Immersive Visual Analysis of Insect Flight Behaviour

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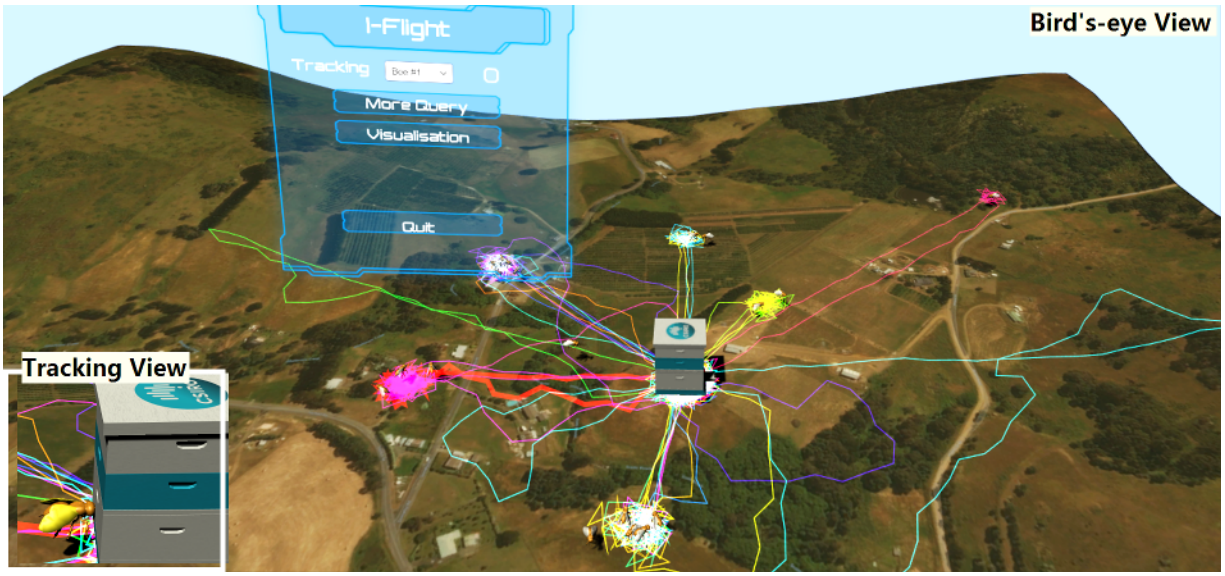

Figure 1: Immersive visualisation of bee flight behaviour. The bird's-eye view provides a global view of the virtual environment with flight paths in a 3D geo-spatial context. The tracking viewpoint (bottom left) provides a close-up perspective on bee flight movements. A drop down menu allows to change different attributes of the tracking data and related visualisation of the paths.

Abstract

We present *I-Flight*, a virtual reality based visual analysis system for insect movement data. I-Flight aids in understanding insect movements and collective flight behaviour in a simulated environment. Towards this end, I-Flight visualises insect flight paths in their natural, 3D geo-spatial context. In this paper, we demonstrate the use of I-Flight for honey bee flight data and related environmental variables. The system is designed to be extendible to other insect flight data by adopting the data attribute space and the respective mapping onto visual variables, such as colours. The value of the presented I-Flight system is not only in complementing existing scientific methods and tools for understanding honey bee behaviour, but also in raising broader awareness for honey bee preservation through an engaging, immersive environment.

Index Terms: H.5.1 [Information Interfaces and Presentation (e.g., HCI)]: Multimedia Information Systems; H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User Interfaces (D.2.2, H.1.2, I.3.6)

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1 Introduction

Foraging and collecting food are essential behaviours of insects to secure their own survival and that of the colony. Understanding foraging behaviour is of great interest to the scientific community and to entomologists in particular. For insect species that feed on plants, for instance honey bees, these activities involve a large range of collective behaviours as a swarm, from forming foraging strategies (increased activity that maximises their chances of encountering a plant, completely random activity, or sensory attraction to a plant from a distance) to executing the exploitation phase and periodically monitoring food availability [11]. These activities are repeated in flight cycles that are established and partially decided by environmental factors, including air temperature, humidity, precipitation, and time of day. Entomologists have uncovered many peculiar flight movements of insects, such as rapid changes in flight direction, vertical take-off and landing, upside-down flying, and lateral and backward movement [5, 14].

The study of insect flight has been advanced in recent years but most of the visualisation work focused on flow features and wing aerodynamics during flight via conventional desktop displays [4, 10]. With the rise of commercial head mounted displays such as Oculus Rift[1] and HTC Vive[2], immersive technology has become more accessible. Previous studies comparing immersive technology with desktop displays demonstrated the benefits of immersion in acquisition of spatial knowledge [1, 9]. In this paper we therefore explore virtual reality for immersive visual analysis of insect flight

[1] https://www.oculus.com/
[2] https://www.vive.com/

Figure 2: Honey bee with an RFID tag on its back.

data and specifically honey bee flight. Honey bee populations are declining globally and the reason is not well understood. Analysing honey bee behaviour and related environmental variables is therefore expected to provide valuable insight into the factors impacting on honey bee health and specifically on factors impacting on population decline. With the system presented in this paper, we aim to contribute to this endeavour by providing an immersive environment that not only allows for effective analysis of honey bee behaviour but also aims to deeply engage the user into the problem.

Towards this end, we present *I-Flight*, a virtual reality based visual analysis system for honey bee movement data. I-Flight aids in understanding honey bee movements and collective flight behaviour in a simulated environment that represents their natural, 3D geospatial context. I-Flight allows for interactive exploration of honey bee flight data as well as environmental data. The motivation for developing I-Flight is threefold. Firstly, it provides users with an interactive exploration tool to study insect flight behaviour in response to in-situ environmental settings. Secondly, head mounted displays allow users to dynamically analyse the flight path data from either exocentric or egocentric viewpoints. Finally, we aim to bring immersive analytics to a broader range of users in educational outreach to raise the awareness of honey bee health and to have a positive impact on the environment.

2 Monitoring and Modelling Honey Bee Flight

The Global Initiative for Honey bee Health (GIHH)[3] is an initiative launched by the CSIRO, which aims to have a global impact on the ecosystem and sustainable development by studying honey bee behaviours, potential threats to their health and the decline in their numbers. The initiative consists of global partners that perform experiments to better understand the factors impacting on honey bee population decline. In this section, we briefly describe how data is collected from these experiments and used to model honey bee flight behaviour.

2.1 Honey Bee Behaviour Monitoring

Miniaturised RFID tags such as the one shown in Fig. 2 are attached to the honey bees to track and study their behaviour in a natural habitat. These tags are detected and recorded by readers installed at the entry to bee hives and feeder stations, thus providing event data for the bees' activity. Each bee is identified with a unique ID and thousands of bees are tagged over the course of an experiment. In addition to the RFID tag data, sensor data is collected from the hives (brood temperature, hive weight, hive humidity) and weather stations (solar radiation, relative humidity, wind speed, precipitation). We have run several experiments over the course of two years. The real settings of our foregoing experiments are remodelled in I-Flight to set up a near realistic environment of bee foraging behaviour.

We previously designed a visual analytics framework to predict and support informed decisions on honey bee health [7]. Using immersive technologies, we designed and implemented MelissAR [6] for augmented visual analysis of bee activity in the field and HoloBee [12] for bee drift data analysis on 3D geo-spatial maps. Unlike these previous systems, I-Flight aims to support visual analysis of honey bee flight behaviour that is modelled based on models from the literature and the event data recorded in the experiments.

2.2 Bee Flight Modelling

Since tracking insects flying in their natural habitat is still an unsolved challenge, the honey bee flight paths used within our system have been simulated using the Swarm Sensing Model[4], a python-based computational model which can be used to simulate, analyse and visualise honey bee flight paths within a three-dimensional foraging environment. The model components relevant to I-Flight include:

- *Honey Bee Flight Simulator*: simulating a range of different honey bee foraging behaviours. The model is based on known behavioural characteristics of the honey bees to generate realistic flight paths [2, 3].
- *Environment Simulator*: simulating the foraging environment that the bees inhabit including three environmental variables: air temperature, solar radiation and relative humidity. Each of these variables can be represented in three dimensions. The Environment Simulator also contains a land surface model to represent the terrain within the local foraging environment.
- *Data Output Module*: exporting the flight paths and the environmental variables in the form of NetCDF[5] files.

More specifically, the bee flight paths simulated for I-Flight include paths typical of honey bee foragers undertaking one of six foraging roles [3, 8]:

- *Novice*: undertaking orientation flights to become familiar with the hive surroundings.
- *Scout*: searching spontaneously for new food sources.
- *Expert*: exploiting a current food source (nectar and pollen) using precise positional information in its memory.
- *Recruit*: searching for a food source using information obtained by observing the waggle dance of an exploiter (providing an indication of the distance, direction and quality of a food source).
- *Water carrier*: exploiting a water source rather than a nectar or pollen source.
- *Inspector*: undertaking reconnaissance flights to a previously exhausted food source to see if it has been replenished.

Besides the foraging roles, the simulator also models bee flight activity according to its current location, environmental conditions and foraging behaviour at any stage during the flight. These activities include exploratory searching, seeking a food source (nectar and pollen, or water), searching for a food source by visual or olfactory sensing, foraging at a food source, returning to the hive, or resting within the hive.

To generate data for I-Flight, the simulated environment is first created and then from 5 to 500 simulated honey bees are released from the hive, each engaged in a particular foraging role. The characteristics of each bee's flight path is determined by its foraging role.

[3]https://research.csiro.au/gihh/about/

[4]http://doi.org/10.4225/08/57A7DE31147FA

[5]https://www.unidata.ucar.edu/software/netcdf/

3 IMMERSIVE VISUAL ANALYSIS OF HONEY BEE FLIGHT

We designed and implemented I-Flight for virtual reality headsets. In this section, we describe in detail the design and implementation aspects, including the visual representation of the honey and environmental data as well as the user interactions therewith.

3.1 System Requirements

As discussed in section 2.2, two sources of data are obtained from the Swarm Sensing Model: (1) flight path data, which contains sampled 3D locations of individual bees over a time period, and (2) environmental data, which contains information of land surface height, air temperature, solar radiation and relative humidity. Four main requirements of designing and implementing I-Flight are as follows:

R1 Visualise all flight paths in a near-realistic setting of the geographic foraging environment of honey bees.

R2 Represent and filter flight paths with regard to certain data attributes, such as honey bee role or ID.

R3 Represent environmental data embedded in the geographic context.

R4 Implement reactive manipulation of the flight paths and environmental data through an interactive user interface.

3.2 Visual Representation

3.2.1 Terrain and Flight Path Representation [R1]

We represent the 3D terrain of the foraging environment as a surface with variable elevation based on land surface height data obtained from the Swarm Sensing Model. To realistically represent the geographical location, a high resolution satellite image is used as a texture map. Bee hives and feeder stations are placed in realistic locations obtained from respective experiments. Flight paths are visualised as continuous, coloured paths in 3D space with data points from the model being linearly interpolated.

3.2.2 Visual Encoding and Filtering of Flight Paths [R2]

The colours of flight paths are encoding different data attributes. Fig. 3 shows colour being used to visually encode either bee activity or bee role for the different paths. These colour mappings allow for identifying patterns in bee behaviour not just collectively for the entire population but also for individual roles and activities. Individual bee activities and roles can be queried and represented to allow for a less visually crowded representation, as presented in Fig. 4.

3.2.3 Environmental Data Representation [R3]

The environmental data obtained from the Swarm Sensing Model are three dimensional. To associate the visualisation of environmental variables with the terrain, we generate a 2D texture map for each environmental variable. Each 3D environmental variable is first averaged along the vertical dimension to obtain a 2D matrix. The 2D matrix is colour coded using half of the Hue channel (blue, purple, red) in HSV colour space. Fig 5 is an example of air temperature projected onto the terrain instead of the satellite image. Air temperature increases from blue through purple to red.

3.3 User Interaction [R4]

The user has several ways of manipulating the data and the viewpoint to interactively explore the honey bee flight paths and related environmental conditions.

3.3.1 Viewpoint Selection

Virtual reality headset natively supports position tracking to allow users to move and look around naturally in the 3D environment. In addition, in our system, the user can choose between two different viewpoints for the inspection of the data, a global bird's-eye view and a close-up tracking view through a tick-box in the user interface (see Fig 1). The bird's-eye view could be considered as a 3D geographic map or a World-In-Miniature. The tracking view, on the other hand, is a representation of flying within the 3D environment. The tracking view can be dynamically configured based on a tracked bee chosen by the user from the list of all the bees. While the bird's-eye view allows for detecting overall patterns in the data, the tracking view may allow for closer inspection of specific behaviours of bees. In both viewpoints, users can use the joystick on a controller (e.g. Oculus Touch) to pan the view for navigation and gaining spatial knowledge. These two viewpoints are built without any changes to the main structure of the virtual environment in order to guarantee the integrity of the virtual world and its future extendibility.

3.3.2 Interactive Attribute Selection and Querying

A pop-up menu (Fig 1) is used for run-time queries of environment features and of collective flight behaviours. Colours of the flight paths can be configured for individual bees, bee roles, and bee activities through the menu (Fig. 3 and Fig. 4). Users can also choose to select uniform colour for all flight paths. Environment maps can be changed between a satellite image terrain texture (Fig. 3), air temperature (Fig. 5), relative humidity, and solar radiation. A uniform texture can further be selected to minimise visual distraction through the background when visually inspecting the flight paths. Users can also pick one of the bee flight path to highlight by choosing it from the list of all the bees. In addition, users can customise the speed of the bee flight during the simulation.

4 DISCUSSION, IMPLEMENTATION, AND LIMITATIONS

For the scenario presented in this paper, we considered a simulated dataset of 20 bees foraging for 30 minutes in Cairns Bay, Tasmania, one of our experimental sites. The bee hive and six feeder stations were placed in the same locations as in the real-world experiment. Simulation of bee flight paths starts with all bees being in the bee hive. As we can observe from the visualisations in this paper, each individual bee, based on its own role and activity over time, can behave very differently. For instance, in Fig. 3 (left), the highlighted route represents flight paths of a foraging scout. The scout carries out an exploratory search activity (yellow path) from the hive, continues with an olfactory search near a food source (short green path), flies around this source to forage available nectar and pollen (purple cluster), then heads back home in a fairly straight line (red path), and staying inside the hive (blue cluster). Compared to foraging scouts, the paths of water carrier, recruit and expert bees are more straight and direct. The percentage of roles that the bees undertake can be dynamically changed in the Swarm Sensing Model.

The I-Flight system presented in this paper is implemented using the Unity game engine that can be easily integrated with most currently available augmented and virtual reality head sets. We used the Oculus Rift CV1 and Oculus Touch controllers for immersive visualisation and interaction, respectively. Other systems such as the HTC Vive may be used instead with only minor amendments to the systems.

We acknowledge several limitation to our system. The Swarm Sensing Model can currently only simulate one hive at a time. For experiments with multiple hives, we would need individual simulations for each hive. However, interaction between hives is not accounted for then. Furthermore, time of day is an important factor impacting on honey bee behaviour that is not taken into account in the simulation model and the immersive visualisation. With regard to interaction, the system is currently mainly based on the pop-up

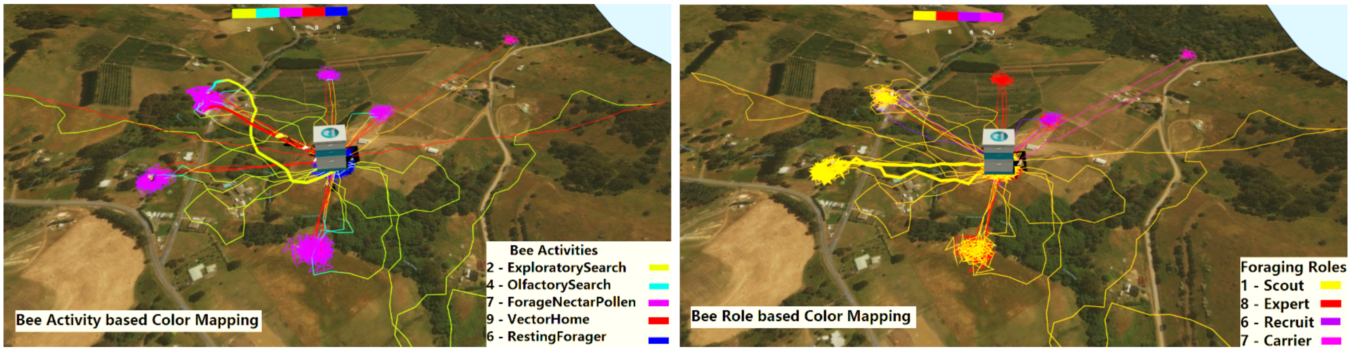

Figure 3: Different types of flight path colour mapping based on bee activities (left) or bee roles (right). The users can pick one of the flight paths to highlight in the bird's-eye view and to follow in the tracking view. The highlighted route of a bee scout (right) represents its five activity phases of simulation (left) including exploratory search, olfactory search, food forage, home going, and resting.

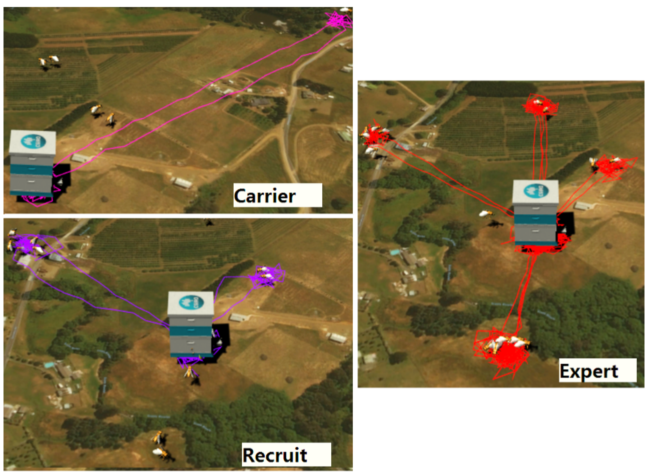

Figure 4: Visual queries of three different foraging roles. This type of query can be used to filter the data and later can be combined with the colour mapping function to visualise closely uncluttered paths.

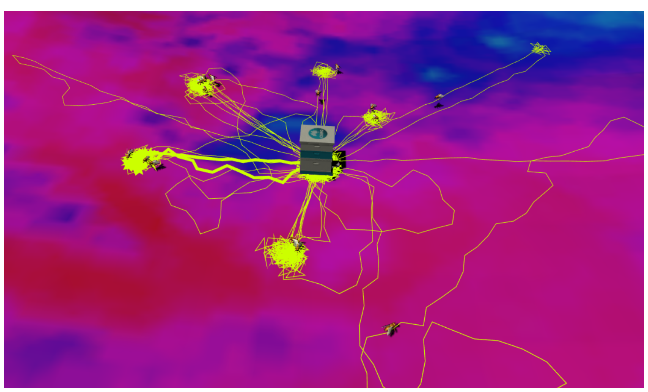

Figure 5: Environmental variable maps are blended with the flight paths to provide a complete view of the swarm movements in relation to different environmental variables. This figure represents the air temperature variable (blue:low, purple:medium, red:high) mapped onto the terrain.

menu. While this works very well with the considered queries, we envision to extend the system to interactions with the flight paths directly in 3D space. This will enable spatial selections of flight paths in addition to selections and filtering based on bee roles, activities, and IDs. Spatial accuracy for these selections will be a key design aspect, especially in challenging cases when many flight paths are visualised encouraging false selection. Finally, we aim to enrich the system with aggregate visualisation techniques that allow for seeing higher level patterns in the trajectory data, especially when a large number of flight paths is simulated.

Our immersive system was designed and implemented to target a range of end users, including scientists, domain experts, broader public, especially young children in an outreach and education programme. All the functionalities and interaction techniques took into account the ease of use and intuitiveness requirements of the system. By providing more engaging experiences through the immersive visualisation, our project can help raise the awareness of protecting honey bees in society to secure ecosystem and sustainable development. We also want to provide an effective visual analytics system to scientists, domain experts and decision makers, allowing them to gain deep insight into bee behaviour and to be able to make well informed decisions. We aim to conduct a user study to properly evaluate the performance and usefulness of our system in practice.

5 Conclusion

We have developed I-Flight, an immersive visual analysis system for exploring insect flight behaviour. Through a virtual reality simulation, I-Flight allows users to have a high level of immersion and feeling of presence in a near realistic 3D world. We presented the specific use case of honey bee flight behaviour simulated through a Swarm Sensing Model to illustrate the design and implementation aspects of our system and its usefulness to identify patterns and details in insect flight path data. The aim of our system is not only to complement the existing scientific methods and tools for understanding honey bee flight behaviour, but also to raise awareness among the general public for honey bee preservation.

We aim to improve further the visualisation and interaction capabilities of I-Flight as well as the underlying honey bee behaviour model. Bee waggle dance simulation could be added to our framework, which is used by foragers to share information about the direction and distance to food and water sources, or to new nest-site locations. These two simulations would complete the whole cycle of foraging, communicating, finding, and collecting food activities of honey bees. Moreover, once the project has progressed to a point where extensive real datasets are available, these datasets will be put into an Analysis module of the Swarm Sensing Model, replacing the simulated data. Supposedly, the real datasets will contain the coordinates of the bees on their flight paths and the values of one of the environmental variables (i.e., air temperature, solar radiation, relative humidity) during the flight. The bee activities and bee roles would be deduced from the Analysis module based on their known behavioural characteristics. Our system will then serve as a visual analytics system for the data being provided by micro-sensors in the field. We also aim to integrate I-Flight into our collaborative framework [13], along with MelissAR [6] and HoloBee [12], allowing multiple users to jointly explore the real-world sensor and simulated flight path data.

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