Come Fly With Me – Perceive the World Through a Mosquito's Senses

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***Abstract*—Mosquitoes are one of the deadliest animal families in the world. They occur in a huge variety with different traits. In a lot of genera, the female mosquitoes suck blood from hosts for being able to reproduce. As a result, mosquitoes are a major vector of infectious diseases. For tracking down their prey, mosquitoes are equipped with specialised senses. We present a serious game in which the player adapts the perspective of a mosquito, thereby understanding the world from a different angle. Accordingly, the player controls the mosquito from a first person view. His objective is finding prey and sucking blood relying on a mosquito's senses. By means of a survey we show that the simulation is suited for gaining knowledge about the mosquito's hunting behaviour.**

I. Introduction

"Mosquito" is the Spanish word for "little fly" [1]. Over 3.000 mosquito species are identified and described [2], and they are spread throughout the whole world [3]. Some of the species' females need to feed on blood to provide the proteins needed for their eggs. Biting the hosts, deadly diseases such as malaria or yellow fever might be transmitted [4]. In light of this, research on the hunting behaviour of mosquitoes, on their senses, and on their reaction to environmental stimuli is important for creating viable counter-measures. In order to promote these topics, specifically, to enable people to comprehend the influences on mosquitoes when searching for hosts, we developed an according, serious simulation game. The game makes it possible for the player to perceive the environment similarly to the way a mosquito does: Through an appropriate mapping of the mosquito's senses, the user is enabled to track down blood sources. In the remainder of this paper, we will first discuss related works in Section II. In Section III, we describe the scientific basis of the game's simulation model, how it is realised, and how the user is tied into the simulation loop. We present the results of a user survey about the simulation' suitability for informing about mosquito's senses and hunting behaviours in Section IV, before we conclude with a short summary in Section V.

II. Related Work

In this section, we first provide some references to computational approaches regarding mosquito modelling – in terms of their senses, their hunting behaviour and potential counter measures. Next, we outline some of the computer games that mosquitoes play a role in. Considering the mosquitoes' senses, some computational modelling work has been done on the compound eyes of insects, which "combine small eye volumes with a large field of view at the cost of comparatively low spatial resolution" [5]. According models and simulations conveying the workings of compound eyes can, for instance, be found in [6]. Cummins et al. [7] focused on the mosquitoes' sense of smell and developed an according spatial model of the host-seeking process. It enabled them to compare different odour plume search strategies in terms of their effectiveness. Their results show, that "crosswind plume finding most reliably led mosquitoes to a blood meal source". Recognising mosquito flight as an important part of mosquitoes being a disease vector, Iams [8] measured and simulated the mosquitoes' motion and examined their flight stability and orientation. He concluded that mosquitoes show significant differences in how they control their flight compared to other Dipterans. Almeida et al. investigated whether and under which circumstances mosquito traps might help mitigate disease spread. They setup an according model representing a mosquito population as multi-agent system [9] and show that traps are indeed suitable for controlling a mosquito population, or at least slow its growth, in case there are too few traps in a specific area. Regarding educational work, Vivas and Sequeda [10] examined the learning success of schoolchildren regarding mosquitoes and their danger as disease vector by using a board game called "Jugando en salud: dengue (Playing for health: dengue)". They showed that the game "helped them acquire greater knowledge about dengue and to develop skills and abilities leading to their incorporation in dengue prevention activities in their respective communities". An example for a video game where the user controls a mosquito and tries to bite humans is called "Ka" [11]—often also referred to as "Mr. Mosquito". A more serious approach can be played at [12]. In "Malaria" you can switch between the parasite part of the game (controlling malaria parasites) and the mosquito part, where you control a mosquito in top down view. The objective is to avoid different traps and find and feed on a human. Before you play, you are presented with some information. Additionally, before you take control of the mosquito, your information intake is tested by a few questions. In contrast to the simulation studies mentioned above, our game does not seek for new knowledge about mosquito behaviour or countermeasures. Instead, we combine scientific results to create a game as informative as Malaria and as fun as Ka. Different from both games, we want the user to directly experience the world through a mosquito's senses to foster the understanding of its hunting behaviour.

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III. THE GAME LOOP

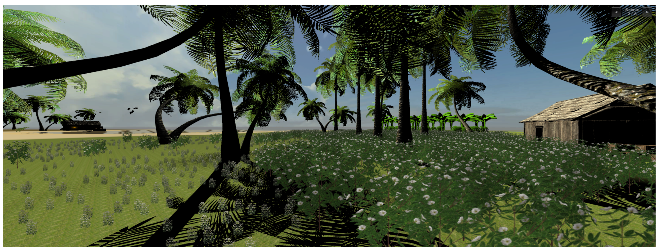


Fig. 1: The tropical island serving as simulation world.

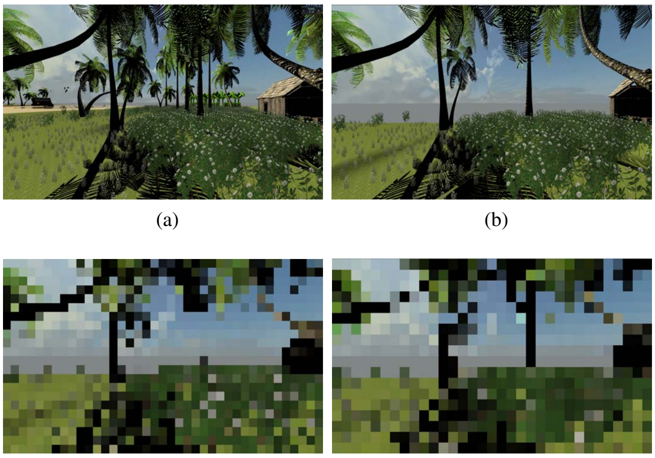
In our game the user controls a female mosquito in first person view. Various senses of the mosquito are visually displayed to allow the user to track down potential hosts. After landing, the player/mosquito can start sucking blood. While doing so, he/it is endangered by the host's counter attack (slapping), which is signalled through a vignette filter. In case the player manages to take off again in due time, he has successfully fed on the host's blood—otherwise he dies. Having succeeded, the simulation starts all over at a higher level of difficulty. The game is staged on a tropical island (cf. Figure 1), which hosts a variety of palm trees, banana trees, bushes, and flowers. It is inhabited by gorillas (cf. Figure 2a) and velociraptor-like dinosaurs (cf. Figure 2b). Some of the animals roam the island, others stand still.

(a) The gorilla. (b) The dinosaur.

Fig. 2: The player can land on his prey and start feeding on its blood. But the animals will defend themselves.

A. *The Mosquito's Senses*

Female mosquitoes of blood-feeding species have highly optimised senses for searching hosts. The three most important of the involved senses consider visual cues, chemical substances and heat. The compound eyes of mosquitoes consist of a varying number of ommatidia, i.e. the individual small, long facets containing the photoreceptors. Singh [13] counted the number of ommatidia for three species. The average number lies between 610 and 900 ommatidia. To account for this low spatial resolution player is presented with a resolution of either 39x22 or 33x18. Furthermore, in line with the mosquitos senses, the viewing distance in the simulation is limited to objects at around 5-15m [14]. The effect of the reduction in viewing distance and in resolution can be seen in



(a) (b) (c) (d)

Fig. 3: Simulation island from an (a) Human perspective, at (b) reduced range of vision, considering (c) additionally reduced spatial resolution, and (d) even further reduced resolution.

Figure 3: In Figure 3a, an unchanged view of the island can be seen, whereas in Figure 3b the range of vision is reduced. Figures 3c and 3d show the same scene but additionally feature reduced resolutions—39x22 in Figure 3c and 33x18 in Figure 3d. We model visual chemical signals, in particular puffs of *carbon-dioxide* (CO_2), which are of great importance for finding potential hosts, as red orbs (cf. Figure 4). This visualisation corresponds well with the mosquitoes' perception as they react to plumes of CO_2 rather than to continuous CO_2 gradients [15]. Every animal breathes out these red orbs, which are moved by the wind and disappear after a certain time. The colour red is very distinct from the mainly green and blue colours of the environment, which makes it easy to identify and follow. Mosquitoes can sense CO_2 up to 35 to 50m [14], [15]. This is farther than the mosquitoes can see, which stresses the importance of odour recognition for the mosquitos orientation. As a consequence, the player needs to rely on "smelling" until the mosquito has come close enough to an animal so its visual sense is triggered. While

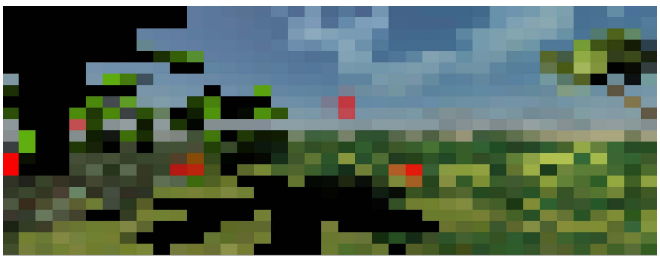


Fig. 4: Example of odour plumes (carbon-dioxide; red colour).

compound eyes exhibit low spatial resolution, they excel in temporal resolution, i.e. motion detection [16]. As humans also respond well to animated visuals, we give credit to this fact by representing motion with a flickering, yellow outline

Fig. 5: Flickering outline (yellow) induced by moving animals.

(outline shader) around moving animals (cf. Figure 5). The colour yellow was chosen because of its uniqueness in the game's colour palette. According to Breugel et al. [14], sensing heat informs a mosquito's decision on where to land at close proximity to the prey, see the orange colour patch in Figure 6. Heat sensing is especially important, if the animal is standing still and no motion cues are conveyed.

Fig. 6: Warm temperatures (in orange) signal a nearby body.

B. User Experience

When starting the game, the player may view a tutorial that informs about the goal and the controls, i.e. movement, landing on a host, initiate blood-sucking. During the simulation all the information the user needs is conveyed in an immersive way without any overlays interfering with the mosquito's view. Rather, we stayed consistent with the theme of sensory-based visualisation. For instance, Figure 7 depicts the colour of an animal after the user has successfully fed on its blood: It gradually changes from orange over yellow to white, indicating to the player when to take off. Figure 8 shows the mosquito's perception of a counter attack instigated by its prey. Generally, due to the alien nature of the picture presented to the player, it is difficult to recognise what he is actually looking at. This makes it necessary for the player to heavily rely on the mosquito's other sensory information and learn how to use it.

Fig. 7: The colour of an animal continuously changes from orange over yellow to white. If it reaches white, the player knows that he has successfully fed. If he manages to take off in time, he wins.

Fig. 8: While sucking blood, the prey may smash the mosquito. Such a counter attach is indicated by a shaking screen and vignetting effects.

IV. Evaluation

We asked 18 persons of arbitrary age and both genders, which kinds of sensory information are used by mosquitoes and to rate their respective impact from 1 ("Strongly disagree") to 5 ("Strongly agree"). Afterwards, the participants were asked to play the game. Their objective was to successfully feed on a prey for at least once. After playing, we asked them again about the mosquitoes' senses. In addition, we inquired about their user experience. The participants originally felt that "smell" (estimated impact averaged over all participants: 4.56 out of 5), "heat" (3.94), and "chance" (3.5) were the three most important factors to guide a mosquito. The participants were undecided whether "movement recognition" (2.94) played an important role or not. With regard to other potential sources of information, such as sounds, communication with other mosquitoes, wind, shape recognition, colour recognition, etc., the participants showed indecision or disagreement about their importance (averages ranged from 1.44 to 2.56). After playing, the participants' top three voted techniques were "heat" (average: 4.78), "movement recognition" (average: 4.00) and "smell" (average: 3.83). The averaged, estimated importance of "chance" dropped from 3.5 to 3.17. The average of nearly all irrelevant sources of information dropped from a total average of 2.19 to 1.61, with two outliers being "colour recognition" (before: 2.00; after: 2.44) and "shape recognition" (before: 2.56; after: 2.89). All of the participants rated "smell" with 4 or 5 before exposure to the simulation, while only 67% shared this opinion after exposure. Yet, with a p-value of 0.1558, this change cannot be considered significant. Regarding "heat", positive answers (4 or 5) increased from 72% to 100%, and for "movement detection" consent increased from 39% to 83%. Based on the respective p-values (both 0.002), we can infer that a significant learning effect occurred. Yet, the participants rated the learning effect higher than the change in the average indicates. The total average of "heat", "smell", and "movement recognition" increased from 3.81 to 4.20, while 94% (average 4.00) of the participants were convinced they achieved the learning goal. One possibility to explain this is that the participants had presumptions when answering the first survey, respectively that they were able to conclude which answers are more probable using common sense. Through experiencing the simulation they could confirm these presumptions and, therefore, concurred to the proposed learning effect. This is additionally supported, if we take into account that the total average of all fictitious techniques decreased from 2.19 to 1.61, indicating a confirmation that these techniques are not used by mosquitoes. Moreover, achieving the learning goal is different from the participants subjective feeling that the simulation successfully taught them about the mosquitoes' blood feeding techniques. Consequently, the measured learning effect does not have to match the participants' assessment. Furthermore, the rating decrease for "smell" is striking. Maybe this implies that the participants did not rely too much on the given game mechanic but were much more successful in using the other mechanics, hence, the participants' perception of the importance of "smell" decreased. This makes it necessary to rebalance the skill in the simulation in order to make the importance of "smell" clear to the user.

The second part of the survey covered the user experience. Being asked to which extent (1 to 5) they learned about the mosquitoes' hunting skills, 94% of the participants replied positively (4 or 5) with a total average of 4.00. All users experienced the simulation to be difficult (average: 4.61). The helpfulness of the tutorial was acknowledged by 72% (average: 3.72). While 89% responded positively to the question whether they felt the objective was clear to them (average 4.06), only 44% felt aware how to achieve it (average: 3.11). For 67% (average: 3.56) of the participants the presentation of the different senses was clear and distinct. 78% relied on these senses in order to achieve the objective (average of 4.06). The conclusions we draw from these results are discussed in the second part in the next section.

V. Summary and Conclusion

In this paper, we presented a serious simulation game in which the player controls a blood-seeking mosquito in first person view. In order to find prey, he is provided with visuals of the mosquito's senses of vision (especially discerning movement), smell (CO_2), and heat (body temperature). The respective signals are shown dependent on the mosquito's proximity to its prey. While feeding on blood, the user has to be aware of the host's counter measures, e.g. getting smashed by the gorilla's arms. In a survey, we showed that the presented simulation effectively teaches about the mosquitoes' senses for tracking down their prey. We may infer that the developed visualisations appropriately map the respective senses. Yet, we encountered a problem that makes it necessary to rebalance the usage of "smell" in the simulation, in order to make users more aware of its importance.

Additionally, the user experience should be improved through an interactive tutorial accompanying the user while he is running the simulation for the first time. Furthermore, challenges that the users faced in the trials such as not knowing the appropriate time for landing on an animal or lacking feedback about successes must be addressed. Another point of criticism brought up by several survey participants was the high movement speed of the animals. In accordance with the users' feedback, reducing it would further improve the user experience. With respect to evaluating the learning effect, it would be beneficial to compare the learning effect achieved with this game with a more conventional medium, e.g. a video recording about mosquitoes. Considering the scientific underpinnings of our simulation, we see the following possible improvements: Since the spectral sensitivity of mosquitoes ranges from 323nm (ultraviolet) to 621nm (orange-red) [17], the simulation should present an image where the colour red has been filtered out. Moreover, compound eyes supply their hosts with a far wider field of view than what we use in the simulation. This could be implemented, for instance, using a multi-camera setup with a pannini projection [18].

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