Determining Physical Positions of Interactive Tabletops using Landmarks

Andrew Hatch, James McNaughton, Liz Burd, Steve Higgins, Phyo Kyaw
Technology Enhanced Learning, Dept. Computer Science
Durham University
South Road, Durham, DH1 3LE
{andrew.hatch, j.a.mcnaughton, liz.burd, s.e.higgins, phyo.kyaw}@durham.ac.uk

Abstract

This work considers the viability of interactive tabletops as integral items of furniture in learning environments, as either an addition to, or replacement for, existing tables. Specifically, the problem of determining table location is addressed. A technique is presented that allows people to estimate the location of a table by performing a simple procedure on each table. An evaluation study is presented indicating that reasonable accuracy for tabletop location can be established using this technique that will allow for a number of spatially aware applications.

1. Introduction and Background

At present, interactive tabletops are thought to provide an effective digital medium in which people can collaborate on various collaborative tasks, including learning [?, ?]. Interactive tabletop research is generally focused on collaboration between multiple participants across a single tabletop. However, when a number of tabletops are available where each tabletop may have one or more people using it, an opportunity arises for sharing content such as learning materials between these tabletops.

Activities of content sharing in multi-display environments (MDEs) are becoming more common [?]. These mechanisms for passing content such as documents, images and on-screen objects from one tabletop to another can benefit from the establishment of a coordinate system, known to all tables, that maps to the physical environment. Such a coordinate system, known by all tabletops, can facilitate natural content movement, for example via sliding content to move or copy items from one table to another - as content is caused to move to the edge of one table, it would then appear on the table next to it.

For this to be achieved intuitively, each table should have information on where it is physically located in the room, and have information of the location of the other tabletops in the room for this to work.

It is possible to physically measure the location and orientation of a tabletop and record this data on each tabletop, and this strategy is suited for an environment in which the tabletops remain in a fixed position for long periods of time, and where accuracy of location is important.

Learning environments, notably school classrooms, are physical spaces in which furniture is frequently moved and reconfigured to accommodate different learning activities during the course of a day. Flexible furniture is known to be an important factor for successful class room environments [?], and so if interactive tabletops are to become part of the furniture of such learning environments, then it is essential that interactive tabletops can be moved, and have the location of the tabletop established quickly.

2. Technique

This paper establishes a mechanism by which a tabletop can know its orientation and location in a coordinate system that represents physical space. Each tabletop has a local coordinate system used for drawing objects on screen. For example, a pixel-based coordinate system might use the bottom-left corner as point (0,0) and top right corner as (1024,768). For to be shared between tabletops, conversion is required between this local coordinate system and the shared coordinate system for the room.

Here, a technique for establishing the shared room coordinate system is presented, illustrating the principles that this method uses, and demonstrating how a tabletop can determine its location and orientation in that shared room coordinate system.

2.1. Room pre-requisites

Establishing a tabletops position in a room requires that room to have two points of reference that will be used throughout the process for all tabletops. For rectangular rooms, a convenient pair of landmark reference points can be taken from the corners of the longest wall in the room at the same height as the surface of the tabletop. The distance between these landmark reference points should be known.

In practice, these landmarks can be established as the corners of the room, or more obvious landmarks specifically placed in the room for the purpose. This might be achieved by placing obvious marker-posters on the wall of the room. Figure 1 shows a plan view of a room with reference points taken to be the corners of the room along the longest side.

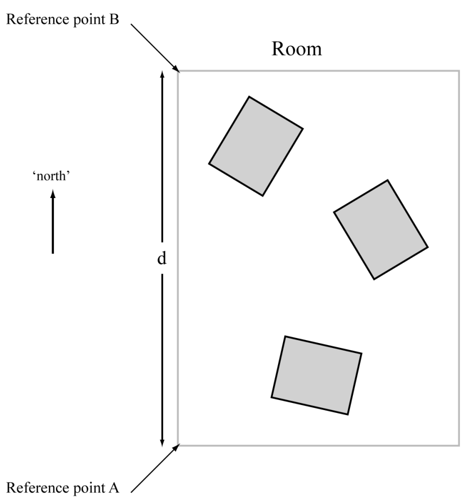

Figure 1. Room reference points

The established two-dimensional Euclidean geometry can serve as the shared coordinate system for the room and the tabletops in it. It is assumed that there is some mechanism by which each of the tabletops can communicate with each other, and that the length of vector AB is known to each tabletop. Typically, this would be achieved by sharing the data across the network.

Each tabletop can now be configured individually so that the tabletop has information of its own position and orientation within this shared coordinate system.

2.2. Tabletop configuration

A user should perform the configuration steps for each tabletop in the room. The steps are outlined first, and detail given later:

1. From the center point of the tabletop, draw a line parallel to, and in the same direction of, the vector AB, called the north direction.

2. From the center point of the tabletop, draw a line in the direction of and pointing to landmark reference point A.

3. From the center point of the tabletop, draw a line in the direction of and pointing to landmark reference point B.

Step (1) informs the tabletop of its orientation within the shared room coordinate system.

Step (2) gives an angle from the centre of the tabletop to point A. This angle, measured in the tabletops coordinate system can then be converted to an angle α in the shared room coordinate system. This is done by taking into account the angle of the vector AB determined in step (1).

Step (3), in a similar fashion to step (2), establishes the angle from the centre of the tabletop to point B. By using the same conversion process as step (2), the local angle can be converted to an angle β in the shared room coordinate system.

The accuracy by which users are able to achieve these steps will have a direct bearing on the accuracy to which each tabletops position and orientation can be established.

2.3. Location

Establishing the location of the centre of the tabletop (x,y) is a trivial step. The problem is trigonometric when simplified as shown in figure 2.

Each angle of the triangle in figure 2 can be determined through the rules of corresponding angles from parallel lines, and that vertical angles are identical. This gives:

$$\sigma = 2\pi - \beta \tag{1}$$

$$\phi = \beta - \alpha \tag{2}$$

$$\rho = \alpha - \pi \tag{3}$$

Using the sine rule, and given distance d, the lengths r and s can be determined as:

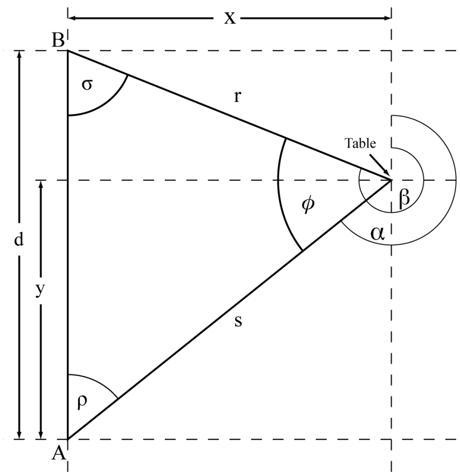

Figure 2. Trigonometric problem

$$\frac{d}{sin(\phi)} = \frac{s}{sin(\sigma)} = \frac{r}{sin(\rho)} \quad (4)$$

From this, distances x and y can be determined as follows:

$$x = r.sin(\sigma) \quad (5)$$

$$y = s.cos(\rho) \quad (6)$$

The values of x and y give the location of the centre of the tabletop in the rooms coordinate system. It is assumed that each tabletop knows its own dimensions, and can share this data with other tabletops along with its location and orientation information.

3. Study

A controlled laboratory study was conducted to determine how accurately people are able to estimate the two angles α and β, and therefore determine how accurately people can estimate the location of a tabletop.

Software for the study was constructed on top of a multitouch framework called SynergySpace. The software allows the users to follow the steps outlined in section 2.2 and logs the results for later processing.

Four interactive tabletops running the software were placed in the laboratory room at location and orientations shown in figure 1. This configuration was chosen to maximise the use of the four available tabletop devices in a non-symmetrical layout. The orientations were chosen to include (i) orientations in line with the room coordinate system (tabletops 1 and 3), (ii) reflection, between tabletop 1 and 3, and (iii) orientations not parallel to the room coordinate system (tabletops 2 and 4).

Sixteen participants took part in the study. These participants were selected by convenience sampling. The profile of this sample is as follows:

- 87% male (n=14)
- 94% right-handed (n=15)
- 100% use computers daily

Each participant was instructed to follow the tabletop configuration instructions given in section 2.2 above, using software that would record the estimated angles and corresponding location and orientation.

Video footage of the experiment was recorded to allow for further analysis. One researcher was present during the experiment to observe and answer questions from participants.

4. Observations

From the in-experiment observations, it was clear that there was variance in the degree to which participants understood and followed instructions. Post-experimental analysis of the video footage focused on obtaining data for the following variables for each setup of an individual table:

1. Comprehension of the north direction some participants did not understand that the direction of north was parallel to the wall in the direction from point A to point B. Some tried to point to geographical north. This variable was measured as either Good or Poor based on their apparent understanding as seen in the video footage.

2. Comprehension of pointing to the reference points rather than corners of the tabletop some participants misunderstood the concept of point A and point B being physical reference points; instead, drawing lines to the corners of the tabletop. This was measured as either Good or Poor based on their apparent understanding as seen in the video footage.

3. Stoop or stand some participants would remain standing through the setup of a table, whereas some participants would sight the line to the reference point by stooping down to obtain a better viewpoint. This was measured as Stand only or Stooped to indicate whether they, at some point, stooped down during line drawing.

4. Movement around the table some participants would freely move around the table to draw lines. Others would attempt to draw lines to reference points without movement, and draw lines over their shoulder. This was recorded as Yes or No based on whether they, at some point, changed their position relative to the tabletop during line-drawing.

5. Re-checked the line after drawing some participants would re-check the lines, once drawn. Some would not. This was recorded as Yes or No based on whether they re-checked lines once or more after they had initially drawn them.

These variables are used along with the results data obtained from the software.

5. Results

Results of the experiment are described below. Three aspects are presented: (i) an analysis of the results when all participants are considered, (ii) a consideration of the results when some participants are filtered from the data set, and (iii) an evaluation of the experimental data.

5.1. All participants

In all, 16 participants performed a total of 70 table setups. It was expected that each participant would perform 4 tabletop setups, resulting in 64 tabletop setups in total. The discrepancy is accounted for by the fact that some participants asked to retry one or more table setups during their session.

Let a setup instance i be a participant setting up an individual table. For each instance, the actual angles for α and β were compared with the estimated angles α' and β' provided by the participant to give errors as follows:

$$err_i(\alpha, \alpha') = |\alpha' - \alpha| \tag{7}$$

$$err_i(\beta, \beta') = |\beta' - \beta| \tag{8}$$

The mean errors for all instances of table setups can then be calculated for both angles:

$$mean\_error(\alpha) = \frac{1}{n} \sum_i err_i(\alpha, \alpha') \tag{9}$$

$$mean\_error(\beta) = \frac{1}{n} \sum_i err_i(\beta, \beta') \tag{10}$$

For all setup instances across all participants, the mean error size for α is 13.90°and the mean error size for β is 11.73°. Corresponding errors in the estimated location of the table from the actual location of the table were also calculated. The mean distance that tables were determined to be away from their actual location was 2.45m.

The importance of error distance should be kept within the context of the size of the tabletop. For a tabletop with a diagonal size of 0.5m, for example, errors of 2.45m could be too great. A tabletop of diagonal size 1.5m might perhaps be more acceptable.

Data was then filtered as a result of the observations in section 4 to determine whether better results are achieved by those participants who best understood and followed instructions.

5.2. Filtered Data

Mean errors for both angles and distances were recalculated on only those setup instances where participants had Good understanding of the north direction, Good comprehension of the instruction of pointing lines to the reference points, who stooped down to draw lines, who moved around the table, and who re-checked lines.

Applying this filter yields 18 table setup instances. For these, the mean angle deviations were 8.17°for α and 6.39°for β. The corresponding mean distance error in tabletop location from actual location is 1.00m.

5.3. Experimental Evaluation

Findings in the data from the tabletops, and the observations of the filmed experiments suggest that the instructions given to the participants in the experiment could have been improved.

6. Room Accuracy Profile

Accurate location information is only possible if users are able to accurately estimate the angles α and β. The location of the tabletop in relation to A and B will affect how accurately the location of a tabletop can be determined. Assuming that a typical user will always estimate angles with an error size of 8.17°for α and 6.39°for β, it is possible to see the impact this will have on the size of location error for tables at different positions in the room.

A heat map diagram can be drawn to show the magnitude of the error distance of the estimated tabletop location from actual location. A profile of a room can be constructed by assuming constant angle error deviations for a sample of locations in the room, and calculating the error distance at that point.

Figure 3 is a heat map diagram that shows location accuracy profile for the constant angle deviations identified above (8.17°for α and 6.39°for β). For figure 3, the map has been produced for a room that is 6m by 6m. A tolerance is represented such that when the error is greater than a threshold (2m in this case), the colour red is used.

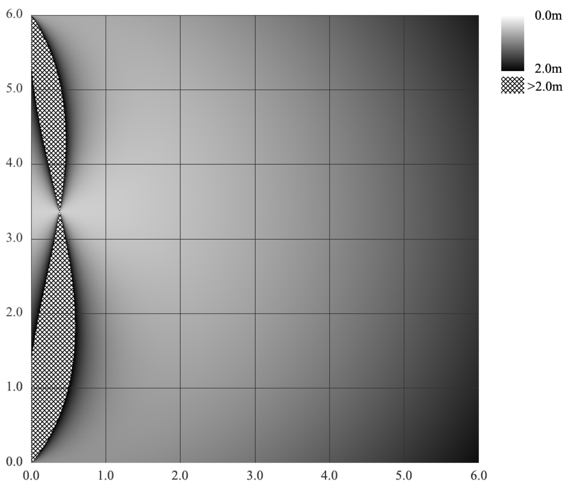

Figure 3. Heat map

In a 6m by 6m room the region of the room most likely to produce more accurate location estimation is towards the left-of-center area. The cross-hatched region on the left hand side of figure 3 indicates regions in the room that would be likely to produce inaccurate location estimation.

Such heat-map diagrams can be useful for determining how accurately users might be able to determine the location of a tabletop at various positions in a room.

7. Conclusions

Using angle estimation on the surface of a tabletop to room landmarks, it is possible to determine the location of a tabletop to reasonable accuracy. This study has shown that for users who are appropriately trained, and follow the procedure properly, they are able to achieve location accuracy within 1m of a tables location, for a room that is approximately 6m in length.

For this method to be used, users should undergo training to ensure that they fully understand the principles of what room landmarks are, and how best to draw lines towards those landmarks.

Predictions can be made on which areas of a room will produce more accurate results by drawing a heat map diagram using typical user errors.

8. Further Work

Further study is required to determine how the size of a tabletop might affect the accuracy to which its location can be determined. A larger tabletop, for example, may allow for longer lines to be drawn.

The ways in which lines can be constructed, moved and changed may also affect how accurately users can judge angles to landmarks.

Whilst this study indicates that the location of a tabletop determines the accuracy to which its location can be estimated, this relationship is not fully understood. For example, the distance the tabletop is away from landmarks will most likely affect the accuracy of angle estimation.

References

[1] I. M. Author. Some related article I wrote. *Some Fine Journal*, 99(7):1–100, January 1999.

[2] A. N. Expert. *A Book He Wrote*. His Publisher, Erewhon, NC, 1999.