 4. Sample movements of an aggressive bee while chasing the target

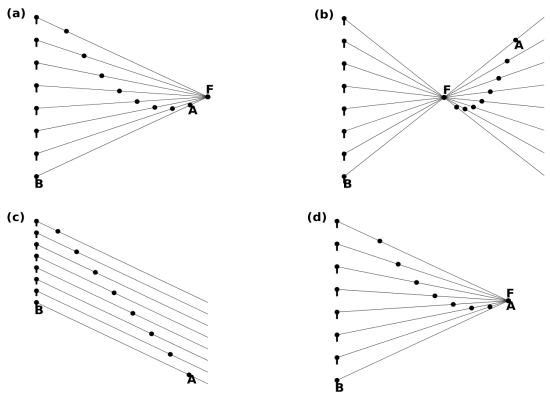


Fig. 5. Trajectories of a shadower (A) and a shadowee (B) with a stationary point F which is (a) behind (b) in front (c) infinity, or (d) located at A's initial position (Picture redrawn from [6]).

pattern and the bee implemented the strategy sequence as Fig 5[(a)-(b)-(b)]. Fig 6(b) shows a bar graph on the observance of motion camouflage for all the targets' movements. Out of 141 trajectories, we have observed one or more motion camouflage strategies in 135 plots. Also, out of 135 plots, the strategies, (a) observed in 87 plots, (b) in 70 plots, (c) in 92 plots, and (d) in 11 plots.

Further, the observation of angle (Bee-Target), distance (Bee-Target), and velocity (Bee) have supported the implementation of multiple strategies by the bee. Here, velocities and accelerations are calculated by the average values.

1). Observation on angle: After obtaining the various trajectory movements of the bee, measured the angle between the line of sight (LOS) and x-axis for all bee-target tuples. By the keen observance of the majority of the plots (Fig. 8), concluded that every bee needs to take an angle deviation before hitting the target. Also found that this shall be the maximum angle for the whole episode. It is named as Preparation For Attack (PFA) point and this can be observed in Fig. 8(a). The PFA point and its statistical observations for all the movements of the target are shown in Fig. 8(b).

2). Observation on Distance and Velocity: It is evident from all plots that the distance between the bee and the target will become zero once the bee intercepted the target. Fig. 9(c) explains the scenario of the distance between the bee and the target. Further, as shown in Fig. 11(a), the variation of the velocity of the bee confirmed that in each plot at one point

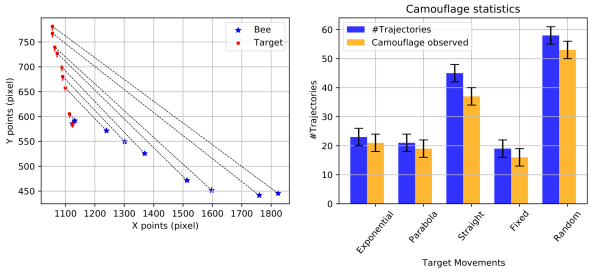


Fig. 6. a. Non-maneuvering target and camouflaged bee with a single fixed point, b. Camouflage observance statistics

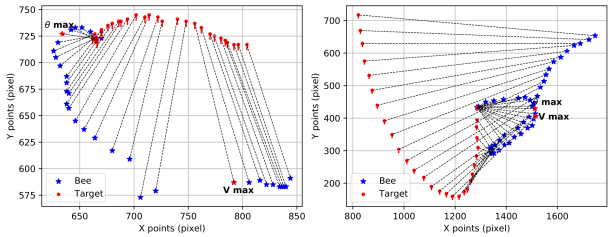


Fig. 7. Maneuvering target and camouflaged bee with multiple fixed points

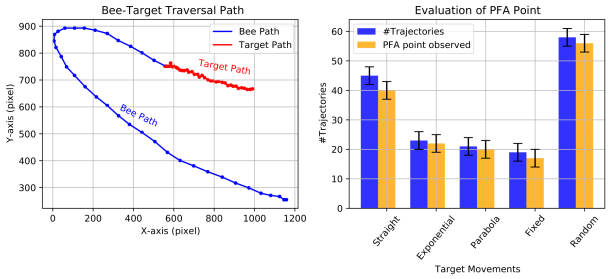


Fig. 8. Preparation for attack point examples

every bee attains maximum velocity irrespective of the target behavior. This has been observed in all the episodes of the experiments (refer Fig. 9(b)).

Coincidence between Camouflage and (maximum velocity - V_{max}, maximum angle - θ_{max}): It is found that the camouflaged bee fixed points are in coincidence with the V_{max} and the θ_{max} points in any episode. This observation is true even in multiple fixed point strategies too. One such coincidence can be seen in Fig. 7 where the transition of strategy coincidence with either V_{max} or θ_{max}. Fig. 6(b) shows the statistical data of the number of plots satisfying this coincidence. Based on this solid coincidence, it is proposed to proceed with extracting aggressive bee behavior with a phase-wise kind of approach and is named the "kinematic model".

B. Kinematic Model

In this proposed approach, the entire bee trajectory is assumed to have three phases. The first two were proposed based on the maximum velocity (V_{max}) of the bee, and the third one is defined based on the maximum angle (θ_{max}). The three phases are explained pictorially Fig. 11(b).

(1). Detection phase:- It is evident from the episodes that after disturbing the bee with the aggravator (target), the majority of the bees try to attack the target in a short amount

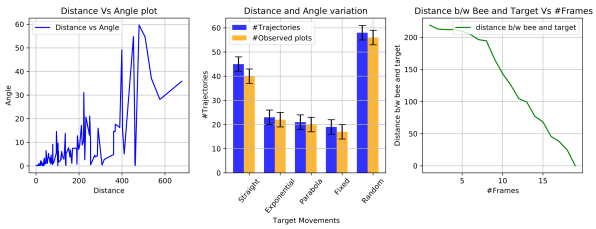


Fig. 9. a. Variation of distance and angle from PFA point b. Statistical observations on Distance Vs Angle c. Distance between bee and target

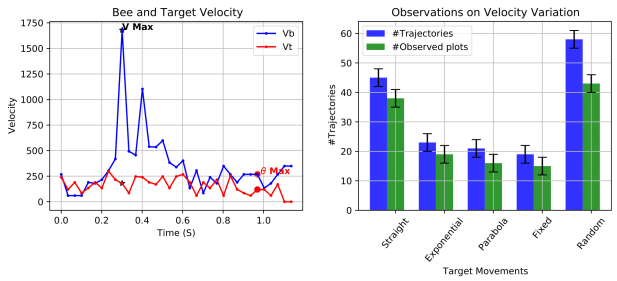


Fig. 10. Velocity comparison between bee and Target

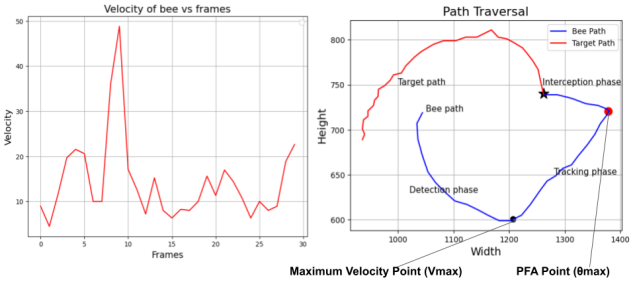


Fig. 11. a. Maximum velocity point b. Three phases of aggressive bee

of time. To do that, the primary need for bees is to detect the target location. In the meantime, before hitting the target, initially, the bee randomly searches for the target. Once the bee located the target and gets the confirmation to track down the target. It is expected that the bee gets this confirmation by increasing its velocity to the maximum velocity (V_{max}). By observing the same behavior in various trajectories, the division was done from the starting point of the bee to the maximum velocity reaching point of the bee. This phase is named as the detection phase and is shown in Fig. 11(b).

(2). Tracking phase: After detecting the target, the bee is looking for the best moment to attack the target. For that purpose, in this phase bee initially decreases its velocity and tracks the target until it decides that it is ready to attack the target, nothing but reaching the PFA point. Based on the expected criteria, and by observing the various trajectories of the bee, it is confirmed that the path between maximum velocity reaching point to the preparation for attack point comes under the tracking phase and is shown in Fig. 11. b. In this phase, the bee follows the velocity pattern of the target, which can be seen between the points V_{max} and θ_{max} in Fig. 10. a. Similar was followed in [13] to track the bats motion.

(3). Interception Phase: This phase starts at the PFA point and ends at the hit/interception point. In this phase, the bee is expected to hit the target in a very short period and cover less path compared to the other two phases. Here, the comparison was made for the velocities between the bee and the target. By taking the velocity values of the bee and target in the detection phase for a considered number of samples, it is found that on average every point in the first phase, the bee velocity is 3.6 times more than the target velocity.

Mixed Strategy of Phases/Phase sequence repetition: The

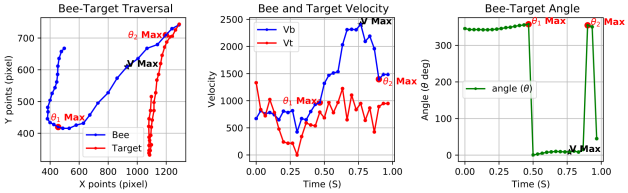


Fig. 12. Observation of more than one tracking phase

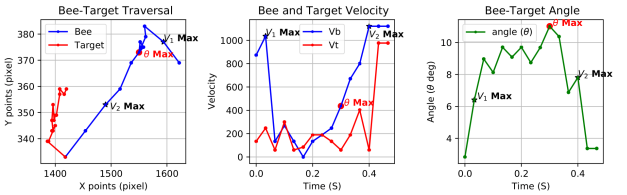


Fig. 13. Observation of more than one detection phases

observation of all the episodes evident that in each episode, bees need not exhibit only three phases in the sequence described above. As shown in the Fig. 12, 13, sometimes a bee can start with the interception phase first and then it can move on to the detection phase based on the target behavior. Here, $\theta_1 max$ is the first maximum angle, $\theta_2 max$ is the next maximum angle, and so on and the same notation is valid for V_{max}. Fig. 12, shows that, bee phase sequence is {tracking-detection-tracking-interception}, in Fig. 13, bee phase sequence is {detection-tracking-detection-interception}.

The crucial observation from the above kind of strategies is that the order of the phase sequence defined in the kinematic model would remain unaltered. At any point, if the bee misses the hitting (immediate V_{max} after θ_{max}) then it would immediately go to the detection phase. With this, it can be concluded that bees can exhibit the 'n' number of phases in a trajectory and a different phase sequence too. Interestingly, these mixed-phase sequences are match with the camouflaged bee multi-fixed point strategies as shown in Fig. 14. In this the matching shall be $\theta_1 max$ with Fig. 5. b, V_{max} with Fig. 5. b and $\theta_2 max$ with Fig. 5. a.

Switching between Camouflage Strategies:-

The above kinematic model proposed with three phases has concluded that in every trajectory, the maximum velocity (V_{max}) and the maximum angle (θ_{max}) would appear. At those points, the switching occurs from one phase to another phase. It means that at these points the bee switched into a strategy which shall be from any of the four camouflage strategies (Fig. 5) by changing the camouflage fixed point (F). Broadly, switching from one strategy to another is equal to switching from one phase to another. To know how the switching occurs, observation was done on the point-to-point of the linear and angular velocities of the bee and target together. It is found that the bee is changing its camouflage strategy whenever there is a continuous increment or continuous decrements for approximately 3 data points in the angular velocity of the target which is shown in Fig. 14.

From Fig. 15, it is observable that in the angular velocities plot, at data points (10, 11, 12), the target has reduced its

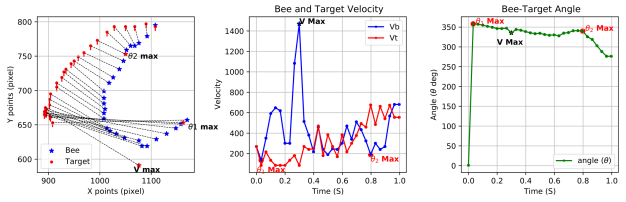


Fig. 14. Episode with camouflage fixed points and multiple (V_{max}, θ_{max}) coincided

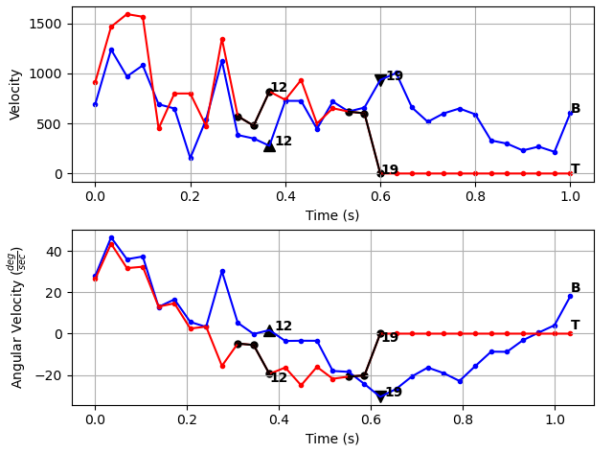


Fig. 15. Angular and linear velocity profiles of bee and target

angular velocity continuously, and at point-12, the bee has changed its strategy (from camouflage behind to front (Fig. 16)) by increasing velocity to V_{max} at point-12. Similarly, at data points (17, 18, 19), the target has reduced its velocity continuously, and at point-19, the bee has changed its strategy (from camouflage behind to front (Fig. 16)) by increasing its angle to θ_{max} at point-19 (Fig. 15). Further observation of the velocity plots of the same trajectory indicated that the target is controlling its velocity in an opposite manner to that of the angular velocity and it can be seen in Fig. 15. This behavior has been observed in 55 out of 91 episodes. In 31 out of 91 episodes, it is observed that the switching is happening with 3-data points and the target linear velocity is behaving the same as that of angular velocity, one such linear-angular velocity plot can be seen in Fig. 15.

V. Conclusions and Future Work

This paper introduces the idea of an aggressive bee attacking a target. An artificial aggravator is used to aggravate and it is given with various movements, videotaped the chasing by the aggressive bees. Two kinematic approaches are implemented, observing the velocity and angle of the bee with respect to the target while tracking and attacking. Also, the aggressive bee has been shown to switch between camouflage strategies using the 3-data points. From these two approaches, it is concluded that the bee follows three phases (namely Observation/detection, Tracking, and Attacking phases) in its path while chasing the target. Currently, our research group is 1. Actively focusing on analyzing the bee selection methodology to switch between camouflage strategies and derive motion control law, 2. Deriving the

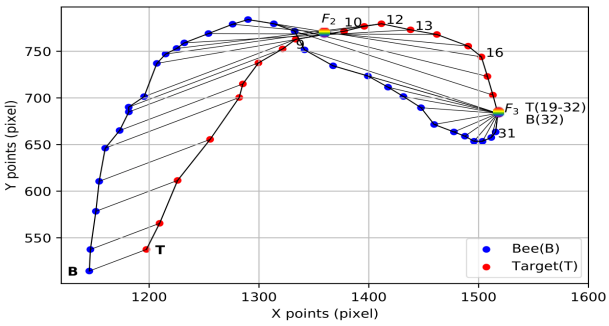


Fig. 16. Motion camouflage switching with various fixed points

motion control laws and comparing them with existing guidance laws such as proportional navigation (PN), and deviated pursuit etc, 3. It is also observed that the number of bees chasing the target is reducing as the bees move towards the interception phase, hence a cooperative controlled strategies direction may be an interesting future research aspect.

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