DISCOVERABLE DESKS

Finding location and orientation in a mobile workplace

SOPHIE SCOTT¹, BEN DOHERTY², ALESSANDRA FABBRI³, NICOLE GARDNER⁴ and M. HANK HAEUSLER⁵
¹,³,⁴UNSW
¹,³,⁴{sophie.scott|a.fabbri|n.gardner}@unsw.edu.au
²BVN
²Ben_Doherty@bvn.com.au
⁵UNSW & CAFA Visual Innovation Institute Beijing
⁵m.haeusler@unsw.edu.au

Abstract. The drive towards increasing productivity through collaborative ways of working has spurred a parallel trend in flexible and adaptable workplace environments. Mobile desks are one feasible solution to this but workplaces that adopt mobile desks risk creating spatial inefficiencies. These range from overcrowding or underutilization, to potential compliance issues in terms of fire egress requirements and health and safety regulations. While there is a need to understand mobile desk configurations there are currently no well-established ways to track the location and orientation of mobile desks within workplaces. Consequently, this paper describes a research project that adopts an action research methodology as an iterative and participatory framework to investigate and develop a unique method for capturing the location and orientation of freely moveable desks in an open workplace environment. This uses an ensemble of Bluetooth location beacons and computer vision techniques to provide a finer resolution than either method alone can currently provide. The demonstration of this ensemble method is the main contribution of this work. This paper demonstrates that combining these methods can enhance the advantages of each; computer vision gives higher resolution and beacons reduce the scope of the image search task.

Keywords. Indoor Positioning Systems; Office Space Planning; Location Data; Computer vision; activity-based working.

1. Introduction

The drive towards increasing productivity through collaborative ways of working has spurred a parallel trend for flexible and adaptable workplace environments. In an Australian context the workplace organisational strategy known as activity-based working (ABW) has gained increasing popularity (Candido et al. 2018). In an ABW environment, users are encouraged to change locations within...
a workplace as often as required to suit the tasks at hand, and to be near those users they need to collaborate with. While a key principle of ABW is ‘desk-ownership removal’ (ibid), that is achieved by allowing users to choose from a variety of spaces to support different tasks, a variation on this approach allows users to reconfigure their own workspaces by being able to freely move their mobile desks. Gaming and hardware development company Valve Corporation were one of the first organisations to adopt mobile desking. For Valve (2012), mobile desks aligned with their corporate strategy that sought to reject hierarchical organisation as a way to promote collaboration and innovation. Consequently, mobile desks served as both a flexible workplace arrangement and “...a symbolic reminder that you should always be considering where you could move yourself to be more valuable” (p.6). As such, a mobile desk is a desk with wheels that can be moved to any location across a workplace, at any time by the user. Yet, while mobile desks can make workplaces easily reconfigurable, the corollary to this approach are issues of find-ability, spatial inefficiency, and regulatory compliance.

When desk arrangements are ‘unknowable’, this risks configurations that are overcrowded, underutilized, or that create potential compliance issues in terms of fire egress requirements and health and safety regulations. Presently, there are no established ways to ‘know’ the location of mobile desks. Consequently, this paper outlines a research project that explores the discoverability of mobile desks through a case study of the BVN workplace in Sydney. This investigates and develops a unique method for capturing the location and orientation of freely moveable desks in an open workplace environment, through an ensemble of Bluetooth location beacon technology and computer vision (CV) techniques to provide a finer resolution than either method alone can currently provide. By locating and orienting desks in space, such data can be used to locate individual users, analyse compliance against minimum space standards and fire egress regulations, and critically, provide empirical insight into how people choose to occupy their workplace. In short, this establishes a method for generating workplace environment intelligence. The following sections of this paper outline the overarching research methodology, the technical methods explored for developing mobile desk discoverability and the outcomes and significance of the research.

2. Methodology

This research adopts the overarching methodology of action research. Originating in the social sciences, action research is people-centred, oriented towards participation, and engages iterative cycles of planning, acting, observing and reflecting (Baldwin 2012; Foth, 2006; O’Brien, 1998). This research project adopts the case study of a section of the BVN Sydney studio to explore the development of methods to locate the position and orientation of mobile desks. Finding a specific mobile desk in a large workplace can be challenging. However, given the exposed and highly figured soffit in the case study office, CV techniques were deemed a suitable approach to explore. While CVing could potentially work alone as a method, it is limited by being computationally intensive and thus slow and prone to error. Similarly, blue tooth Estimate location beacons alone could
be used locate a desk within a tolerance of 1.5m (Estimote, 2018) however this is insufficient information to accurately gauge spatial compliance. For these reasons, this research explores the combination of Bluetooth Estimate location beacons and CV techniques to provide a finer resolution than either method alone can achieve.

3. Background Research

In a contemporary context, mobile digital technologies, such as the smartphone, enable a user’s location to be readily and accurately tracked. Significantly, the accuracy of a user’s location in geographic space is determined through a combination of technical features within the device, such as the accelerometer, magnetic field, and orientation sensors, and communication with a global positioning system (GPS) (Gubi et al, 2006). Yet, while the technologies that support a smart device’s locatability are reasonably accurate for outdoor environments, they are less reliable in terms of indoor environments, such as workplaces. As such, this research is situated within a larger field of indoor positioning systems (IPS) research that address the challenges of tracking and locating moveable objects indoors (Gu et al. 2009; Zafari et al. 2018).

As Rizal et al. (2016) note in their recent research on IPS for human presence tracking, in relation to GPS for outdoor environments there has been “no comparably ubiquitous positioning system that can be used to make device-driven position tracking that is specifically adapted to indoor environments” (p.46). Indeed IPS developed for indoor environments to date has explored a variety technologies such as Bluetooth, Infrared, wireless local area network, radio frequency identification (RFID) and Ultra-wideband to name a few. In their review of locating methods, Kim and Han (2018) reflect that commonly proposed solutions for indoor location tracking “have problems, such as multi-path, obstacle (shadow area), and signal loss” (2018, p.3). Consequently, cost effectiveness emerges as a key challenge across numerous IPS research projects to date with several studies exploring opportunities to leverage already-deployed technologies such as smart mobile devices and low-cost trackers (Dardari et al. 2015; Rizal et al. 2016; Zhao et al. 2008).

As an alternative to location tracking that relies on user’s carrying smart devices, numerous IPS approaches have explored wearable location tracking devices. The Active Badge System requires end-users to “wear tags that broadcast their location to a centralised service through a network of sensors” (Dardari et al. 2015). Similarly, Rizal et al’s (2016) human presence tracking project relied on users carrying a Bluetooth enabled device. This project documents a number of problems that faced when employing mobile beacons and sensors for location tracking including users carrying multiple detectable devices, the interference of human bodies within the line of sight between emitter to receiver, the accuracy of data, and processing issues associated with real-time data collection (Rizal et al. 2016). Collectively, these IPS studies point to a range of challenges that are faced when devising methods to track objects in indoor environments. Equally, they highlight the ways IPS engage multiple technologies in often bespoke configurations informed by issues of cost, context, tracking subjects, and data use intentions. The case example in this paper differs from these existing
research examples primarily as the object to be tracked is a desk rather than a human and the data to be collected intends to inform, not only locatability, but also spatial regulation analysis. Given the case example necessitates a high degree of data veracity, this research explores the novel combination of low-cost Bluetooth location beacons in conjunction with CV techniques to achieve higher spatial tracking accuracy.

4. Case Study

This research explores the development of a system to identify the location and orientation of mobile desks in a workplace. Given the exposed and highly figured soffit in the case study office, this research employs a combination of CV techniques in conjunction with Estimote location beacons. This aims to create a data collection method that mobile desk users could easily follow by using their own mobile device to capture high resolution images of the workplace ceiling as a reference point to locate mobile desks. The end user would place the phone in a known position on their own desk to record its position. The Estimote location beacons complement this approach by narrowing down the search area of the workplace ceiling to within a tolerance of approximately 1.5m (Figure 1), while CV techniques then work to achieve enhanced position and orientation accuracy. Consequently, the research commenced with iterative cycles of developing and testing a method for capturing a high resolution ceiling image, developing and testing a method to merge the captured images and testing data interoperability with the OpenCV algorithms. Secondly, the location beacons were tested to establish a satisficing quantity and position for beacons in the case study workplace.

The method taken distinguishes between location—the coordinates of the origin point of the desk, relative to a local coordinate system—and orientation—rotation around the z axis of the local coordinate system, in degrees. The term ‘position’ in this case denotes the combination of location and rotation.

To locate a desk in space we assume that the mobile device is in a known position on the desk’s top. If we assume that the desk’s wheels are on the floor then, to remove additional degrees of freedom, we need to know either the position and rotation from a single datum, or two positions. In this case study we have chosen to work with the former.
4.1. CREATING A CEILING IMAGE

To test methods for capturing a high resolution ceiling image, the research began by exploring CV algorithms such as homography that can effectively position similar objects and patterns in pairs of images. This process however is computationally intensive meaning the growth of time complexity can be above linear with respect to pixel count. Equally, the case study ceiling presented a further challenge as it comprises many similar elements, meaning the possibility for false-positive matches returned was high. Using the beacons provided a coarse location, and helped narrowed the scope of the image search task. The ceiling was photographed, merged into a single image, then tiled into a collection of images that can be retrieved beacon’s coordinates. These images were processed with a CV algorithm that identifies the centre of the sample image, and ultimately returns the centre coordinate and rotation angle (Figure 2).

While the ideal image for searching would be perfectly parallel this was impossible and therefore multiple photos were taken of the ceiling from desk height. These were combined into one overall ceiling image (super image). To create and stitch together an image from many photographs necessitates
significant overlap, and only the central portion of the image is useful due to image distortion created at the perimeter by the larger angle deviation from the normal. Experimentation here showed that care and precision was needed to ensure complete coverage. However the most successful technique was to take a very large number images without any prior planning.

Figure 3. How the camera will locate an image on the ceiling, and the dimensions required (LHS) and 40% overlaps between images shown in grey (RHS).

Figure 4. Resulting photo merge.

4.2. COMPUTER VISION

With a method established to create a super-image (comprised of 4 individual ceiling images merged together) (Figure 4), the next part of the process sought to find an efficient and successful way to locate a search-image (the fifth photo within the bounds of the first four and rotated) within the super-image.
A number of image capture techniques were tested from the OpenCV library (OpenCV Dev Team, 2014). Template Matching failed because the search-image wasn’t an exact subset of the super-image. OnlyMatches showed more promise, as did RANSAC, Shi-Tomasi and ORB, but were unable to complete the task of positioning. Ultimately SIFT and FLANN provided reliable positioning results.

Bobade and Jagtap (2014), explain the SIFT (Scale-Invariant Feature Transform) algorithm as “The first stage of computation searches over all scales and image locations”. It also has an orientation assignment where each key point is assigned one or more orientations based on image data that has been transformed. This was used in conjunction with FLANN (Fast Library for Approximate Nearest Neighbours), “which contains a collection of algorithms optimised for fast nearest neighbour search in large datasets and for high dimensional features”, as it is a faster process than the Brute-Force Matcher (Mordvintsev and Rahman 2013).

The algorithm retrieves the SIFT features of the images, puts these through the FLANN algorithm, before applying homography and a perspective transform to get the quadrilateral. The results (Figure 6) show the features identified in each image, with a boundary and centre point which correctly identify matched features to the super-image. It also returns a rotation angle of 31 degrees. SIFT and FLANN based matchers also returned a successful match of the super and search images. This resulted in two different images with a change in scale and rotation, something that is likely in the context of this application. This was especially significant in this research phase as it allowed the desk’s position to be determined using this method.
4.3. TOLERANCE TESTING

To validate the system, and to give a sense of the possible tolerances within the system this paper outlines four examples (Figure 6, Table 1.0). The resulting difference between the exact angle and the returned angle was similar, showing an average difference of 1.8 degrees across the four tests. Distances are rounded up to the next 10mm as confidence in the centroid reporting led the research to be conservative.

Table 1. Results of the location & orientation testing, showing reported Δ from actual position.

<table>
<thead>
<tr>
<th>Image</th>
<th>Actual Angle</th>
<th>Returned Angle</th>
<th>Difference</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 01</td>
<td>31°</td>
<td>32.03°</td>
<td>1.03°</td>
<td>50mm</td>
</tr>
<tr>
<td>Test 02</td>
<td>90°</td>
<td>86.73°</td>
<td>3.27°</td>
<td>30mm</td>
</tr>
<tr>
<td>Test 03</td>
<td>24°</td>
<td>21.74°</td>
<td>2.26°</td>
<td>30mm</td>
</tr>
<tr>
<td>Test 04</td>
<td>90°</td>
<td>89.30°</td>
<td>0.7°</td>
<td>70mm</td>
</tr>
</tbody>
</table>

4.4. BEACONS

This research adopted Estimote location beacons to provide coarse grain location. Based on Rizal’s (2016) research its was assumed that bluetooth signals are analogous to light. To establish a location, a mobile device must be able to ‘see’ at least three beacons. A count of overlapping isovists established an acceptable arrangement and quantity (6) of beacons to cover the case study area. A differentiation to Rizal’s (2016) research where data was being tracked in real time, was in this research the data output from the beacons and the CV was on-demand to avoid the challenge of continually processing high volumes of data.
5. Significance of research

This research builds on existing IPS research by proposing a method to locate the position and orientation of mobile desks in a workplace through a combination of CV and location beacons to improve the accuracy of locational data results. Capturing the ceiling image in a busily occupied workplace proved to be the first challenge of this process. Secondly, while the image capture enabled the identification of unique elements of the ceiling for the CV process, having an exposed soffit also meant that with many repeated elements there was potential for false positives. To resolve this, the research used location beacons to reduce scope of the task of searching a large image as it can be computationally intensive. The beacons operated to provide a coarse resolution to significantly reduce the size of the image to search. The location beacons alone were able to identify the location (but not rotation) of a desk with limited accuracy (±1.5m). Coupled with CV techniques this ensemble method allowed the positioning of mobile desks to <0.25m and <5° (ave: 1.8°). These initial results indicate that this application is productive, and can be built upon in future studies. The development of a mobile phone application to visualise the spatial data collection, while out of the scope of this project, is a logical next step for this research. Furthermore, future work could aim to develop a higher density ceiling map, and explore the use of the accelerometer in a mobile phone to ensure parallel images, while other sensors could add further to the ensemble.

6. Conclusion

Mobile desks are part of a current workplace trend that aims to promote collaborative and innovative ways of working by allowing users to freely
reconfigure their environments on an as-needs basis, yet this risks not knowing where people are located and creating fire egress and health and safety spatial compliance issues. This research has sought to address this problem by developing an IPS location method that combines CV and location beacons to enable mobile desk discoverability. This demonstrates that combining these methods enhances the advantages of each; CV gives higher resolution and beacons reduce the scope of the image search task.

This paper contributes to knowledge on IPS methods and outlines extended uses for image recognition and CV systems in indoor environments. Developing intelligent and informed systems to collect data and evaluate spatial compliance with health and safety regulations and fire egress regulations such as proposed here has extensibility well beyond this case example, from the health sector and construction industry to building management to name a few (Zafari et al. 2018). This research establishes a firm foundation for future work wherein more meticulous measurements are required to develop systems for enhanced spatial intelligence towards promoting safe and functional workplaces.

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