DISCOVERABLE DESKS: FINDING LOCATION AND ORIENTATION IN A MOBILE WORKPLACE

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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 desking 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 beacons and computer vision to provide a finer resolution than either method alone can currently provide. This paper demonstrates that combining these methods can enhance the advantages of each, where computer vision gives higher resolution and beacons reduce the scope of the image search task.

Keywords. Indoor Positioning Systems; Office Space Planning; Adaptable Space Planning; Location Data; Computer Vision

1. Introduction

The drive towards increasing productivity through collaborative ways of working has spurred a parallel trend for flexible and adaptable workplace environments.

A mobile desk is a desk that has wheels, and can be moved to any location across a workplace, at any time, for any given amount of time by the user. This has become an option for businesses seeking to adopt activity-based work environments (ABW) (Candido et al, 2018). The process is simple, the desk's owner can unplug the power and data, move the desk to a new location, plug the power and data cords back in, and they are ready to work again. An early example of this is gaming and hardware development company Valve. Valve (2012) states that "having desks with wheels is not only a literal concept, but also a symbolic reminder that you should always be considering where you could move yourself to be more valuable". It has promoted the notion that "there is no organizational structure keeping you from being in close proximity to the people who you'd help or be helped by most".

The BVN Sydney studio has implemented a workplace environment with mobile desks. This is enabled by the installation of power sources on the ceiling, and a power and data distribution box that is able to easily connect to up to eight computers at a time (Reinhardt et al, 2018). However, it is difficult to know where any particular desk is at any given time. This leads to questions around where someone's desk is, and consequently, where they are working in the workplace. If we are able to locate the desk, we can improve the accuracy of that location, and use these findings to establish whether the desk layout is compliant with minimum space standards and fire egress requirements.

Presently, there is no effective and accurate way to know the location of a desk and any of the information above. Therefore, this research demonstrates a method for locating a desk and its orientation in a workplace.

2. Research Objectives

The main objective of this research is to find the location and orientation of desks within a section of the BVN studio in Sydney. It will provide a platform for further exploration, in particular, a better understanding of how people choose to work in the space, compliance with layout standards and fire egress requirements.

In a large workplace, using Estimote location beacons is a successful way to locate a desk with a tolerance of 1.5m (Estimote, 2018). This system narrows down the location of the desk, but cannot identify its exact location in the workplace (Figure 1).

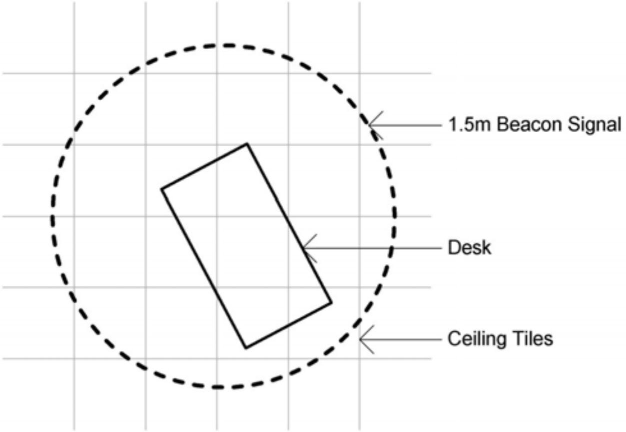

Figure 1. Diagram showing that the desk can be located anywhere within the 1.5m tolerance of the beacon signal.

The soffit of the BVN Sydney studio is exposed and is highly figured, so computer vision techniques are a feasible option to experiment with. Still, it is currently computationally intensive as computer vision alone could work, but it is slow and has the potential for multiple results. Beacons can reduce the scope and filter the options.

These two methods contain aspects that could positively contribute to identifying the location of a desk, but used individually are not successful enough for this research. To create a platform that enables an accurate location of a desk, this research uses a combination of Bluetooth beacons and computer vision techniques to provide a finer resolution of result than either method can alone.

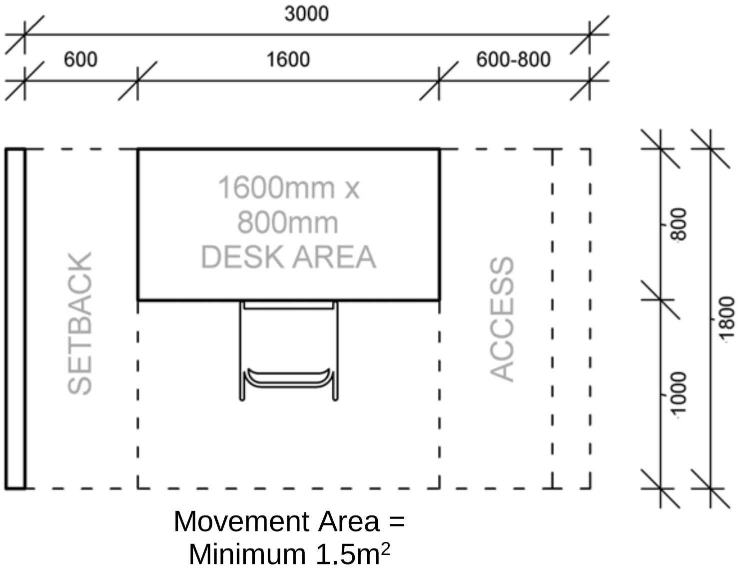

Figure 2. Diagram from Neufert Architects' Data Fourth Edition.

A finer resolution result aids in the potential exploration of desk layout compliancy. According to Neufert Architects' Data (2012) desk layouts require minimum movement areas, not only for the person using the desk, but also for people to navigate around the desk (Figure 2).

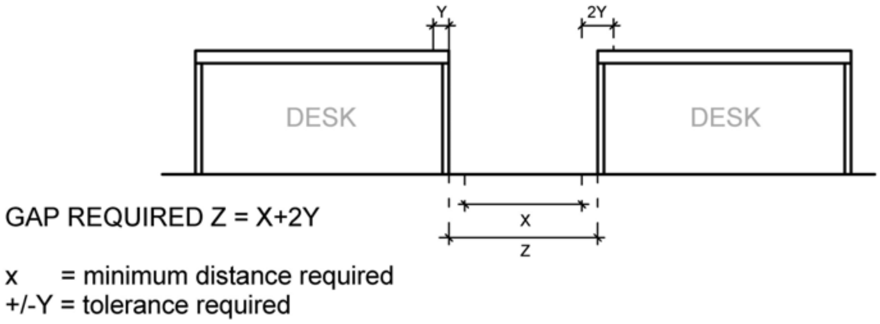

Figure 3. Diagram to determine tolerances for detailed results.

3. Research Question

Based on the issues of locating a desk, desk layout compliancy and fire egress requirements, this research aims to address one question: *how can we accurately capture the layout of mobile desks in a workplace?*

4. Methodology

The methodology of the project refers to "the choices we make about cases to study, methods of data gathering, forms of data analysis, in planning and executing a research study" (Silverman, 2015). The action based research method takes a problem solving approach as opposed to a "single method for collecting and analysing data" (O'Brien, 1998). This puts a strong focus on people-centred and participatory methods (Foth, 2006) using multiple research tools. According to Baldwin (2012), "It is one of the few research approaches embracing the principles of participation and critical reflection". Therefore, this research will undertake an action based research approach following Stephen Kemmis' Simple Model of action research (O'Brien, 1998);

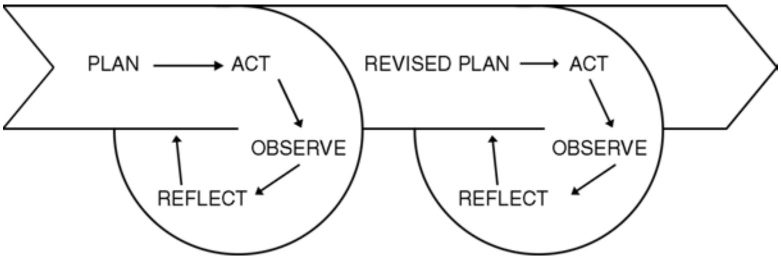

Figure 4. Stephen Kemmis' Simple Action Research Model.

Finding a particular mobile desk in a large workplace can be challenging. Consequently, a successful system to identify the location and orientation of these desks is to be developed. This research established a method that was undertaken and repeated until the desired results were achieved. This included:

1. Computer Vision
    a. Develop a method for capturing a high resolution ceiling image
    b. Develop a method to merge the captured images
    c. Research and test OpenCV algorithms
2. Estimote Location Beacon
    a. Establish a satisficing position for each beacon in the workplace

By creating these plans of action, we are able to document the failures and successes of the experimentation phase, so as to improve the process of the research and for future progression.

5. Background Research

"A positioning system enables a mobile device to determine its position, and makes the position of the device available for position-based services such as navigating, tracking or monitoring, etc." (Gu, Lo, Niemegeers, 2009). Indoor Positioning Systems (IPS) work specifically in indoor environments using technologies such as Bluetooth, Infrared (IR), wireless local area network (WLAN), Ultra-wideband (UWB), to name a few. "These methods have problems, such as multi-path, obstacle (shadow area), and signal loss" (Kim, Han, 2018). With current technologies, one of the main challenges with indoor positioning systems is creating "seamless solutions" using "standard, low cost and already-deployed technologies" (Dardari, Closas, Duijuric, 2015).

The concept of determining a position or tracking something somewhere is not new, with perhaps one of the first stories coming from Greek mythology, the story of Theseus and The Minotaur, where Theseus used a thread to retrace his way out of the Labyrinth after killing the Minotaur. Even the importance of scale drawings with accurate information only appeared, in a military context, in the 1500's in England, where gun emplacements were hidden and positioned to provide cover for neighbouring angled bastions, "leaving no blind spots or dead ground anywhere within the cannon range" (Gerbino, Johnston, 2009). This idea reinforces the need for accuracy in the overall ceiling image, ensuring the best possible outcome for determining a location.

Today, the use of mobile devices such as smartphones is a part of everyday life. These devices are equipped with technologies for location sensing, such as the accelerometer, magnetic field, orientation sensors, GPS, etc. (Gubi et al, 2006) The challenge is to combine these technologies to create a platform that can accurately determine a location by utilising the benefits of more than one of these components.

One current indoor positioning system known as the Active Badge System, requires end-users to "wear tags that broadcast their location to a centralised service through a network of sensors" (ibid). Rizal's (2016) research into human presence tracking relied on users to carry a Bluetooth enabled device, but results showed that users often carried more than one device and that "human bodies could interfere with the line of sight between emitter to receiver". Her research still presented significant challenges in indoor environments when attempting to detect real-time and accurate data.

Article and inventory tracking systems for tracking and controlling item movements within facilities are successful. A library, for example, has each item (whether a book, cd, magazine), having its own unique barcode that a computer can scan to see if the particular item can be removed from the library, for how long it can be borrowed for and who previously may have borrowed it (Belka, Brace, 1998).

6. Case Study

The Estimote location beacons will be adopted for the purpose of narrowing down the search area of the workplace ceiling (Figure 1). However, with the location accuracy of approximately 1.5m, this alone is not enough to accurately locate the position of a desk for our needs.

The computer vision algorithms can effectively locate similar objects and patterns effectively in many applications, though is currently computationally intensive. With an exposed ceiling comprising of structural and electrical elements, the possibility for elements to look alike is high, and therefore multiple matches could be returned. In light of this, these methods can be combined and explored to achieve an accurate location of a desk in a workplace.

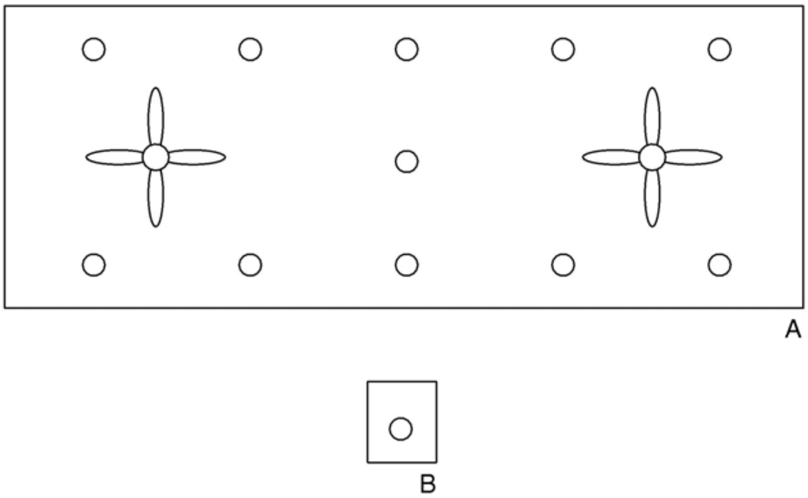

Figure 5. A. An example ceiling plan, where downlights and fans are duplicated, and therefore trying to find image B. within image A. can return a possible 11 results.

The result of the experimentation would be a database of images that can be narrowed down by the 1.5m radius of the beacon. These images would then be processed with a computer vision algorithm that could correctly identify the centre of the image taken, and ultimately the centre coordinate and rotation angle (Figure 6).

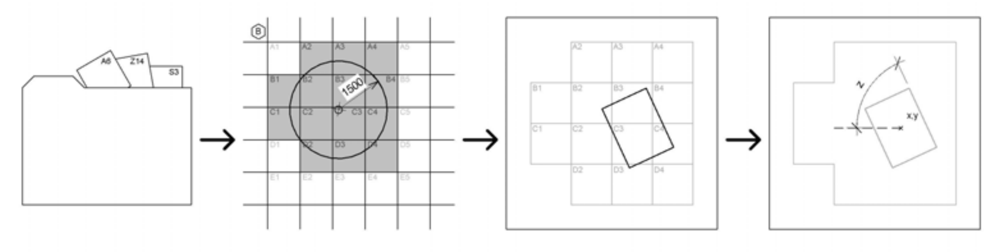

Figure 6. From left to right: Database of ceiling image tiles. Beacon location to 1.5m radius. Location of the image within those specific ceiling tiles. Accurate data location of the image

6.1 CREATING A CEILING IMAGE

The experimental process begins with creating a method to generate a ceiling image, before testing computer vision techniques on the image constructed. Multiple photos will be taken of the ceiling, before combining them and generating one overall ceiling image.

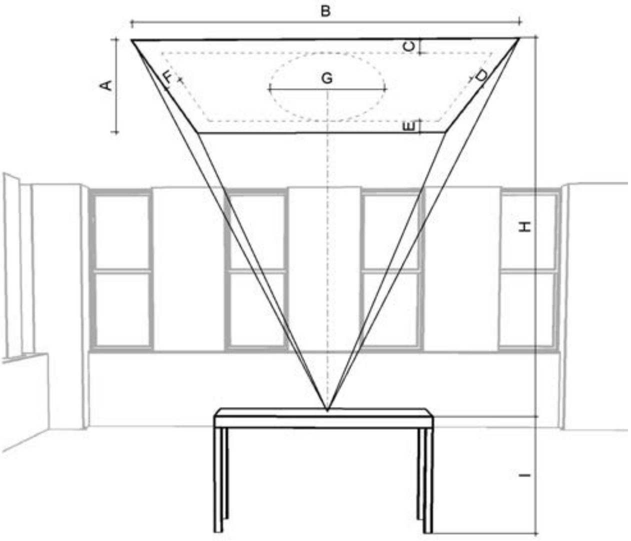

Figure 7. Diagram explaining how the phone will locate an image on the ceiling, and the dimensions required.

6.1.1 Experiment 1

The field of view of the phone's front camera was established to determine how much of the ceiling is visible from a given height. In order for each individual image to be stitched together successfully, a thirty per cent overlap was suggested. Based on these measurements, the distance in which the camera had to be spaced apart was established. In this experiment, a forty per cent overlap was established to decrease the distortion created by the angle of the front camera.

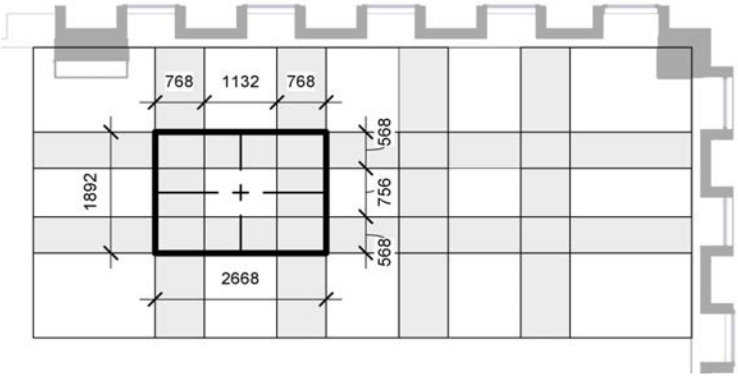

Figure 8. Overlap dimensions from the experiments with the overlap shown in grey.

A circular stool was used to hold the phone (Figure 9), and from this a grid was marked on the floor to position that stool correctly. Once the stool was in place, a photo was taken from the front camera of the phone, and then the process is repeated from the other identified positions of the grid.

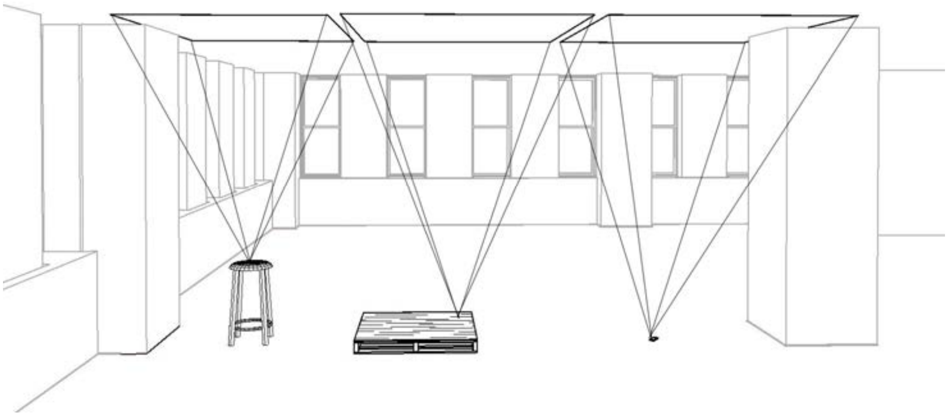

Figure 9. From left experiments 1, 2, and 3 in finding a technique to capture the ceiling image.

Having captured multiple images a Photoshop ‘photo merge’ was automated (Adobe, 2017). The images were uploaded in the same order they were taken, making sure they were all orientated the same way.

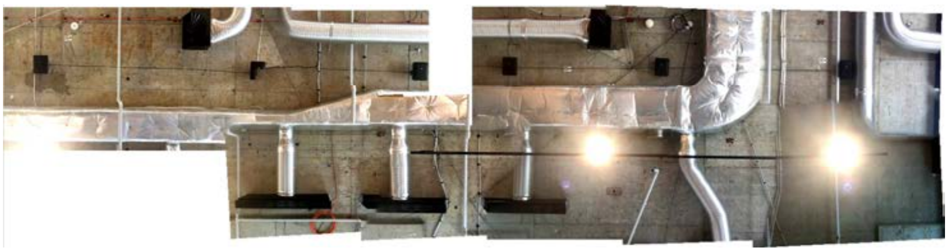

Figure 10. Resulting photo merge of Experiment 1.

From this initial experiment, a few issues arose. Firstly, the choice of the stool wasn’t ideal. Initially, the phone was taped to the seat and a circular stool made it difficult to have the phone in the same position every time. The shape of the stool also made it difficult to move along the grid lines accurately, because any rotation of the stool meant the image view would change. In order to overcome this for the experiment, a second grid line was established, therefore the four legs of the stool were always positioned on a grid line, resulting in no rotation or direction change through the repeated process of moving the stool. Then through capturing an image, one capture was missed, resulting in a gap in the merged ceiling image. Although it didn’t significantly impact the overall image, it was important to note for future experiments.

6.1.2 Experiment 2

In the second experiment, the stools were replaced by pallets that were 1160×1160mm (Figure 9), with the intent that a tessellating pattern would improve the alignment issues, and the experiment was repeated. Although the pallets were square, it was quickly realised that a grid line would need to be placed along the floor so that the pallets moved parallel to the wall, without any direction change. Structural obstacles in the space, such as the column, also proved to be an issue, but could be overcome by repositioning the phone on the pallet.

Figure 11. Resulting photo merge of the second experiment.

This process was quite successful, as something that could be easily tessellated meant a more meticulous way of keeping the camera in the correct position.

6.1.3 Experiment 3

For the third experiment, an area of the floor was identified, and then photos were taken at random with the phone positioned directly on the floor (Figure 9). This experiment was quite successful, and in relation to the other experiments had double the number of photos taken, which could have been the reason for its success. The only issue identified is that without knowing the exact location of where the photos were taken from initially, we are unable to verify the accuracy of future photos that are taken. This became something critical in the success of the computer vision aspect of the project.

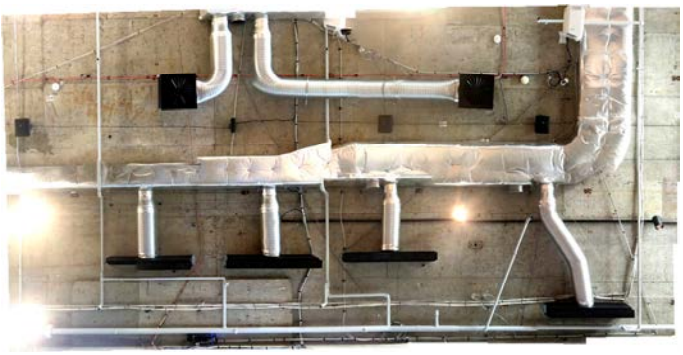

Figure 12. Resulting photo merge of Experiment 3.

These experiments detail an effective way to gain a basic ceiling image that will be sufficiently clear to carry out further computer vision processes. Although all experiments resulted in a similar final image, the more photos that were taken produced an improved overall image.

The result of this experiment is the input to the next stage of the computer vision research.

6.2 COMPUTER VISION

Having established a way of creating a super image (overall ceiling image), the next part of the process is discovering a successful way of finding the location of a different image (the search image) within that super image.

The first image was a sample of 4 individual ceiling images merged together (the super image, Figure 13), and the second image was a separate photo taken in the same location, rotated and at a different scale (the search image, Figure 14). It is important that this image is a completely different image taken, otherwise the results will be impacted significantly.

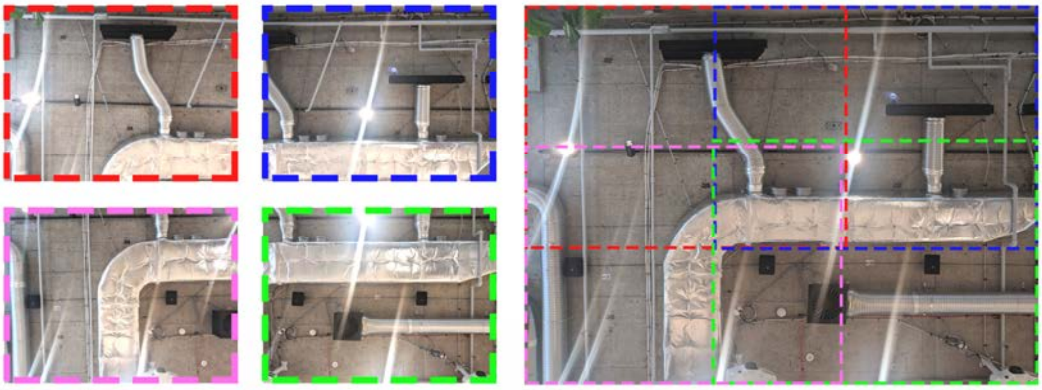

Figure 13. Four photos that were taken and merged together to create the Super Image

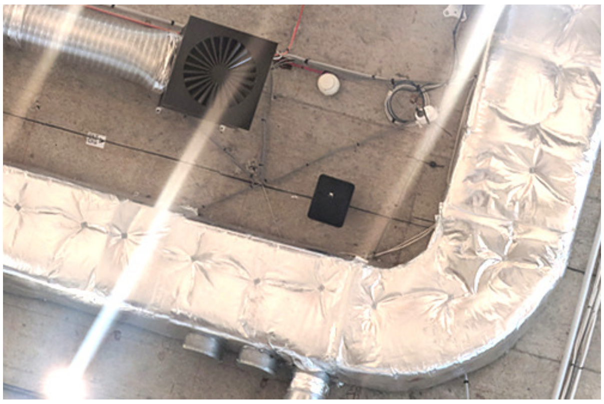

Figure 14. A separate photo taken within the Super image in a different orientation and scale, described as the Search Image

6.2.1 Template Matching

Template Matching is used for searching and finding the location of a template image within a larger image. "It simply slides the template image over the input image and compares the two images" (OpenCV Dev Team, 2014). In this experiment, the template image is the search image, and the larger image is the super image.

Figure 15. The super image and the search image.

The template matching attempt was unsuccessful because the search image was not a subset (or crop) of the super image, and also because the search image was not in the same orientation as the super image. To validate this, an exact crop was taken from the super image which remained in its exact size and orientation, and the process was executed again.

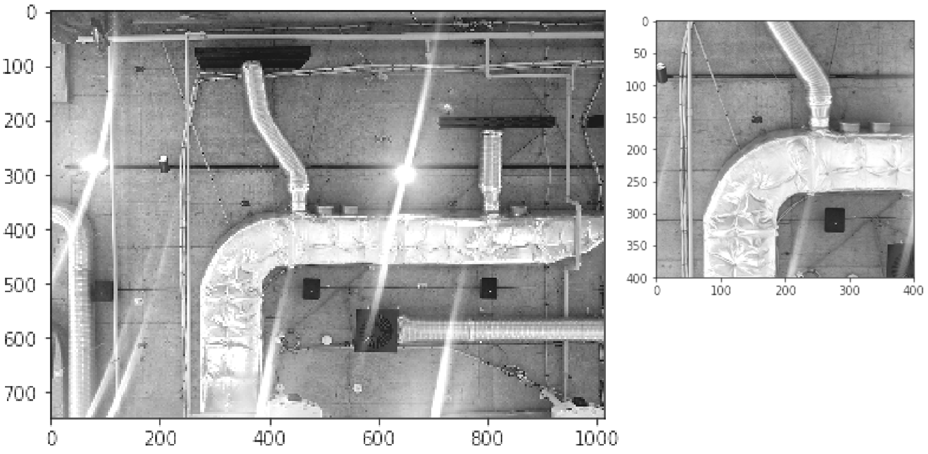

Figure 16. The super image and the cropped image.

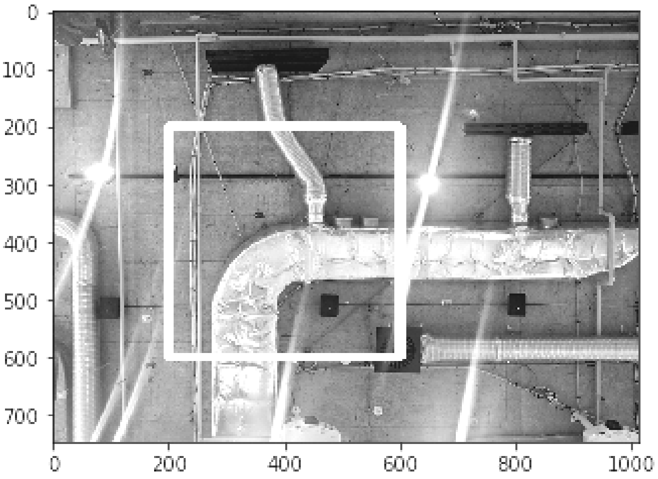

Figure 17. The white square representing the location of the cropped image within the super image, showing a successful match.

Although successful in this case, this process would not work in the context that is required as an image taken from a phone will always be different from the super image as no two images are identical unless it is a duplicated image. The image from a phone could also have a different orientation, and that data is important for knowing the orientation of the desk.

6.2.2 Identifying OnlyMatches

The second test involved solely identifying only matches of key points in each of the images (OpenCV Dev Team, 2014). The super and search images were used. The key points of the images are considered as unique points which stand out in the images. No matter how the image is modified (whether it be scaled, rotated, distorted, etc), those points should still be identified within the image (stackoverflow, 2015).

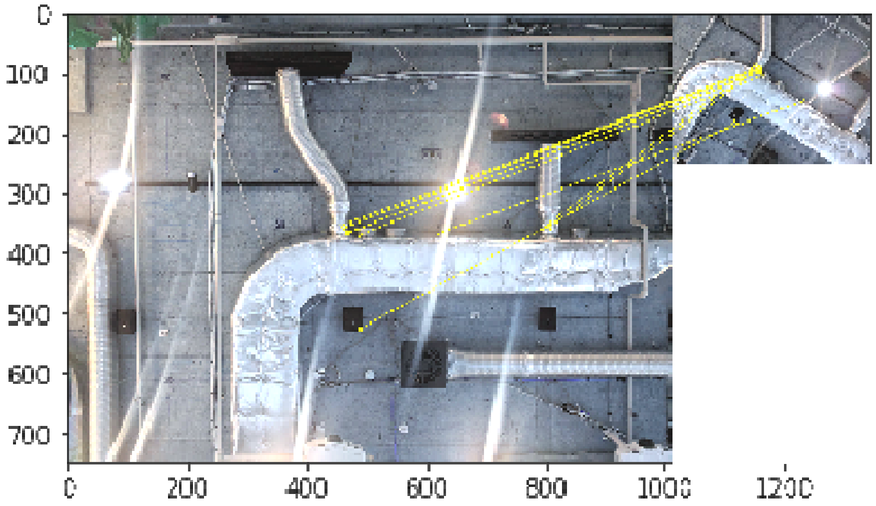

Figure 18. Lines connecting the top 10 key points in each of the super and search images.

In Figure 18, the top 10 key points were identified in each of the images and lines were drawn to show where the key points matched in each of the images.

This process appears to be successful. However, by looking at the image there seems to be more unique points that the algorithm could be picking up.

6.2.3 RANSAC Method

The Random Sample Consensus method was then used. “RANSAC is a resampling technique that generates candidate solutions by using the minimum number of data points required”. This method was explored because unlike other sampling techniques, RANSAC uses the smallest set of data possible and proceeds to enlarge this set with consistent data, whereas other techniques are known to use as much data as possible (Hasso, Elyas, 2014). As shown in Figure 19, this test was unsuccessful as it should have returned a red box around the image area, but has instead drawn a red line across the super image.

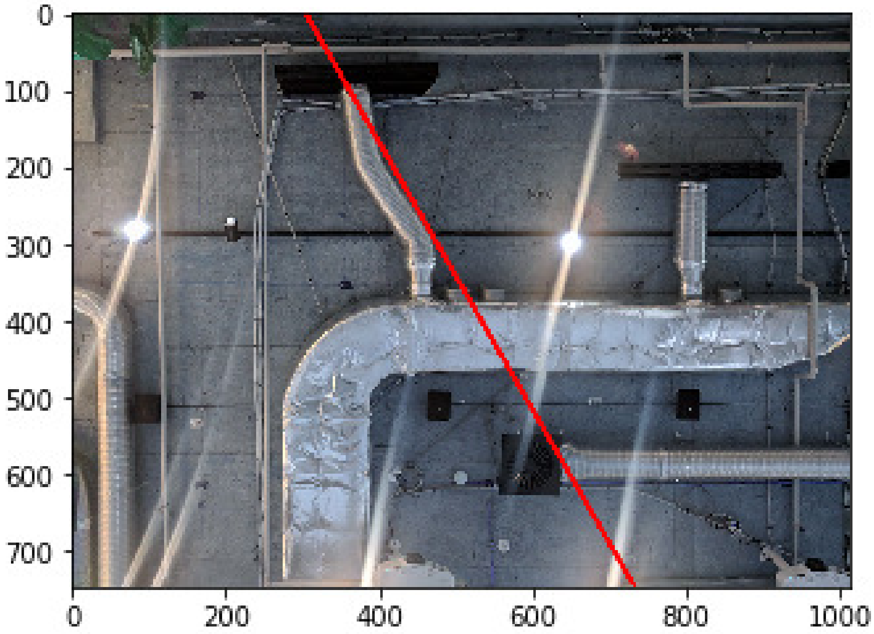

Figure 19. The red line representing a failed match of the super and search images using the RANSAC method.

To further test how successful this method was, another image was cropped from the super image and the process was repeated again using both onlyMatches and the RANSAC method.

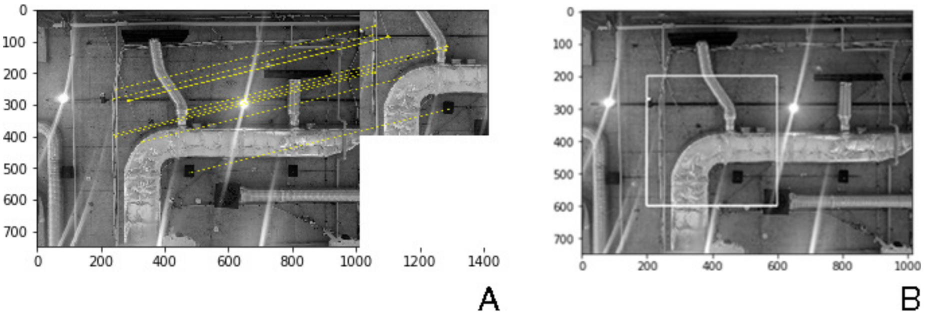

Figure 20. A. A successful match using onlyMatches. B. A successful match of the super and cropped images using the RANSAC method

As shown in Figure 20, both the onlyMatches and RANSAC methods are successful in identifying a cropped image. When the RANSAC method was used with the search image, a failed result was returned. Consequently, this process would be unsuccessful in the context required.

6.2.4 ORB (Oriented Fast and Rotated Brief)

The next step in the experimentation phase was through the use of feature detection and description processes. The first was through the use of ORB (Oriented Fast and Rotated Brief), which is described as “a fusion of FAST (Features from Accelerated Segment Test) key point detector and BRIEF (Binary Robust Independent Elementary Features) descriptors with many modifications to enhance the performance” (OpenCV Dev Team, 2014).

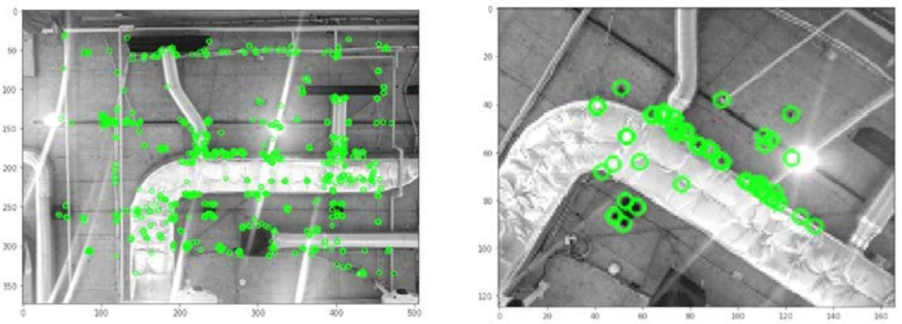

Figure 21. Identified key points using the ORB feature detection method in the super and search images.

The results in Figure 21 show there are various positions in each of the images which are identified. However, some of which do not match up in each of the images. There also appears to be features in the search images which to the human eye appear to be unique and would be thought to have been identified in this process.

6.2.5 Shi-Tomasi Method

Next, we look to identify different points within the images. To do this the Shi-Tomasi method was explored. The Shi-Tomasi method “is based on Harris Corner Detection (an operator that detects corners and edges in images) but has one slight difference, it has removed the corner selection criteria and only uses the eigenvalues to determine if the pixel is a corner or not” (Sinha, 2010).

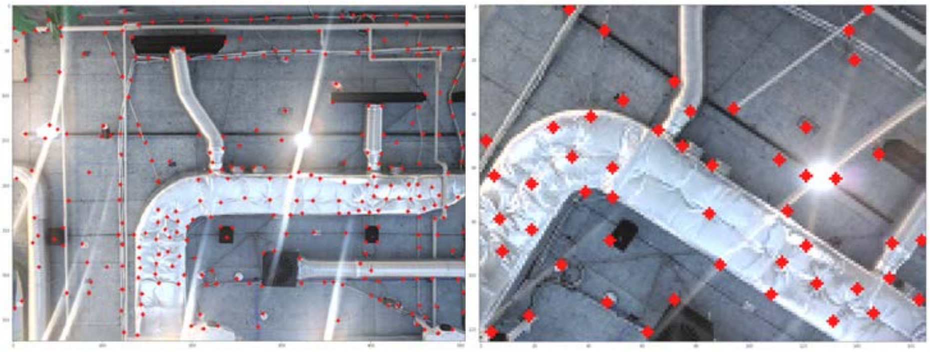

Figure 22. Identified corner points using the Shi-Tomasi Method in the super and search images.

In Figure 22, the results returned are very similar to that of the ORB feature detection. Although it is identifying points across both the super and search images, some of the points are not directly relating, and therefore not producing an accurate match.

6.2.6 SIFT and FLANN

In the next phase of experimenting, SIFT (Scale-Invariant Feature Transform) was explored. “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 (Bobade, Jagtap, 2014).

This feature 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”. It is a faster process than the Brute-Force Matcher, “which takes the descriptor of one feature in the first set and is matched with all the other features in the second set using some distance calculations, returning the closest distance” (Mordvintesv, Rahman K, 2013).

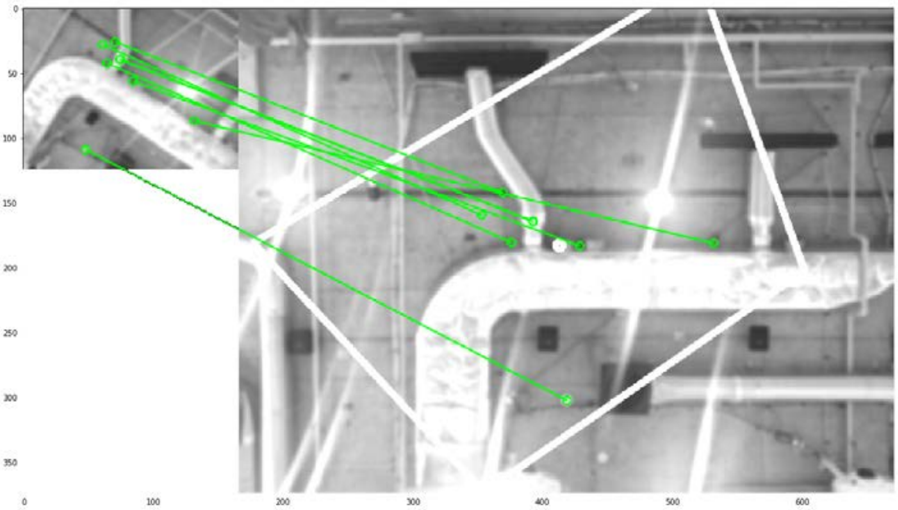

Figure 23. A successful match of the super image and the search image using a combination of SIFT and FLANN matchers.

The process creates a function to find the centre of the quadrilateral, get the SIFT features of the images, puts these features through the FLANN algorithm, before applying homography and a perspective transform to get the bounding box of the quadrilateral. The result as shown in Figure 23 shows the features identified in each image, and a bounding box and centre point which correctly identify matched features and the region in which the search image is located within the super image. It also returns a rotation angle of 31 degrees.

Through the experimentation, the process of searching using the SIFT and FLANN based matchers has returned a successful match of the super and search images. This results in two different images with a change in scale and rotation, something that is likely in the context of this application. This is especially significant in this research phase, as it allows the desks location and orientation to be determined using this method.

6.3 ORIENTATION TESTING

Having the code determine matches between the super and search images, the angles were then examined. Having recorded the angle that the photos were initially taken, this figure was then compared to the resulting matches. This process compared photos at different heights, different scales and different angles.

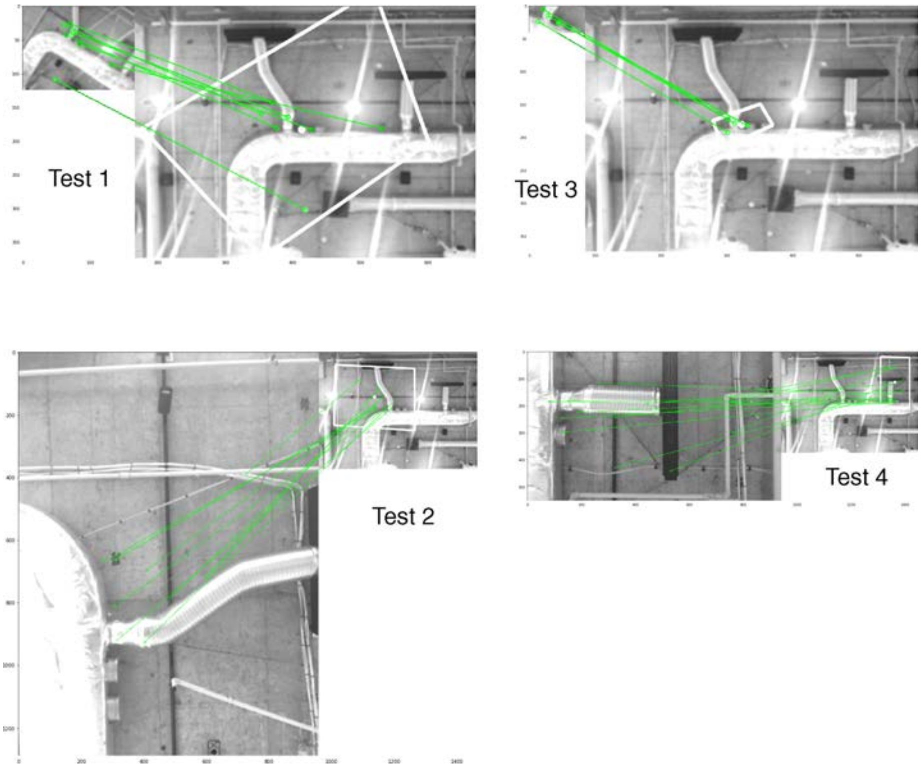

Figure 24. Four repeated results from the SIFT and FLANN Matcher

As shown in Figure 25, the resulting difference between the exact angle and the returned angle was similar, showing an average difference of 1.8 degrees across the four tested images.

Image	**Actual Angle**	**Returned Angle**	**Difference**
Test 01	31°	32.03°	1.03°
Test 02	90°	86.73°	3.27°
Test 03	24°	21.74°	2.26°
Test 04	90 °	89.30 °	0.7°

Figure 25. Table showing results of the orientation testing.

6.4 BEACON RESEARCH

The choice was made to explore Estimote and their indoor location beacons alongside the Estimote SDK, with the intent of creating a mobile application in the future. There were 3 beacons that could have been implemented into this research, which include proximity beacons, location beacons and UWB beacons.

The first was the proximity beacon. The proximity beacon works on the basis of the app on your phone detecting an area of interest. For example, the beacon could be set up on a desk with a signal radius of 5m.

When a person with the app on their phone enters within that 5m radius, the phone can detect that the person is in proximity of that desk. However, this beacon is not ideal for the current research, due to cost implications that each desk would need a beacon.

The UWB beacon uses a time-of-flight technique which measures the distance between multiple beacons and creates a floor plan of the space. These beacons would need to be set up on each desk as well as a few around the walls of the space. These beacons were the most expensive, another reason to find another beacon.

The location beacon is the hardest to set up, as each beacon needed to be placed on the walls of the space as well as having to map out the area. However, once the system is set up and a mobile phone with the app is positioned on the desk, the beacon is able to estimate where that phone is within the space. This beacon was the most suitable for this part of the research.

6.4.1 Beacon Number and Placement

These beacons need one per 10m^2, and have a range of up to 200m. With this information, and a workplace floorplan, we determined the area of space visible from each beacon (the isovist), ensuring that all the areas of the space could be seen.

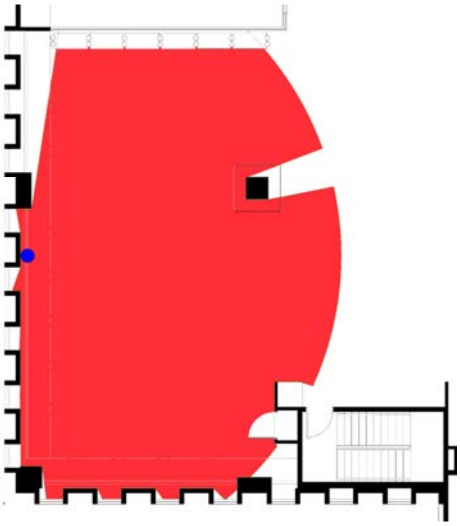

Figure 26. An example isovist from one beacon (blue circle) with a signal of 10m.

Figure 27 shows the location of the beacons, presuming a 10m and 15m signal radius. The different colours highlight the number of beacons that overlap that area of the space.

This exercise established that this defined area of the workplace could be covered confidently with 6 location beacons.

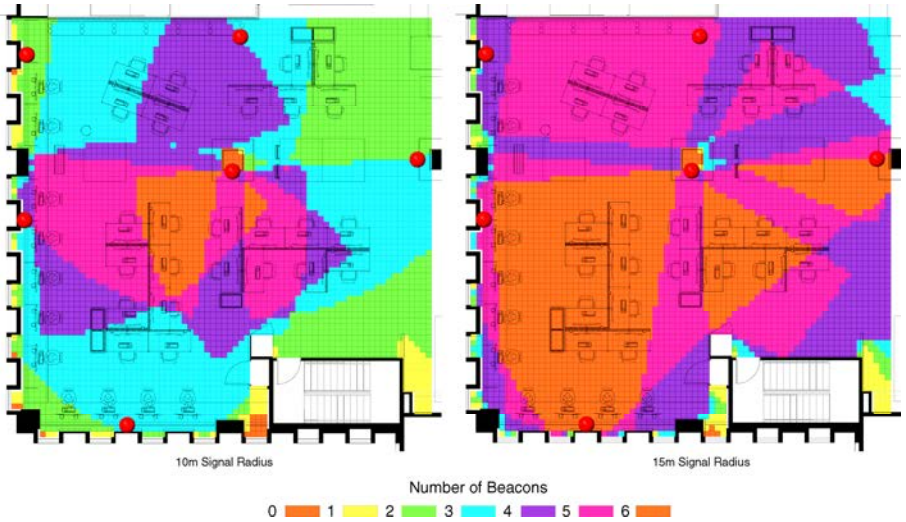

Figure 27. The left plan showing the beacon signal radius of $10m^2$, and the right image showing the beacon signal radius of $15m^2$, and how many beacons can cover each part of the space.

7. Significance of Research

To track something, especially in an indoor environment, generally employs one type of technology, whether it be Bluetooth, GPS or Wi-Fi. This research explores the benefits of using more than one type of technology to increase the accuracy of results.

Having an exposed ceiling soffit in the workplace meant that computer vision was a feasible option to find the location and orientation of desks. What became clear early on was that although the ceiling was unique, a lot of the same elements appeared across the ceiling. This meant that trying to find where an image was taken could return multiple results or locations across the workplace. Although successful in matching images, it was not giving the exact location immediately.

Beacons are a successful way to find where a desk is in a particular space at a coarse resolution. If a workplace were to be undertaking a method to track desks, the space would presumably be quite large. With the beacons tolerance of 1.5m, it means that although you have narrowed down where the desk is, it is still quite a large area of space which the desk could fall into.

By combining these two methods, the result meant that the beacons could narrow down the search field for the image, something that the computer vision process could not do successfully, and then the computer vision process could much more accurately locate that image within the narrowed space.

8. Evaluation and Conclusion

This research established a method of combining computer vision technology and beacon technology to successfully locate a desk and its orientation within a workplace. A set of beacons set up around a space can be used as a way to identify the location of a desk within a workplace independently, though sets a limitation on the accuracy, only being able to identify the desk to a 1.5m radius of the signal.

The integration of computer vision technologies into this process has created the ability to locate a desk successfully from where the image was taken through the use of SIFT based feature detection and Flann Based Matcher. The SIFT based feature detection process also allows for the recognition of the degree change in the photo, providing an average tolerance of 1.8 degrees for the desks orientation within a space.

The initial results of this experiment show that the research and application is productive, but can be built upon in future studies. The process of capturing the ceiling image is a challenging one, especially in workplaces that are constantly occupied. In this research the image capture enabled the identification of unique elements of the ceiling for the computer vision process.

A future approach could involve developing a higher density ceiling map, and capturing the ceiling could use the accelerometer in the phone to prevent distorted, non-parallel images being taken. The development of a phone application to create a smoother process of visualising was out of the scope of this project, but could be a part of future research.

In contrast to Anderson’s et al, (2018) work in finding algorithms to automate the design process, this research enables the users themselves to design their workplace while establishing a platform to meet a range of compliance requirements. The data output from the beacons and the computer vision is also only outputted on demand, as opposed to Rizal’s (2016) research where data was being tracked in real time, presenting significant issues with the constant high level of output data.

This paper demonstrates that combining these methods can leverage and enhance the advantages of each where computer vision gives higher resolution and beacons reduce the scope of the image search task. This paper contributes the knowledge and potential use for image recognition and computer vision systems in indoor environments. This research has set a basis for future work where more meticulous measurements are required, such as providing workplaces with a system that can determine if the desk layout at any given point complies with health and safety regulations and fire egress regulations. This in turn looks to promote safer, more functional workplaces at any given point in time, which drives the need for high accuracy results throughout this research.

Acknowledgements

I would like to thank Nicole Gardner, Alessandra Fabbri, Matthias Haeusler from UNSW and Ben Doherty, Annisa Rizal, Baptiste Higgs, Aiden Ray and Ishaan Varshney from BVN Sydney for their continuous guidance, support and dedication throughout this research project. I would also like to thank Brett Ketelaar for his ongoing support throughout my studies.

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