

**[POSTER] HoloBee: Augmented Reality Based Bee Drift Analysis**Huyen Nguyen <sup>1\*</sup> Sarah Ketchell <sup>1,2†</sup> Ulrich Engelke <sup>1‡</sup> Bruce Thomas <sup>3§</sup> Paulo de Souza <sup>1¶</sup><sup>1</sup> Data61, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Sandy Bay TAS 7005, Australia<sup>2</sup> School of Engineering and ICT, University of Tasmania, Sandy Bay TAS 7005, Australia<sup>3</sup> School of Information Technology and Mathematical Sciences, University of South Australia, Mawson Lakes SA 5095, Australia

Figure 1: A honey bee with a microsensor backpack that allows for studying their behaviour in-situ in their normal environment (left). Bee drift is one of the important behaviours derived from the microsensing data. A user explores bee drift using a Microsoft HoloLens visualising a 3D spatial map of the experiment site where the data was recorded (right).

**ABSTRACT**

In this paper, we introduce *HoloBee*, a visual analytics system that enables end users to analyse bee drift data using HoloLens as a head mounted augmented reality interface. HoloBee was designed to allow for interactive exploration of bee behaviour and specifically bee drift: the phenomenon of a bee leaving a hive and returning to another hive. For exploration in the bees' natural environment, bee drift is visualised as arcs connecting bee hives positioned in 3D geo-spatial maps. We describe in detail the design aspects of HoloBee, including command language, system feedback, and information display. We discuss the unique capabilities and limitations of the HoloLens as a guide to other researchers who intend to use it for visual analytics of spatio-temporal scientific data.

**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); H.4.2 [Information Systems Applications]: Types of Systems

**1 INTRODUCTION**

The bees are dying globally and it is not well understood why. Pests, pesticides, pathogens, agriculture intensification, and hive management are understood to adversely affect bee health and contribute to colony collapse, but we are lacking a clear understanding

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as to the severeness of these and other factors. Yet bees are so important to the diversity of our ecosystems and the quality of our agriculture. Animal pollination affects around 75% of global crop production with bees being the most important group of pollinators visiting approximately 90% of the leading crop types [34]. The economic impact as well as the impact on our future food security are dramatic, should honey bee populations continue to decline. While encouraging progress on understanding colony collapse has been made in recent years, further research on bee health is needed [35].

In response to this issue, the CSIRO has launched the Global Initiative for Honey Bee Health (GIHH)<sup>1</sup> in 2015 with the aim to bring together researchers from across the globe to study in collaboration the factors impacting on honey bee health. By means of attaching tiny RFID tags to the bees and respective readers to hives and feeder stations, bee activity is studied in-situ in their normal environment. Dedicated experiments are carried out to study how specific factors impact on bee behaviour and ultimately on their health. Weather data and experimental meta-data are additionally recorded to correlate bee behaviour with environmental conditions. The data of all GIHH partners is stored in a central database at the CSIRO for collaborative analysis. Many bee activity measures can be computed from the data to assess their significance as an early indicator for honey bee health. One such measure is *bee drift*, which relates to the behaviour of a bee leaving one colony to join a colony in a different hive [11]. Understanding drift behaviour may constitute an early indicator for hive health decline caused by hive arrangements or changes in weather conditions, and therefore provides a critical decision support tool.

Effectively communicating the heterogeneous data and derivatives thereof to a range of end users, including scientists, bee keepers, industry partners, and government officials, and allowing them to gain deep insight into bee behaviour is one of the major chal-

<sup>1</sup> <https://research.csiro.au/gihh/about/>

lenges of this project. To address this challenge, we are currently developing a visual analytics framework at the CSIRO that allows for interactive exploration of the complex sensor data [9]. Visual analytics [21] integrates interactive visual interfaces with computational data analytics and as such it takes a vital role in helping to find patterns and meaningful insights for the user to make well-informed decisions and take responsive actions. Within the GIHH we are especially focused on enabling collaboration [32] of several analysts at co-located or remote locations through dedicated mobile interfaces. With the advances in technology for the availability, mobility and affordability of head-mounted displays, augmented reality (AR) has the potential to be widely used to support collaborative visual analytics work. Augmented reality interfaces typically need to fulfill different design constraints as compared to conventional desktop interfaces, for instances, related to the naturalness of the user interface and the contextual interactions of the visualised content with the real world in which they are embedded. We previously designed and implemented *MelissAR* [8], a tablet-based AR system for visual analytics of honey bee behaviour in the field. *MelissAR* provides a powerful decision support tool through visualisation of statistical information augmented into the real world context. However, *MelissAR* requires for the user to hold a device in their hands (the tablet), focuses on statistical rather than spatial visualisation, and does not support collaboration of several analysts.

In this work we present a more sophisticated AR-based visual analytics system called *HoloBee*, which allows for end users to interactively explore bee drift data in a 3D spatial visualisation using a head mounted AR interface, the Microsoft HoloLens<sup>2</sup>. *HoloBee* enables several analysts to explore the bee data collaboratively using natural interactions and without loosing the context to the real world. The motivation for developing *HoloBee* was threefold. Firstly, the 3D visual representation provides users with an effective overview of the spatial relationships between hives in their geo-spatial context. Secondly, head mounted AR displays allow for several users to collaboratively analyse the data from an exocentric viewpoint, for instance, with the visualisation mapped onto a large meeting room table. Finally, head mounted AR may ultimately allow for users to analyse bee drift in-situ at the experiment site from an egocentric viewpoint.

In this paper, we describe in detail the design aspects of *HoloBee*, including command language, system feedback, and information display. We provide all relevant implementation aspects of the system and discuss the unique capabilities and limitations of the HoloLens with the aim to provide guidance to other researchers intending to develop a visual analytics system using the HoloLens.

## 2 RELATED WORK

As spatial data often needs to be investigated in three or more dimensions, conventional 2D monitors used for data visualisation and interaction may limit our experience and insights into the data. With the advances in technology of many display devices for AR, data visualisation and visual analytics work can be widely supported through AR techniques [36]. Several AR based information visualisation and visual analytics techniques have been proposed in the literature. According to Kalkofen et al. [19], AR visualisation techniques can be categorised into three major approaches: data integration, scene manipulation, and context-driven visualisation. Data integration techniques create and compute perception clues, by registering the virtual data onto the physical world [18]. Scene manipulation techniques annotate the physical scene to embed information content, change the visual position of physical world objects [20], incorporate diminished reality [26], or adjust perceived colour [12, 13]. Context-driven visualisation methods modify the visualisation appearance determined by the context of the physical scene [39].

Several traditional visualisation techniques have been deployed in AR systems. Complexity reduction and filtering are frequently employed for data reduction in AR information visualisation. AR filters may be based on the users tasks [17], profiles [15], or position [27], and the filter may be a combination of position and context [28]. Interactive in situ AR is also a critical aspect that enhances a visualisation experience [14, 22, 23, 25, 40]. Layout optimisation and view management approaches [1, 2, 37] facilitate data comprehension when a large quantity of information is presented to the user. Virtual data registration and overlaying techniques are crucial characteristics of AR visualisation, and influence information understanding and perception [7, 24, 33], along with annotation management [3, 10, 16].

With recent advances in holographic display technology, such as the Microsoft HoloLens, there is a potential for greatly advancing the information visualisation and data analytics fields. The HoloLens offers a unique set of functionalities that allows users to easily and naturally manipulate data holograms through rotation, scale, reposition operations by gaze, gestures, voice commands or a remote control. With its own self-sufficient computer, the cordless capability of the HoloLens provides users the possibility of moving freely in space to observe scenes from different perspectives. The HoloLens is still relatively new and only limited prior research using this system exists [4, 29, 38]. Chen et al. [4] describe a collaboration design between HoloLens and other devices such as tablets or PCs through Skype<sup>3</sup>. Mahfoud et al. [29] explore the benefits of using gaze-directed visualisation in mixed-reality using the HoloLens compared to desktop applications. Benefits include the availability of more space to interact with data and objects as well as the intuitiveness that using gaze brings to an application. Voinea et al. [38] propose a system for HoloLens which enables users to effectively learn about biomechanics. The immersive and natural interaction is identified to be of great value, but mobility issues and limited access to the application when deployed solely to the HoloLens are identified as limitations.

To the best of our knowledge, there were no guiding principles and limitations investigated and available in previous research on AR based visual analytics and especially when using the HoloLens. Given the prior art that we identified, *HoloBee* is one of the first AR based systems for visual analytics of spatial data in a natural context using the HoloLens. We believe it is the first system that focuses specifically on the analysis of honey bee behaviour. Unlike many of the previous systems, we evaluate task performance and user experience with *HoloBee* by conducting a formal user study.

## 3 HOLOBEE SYSTEM DESIGN AND IMPLEMENTATION

In this section we describe the *HoloBee* system with a particular focus on the user interface design and implementation.

### 3.1 Data Collection, Post-Processing, and Analysis

We attach miniaturised RFID tags to the backs of the honey bees to study their behaviour in their natural environment. Readers are installed to register if bees are entering or leaving hives and feeder stations. In a typical experiment, several thousand bees are tagged over the course of several months, each with its unique ID. As the lifetime of honey bees is typically only five to seven weeks, we do not tag all bees at the beginning of the experiment but continuously throughout the experiment, several hundred a week. In this paper, we focus on one specific experiment that we performed in the Geeveston and Cairns Bay sites in Tasmania, Australia. During this experiment, 8,230 honey bees have been tagged from 12th January 2015 to 25th June 2015. In addition to the RFID tag data, sensor data was collected from the hives (brood temperature, hive

<sup>2</sup><https://www.microsoft.com/microsoft-hololens/en-us>

<sup>3</sup><https://www.skype.com>

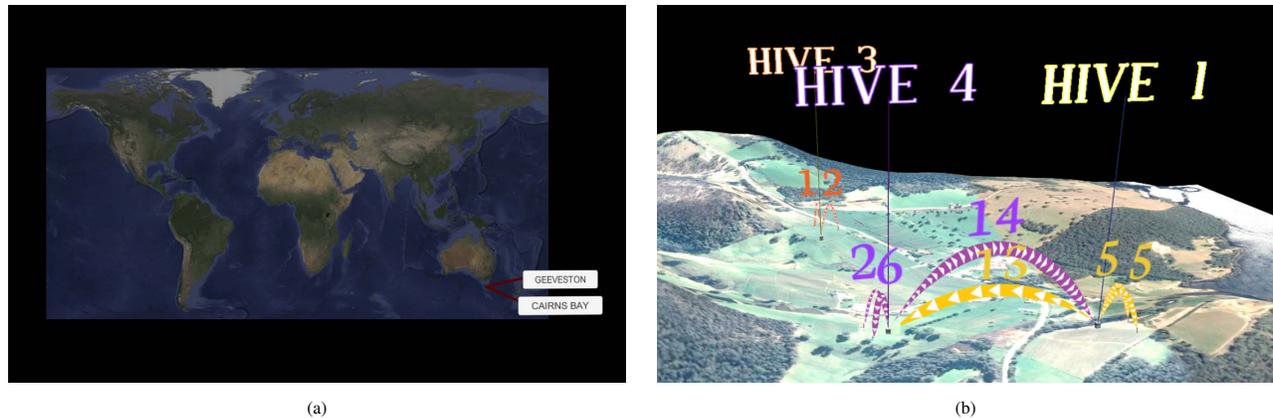


Figure 2: *Global scene* (a) of the system with all experiment sites labelled and *site scene* (b) that visualises hive drift as well as visits to feeder stations in a 3D geo-spatial map. In this example, the experiments sites in Geeveston and Cairns Bay site are available for selection and details for hive drift in February 2015 are presented for the Cairns Bay site. Distinguishable colours are used to represent the drift data of different hives.

weight, hive humidity) and weather stations (solar radiation, relative humidity, wind speed, precipitation). For the purpose of this study, we consider only the RFID tag data.

The collected RFID data needs post-processing prior to analysis, comprising of three operations: cleaning, classification, and aggregation. The cleaning operation removes any data points that are deemed to be invalid. This can include multiple consecutive detections when bees are residing on the reader or even die on the reader. The classification operation determines whether a detection relates to entering or leaving a hive/feeder station. The first detection every day is assumed to be leaving the hive and subsequent detections are classified accordingly. Finally, temporal aggregation of detections can be performed that allows for establishing relationships between the RFID data and the other data sources (hives and weather stations).

Several activity measures can be determined from the RFID data. In this work, we focus on one particular measure that is thought to be of relevance to hive health prediction: hive drift. Hive drift relates to the phenomenon that a bee leaves one hive and enters into another hive instead of returning to the original hive. In our data, we determine this behaviour when an ‘entrance’ reading of a bee with a specific ID is associated to a different hive than a preceding ‘exit’ reading. Hive drift is typically a rare event for which reason associated readings are very low as compared to overall bee activity.

### 3.2 User Interface and Visualisation Design

Three main user interface (UI) components have been considered in the HoloBee design: command language, system feedback, and information display [30]. We note that the system has been specifically designed taking into account features and limitations of the Microsoft HoloLens. Many design aspects, however, are easily transferable to other AR headsets in the future by adapting the design constraints.

#### 3.2.1 User Interface Overview

The system is designed such as to provide novice and expert users with an effective data exploration experience through an interactive visual interface. We took into consideration constraints of the HoloLens (e.g. field of view), the 3D space, and the ability of the user to move and interact therein. We loosely followed the Overview+detail paradigm [5] and Cognitive Task analysis [6] to build a UI that aids the user to easily situate the information of a

particular experiment in a global context. The application therefore includes two different scenes that the user can view and interact with: the *global scene* and *site scene*, as shown in Fig. 2a and Fig. 2b, respectively. Upon starting the application, the global scene is showing the experiment sites. Ultimately, this map will include all experiment sites within the GIHH, but for the purpose of this study, we visualise the considered experiment sites in Geeveston and Cairns Bay. Upon selection of a site, the user is taken to the site scene that visualises hive drift as well as visits to feeder stations in a 3D geo-spatial map. We note that although visits to feeder stations are not classified as bee drift, they exhibit the same analytics and visualisation properties as drift between hives.

#### 3.2.2 Command Language and System Feedback

The command language and system feedback should facilitate a natural and intuitive interaction of the user with the system for high task performance and user experience. The Microsoft HoloLens offers a unique set of functionalities in this regard, including, voice control, gaze tracking, gesture recognition, spatial mapping, spatial sound, and 3D visualisation in a real-world context.

We utilise *voice control*, *gaze tracking*, and *gesture recognition* as means for the user to interact with the system. Unlike many conventional interaction techniques, such as using a mouse, keyboard, or joystick, voice control is intuitive and therefore easy to learn, has a large degree of freedom for control commands, and reduces prior expectations as to the effect of certain commands. Modern speech recognition engines, such as the one by Microsoft integrated into the HoloLens, allow for seamless voice control without cumbersome training periods. Voice control is used in our system to select certain months for which data should be visualised, to move in and out of scenes, and to switch between scenes. Gesture recognition in the HoloLens is limited to two interactions, one of which allows for the user to make selections and the other allowing the user return to the main menu. We utilise the selection gesture to pick sites from the global scene and to navigate menus, such as selecting a help menu for available voice commands. The site to be selected is indicated by moving the eye gaze to the respective tab, as facilitated by the gaze tracker. An overview of the commands and respective actions they initiate is shown in Table 1.

Instant system feedback assists the user in manipulating and exploring the data. We integrated both *visual* and *auditory* feedback mechanisms into the system. Visual, directional pointers guide the user’s gaze and direct the user’s attention to the important part(s) of

Table 1: Command language for the Augmented Reality interface and the respective actions the commands initiate.

Scene	Command Language			Action
	<i>Voice</i>	<i>Gesture</i>	<i>Moving</i>	
Global	“Cairns Bay”	Select “Cairns Bay” button		Enter Cairns Bay site
	“Geeveston”	Select “Geeveston” button		Enter Geeveston site
Site	“Main menu”	Select ”Menu” button		Return to Global scene
	“Display” + Month			Display monthly drift data (January, ..., June)
Any			Forward / Backward	Zoom In / Out
			Around the scene	Rotate the scene
			Left / Right	Translate the scene
	“Finish”			Complete task



Figure 3: Directional pointer showing the user where to see the terrain at Geeveston site.

the visualisation, facilitating their spatial awareness of the data visualisation in the limited field of view of the HoloLens (see Fig. 3). Additionally, a visual cursor is used to reflect the centre of the user’s viewpoint, allowing the user to manipulate the interactive artifacts of the environment. It changes its size and orientation to be three-dimensionally mapped onto the environment. These expressive cues help the user to be instinctively aware of the state of the application, facilitating the perception process of entities in the virtual world. In a collaborative context, these cues can be further developed to represent users’ activities to their peers [31].

Auditory feedback is also an intuitive and useful method to help the user explore the data and the environment. As a consequence of readability issues due to the limited field of view as well as of the live background of the HoloLens, it can be difficult to read large amounts of text in the HoloLens’ display. We therefore utilise the auditory channel to provide information to the user during exploration without cluttering the UI with unnecessary buttons and text. Specifically, upon startup of the application, vocal messages explain how to use voice controls to explore the data. The detailed information of the current site including name, position on the global map, number of hives, current month, etc. is explained to the user through vocal explanatory messages. Additional information in the text format can be accessed during runtime via a “Help” menu. The content shown through the “Help” menu can be context-driven.

### 3.2.3 Information Display

The information display component is an important part in the UI to effectively convey the information to the user. The experimental

sites are visualised as elevation maps with satellite images overlaid to provide a real world context for the bee drift visualisation. We created 3D models of hives and feeder stations and placed them at their respective GPS locations in the geo-spatial maps.

Bee drift is represented by arcs drawn between any two hives as shown in Fig. 2b. The bee drift visualisation needs to encode several properties: a source hive, a destination hive, and the number of bees drifting. Each source hive is assigned its own colour, which is mapped onto the arc leaving a source hive and a label hovering above the hive. The end of the arc leads to the destination hive. The width of the arc corresponds to the number of bees drifting: a wider arc indicates higher drift. Numbers are additionally placed above the arc to allow the user to easily find the exact number of bee movement between hives. While being a redundant encoding, the arcs also have arrows on them to show directionality between source and destination hives. Bright and easily distinguishable colours were chosen so that they could be clearly observed in the HoloLens, given the cluttered background of the satellite image. Figure 2b shows drift data of Hive 4 (purple), Hive 1 (yellow), and Hive 3 (orange) for Cairns Bay in February 2015.

### 3.3 Implementation

The HoloBee system was implemented using Unity and Visual Studio, with the C# programming language. A connection to the database was established using C# code and SQLite plugins. Terrains of the experiment sites were generated from elevation data and overlaid with high resolution Google Maps images taken from Google Earth<sup>4</sup>. HoloLens specific aspects were integrated using the HoloToolkit<sup>5</sup> following instructions from the Microsoft Holographic Academy<sup>6</sup>. Hive and feeder station 3D models were created in Blender and were then placed in the scene in the position they are in the real world. To model drift between hives, the line renderer component was used to draw arcs between relevant hives, based on retrieved data from the database.

### 4 DISCUSSION

We designed and implemented HoloBee, an AR based visual analytics system for the exploration of bee drift in a natural context. During development we were already able to derive some early observations and insight into bee drift. For instance, we found drift between the Cairns Bay and Geeveston sites, despite them being approximately 7.5 km apart. The possibility of such occurrence was then confirmed by an entomologist and an experimenter in our

<sup>4</sup><https://www.google.com/earth/>

<sup>5</sup><https://github.com/Microsoft/HoloToolkit-Unity>

<sup>6</sup><https://developer.microsoft.com/en-us/windows/holographic/academy>



Figure 4: Actual field of view of HoloLens captured from the screenshot of the device.

team. While bees have been known to travel as far as 10 km to gather pollen and nectar, this remains to be a peculiar insight derived from our system.

We conducted a preliminary study and from interviews with the participant we received positive feedback on the immersive experience using HoloBee. Most of the participants found that it was simple to use the system by only having to memorise four main types of voice commands with natural linguistic meanings behind them. The capability of freely walking around the scene to observe the data was also highly appreciated. According to many participants, looking at the bee drift data through a HoloLens device was found to be exciting and engaging.

The user interface design had to take into account several limitations in relation to the capabilities of the HoloLens and most importantly, the limited field of view. Figure 4 illustrates the field of view from a users viewpoint. The positioning of the objects in the scene had to take these limitations into account, and sizing was deliberate to enable users to see more of the scene. In the context of our work, the limited field of view may have had an impact on how the users interact with the 3D environment as they would have to move around more to observe the scene closely compared to when a broader field of view would be available. With advancements in head-mounted AR technology, such limitation will likely disappear in coming years.

We designed HoloBee using head mounted AR with two main purposes in mind, collaborative analysis and in-situ analysis in the field. The former facilitates analysis of bee drift and other bee activity measures from an exocentric viewpoint in an office-like environment. In-situ analysis in the field would allow for bee keepers and scientists to study bee behaviour from an egocentric viewpoint at the hives. While the visualisation part of HoloBee should be easily adopted to facilitate this, currently such application of HoloBee is limited by the feasibility of using HoloLens in an outdoor environment. Specifically, the HoloLens is not weather resistant and screen brightness is not sufficiently high to perform well in bright environments (such as on a sunny day). As with the field of view, these limitations are likely overcome in the near future.

## 5 CONCLUSION

We present HoloBee, a visual analytics system that allows end users to analyse bee drift data through a head mounted AR interface. The system was designed and implemented to facilitate effective interactive visualisation of the data in a given context, keeping in mind the functionalities and limitations of the HoloLens. HoloBee allowed us to draw some early observations and meaningful insight into bee drift within and between experiment sites.

While HoloBee is designed for a specific analysis task, it can be easily expanded to include new data, analytics, and visualisa-

tion techniques. We plan to extend HoloBee in several directions to facilitate collaborative analysis as well as in-situ analysis in the field. We will include data from additional experiments as they become available and amend the visual analytics pipeline to allow for exploration of other bee activity measures, such as hive statistics and flight trajectories, as well as weather conditions. Further system validation through user studies will be needed to assess the performance and user experience of HoloBee as compared to conventional desktop application.

To the best of our knowledge, HoloBee is one of the first AR based systems for visual analytics of spatial data in a natural context using the HoloLens. We believe it is the first system that focuses specifically on the analysis of honey bee behaviour. We hope that the design and implementation insight that we are sharing in this paper will aid other teams in developing successful AR applications in this space and especially when using the HoloLens.

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