SLFiducials: 6DoF markers for tabletop interaction

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Abstract
In this paper we introduce a new method for 6DoF marker tracking, specially designed for Microsoft SecondLight or any camera-based tabletop interface that is able to see objects through the surface. Our method is based on topological region adjacency for the identification of the markers, which are fitted into a squared shape for properly track the marker pose in the real world. We also describe the constraints imposed by the system which will determine the size and ID range of the new markers, and we finally evaluate the system.

Author Keywords
Markers; tabletop; hover interaction; video tracking.

ACM Classification Keywords
I.5.0 Pattern recognition general

Introduction
Although some tangible and tabletop interfaces use data input methods such as accelerometers, multi-touch capacitive surfaces, or 3D motion sensing devices, optical based tracking methods are still the most frequently used on tangible multi-touch devices, especially on “do it yourself” (DIY) tables [4], [7].

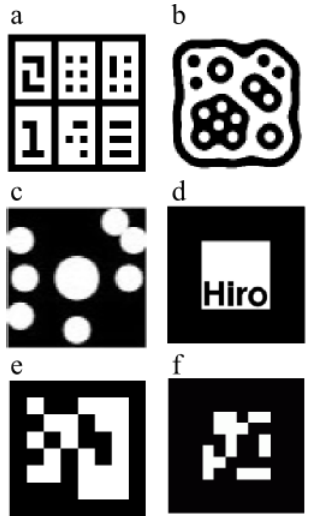

Figure 1. a:dtouch; b:reacTIVision; c: pixelsense tag; d:ARToolkit; e:ARToolkit plus; f:ARTag.

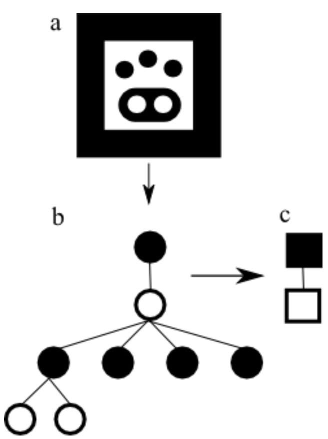

Figure 2. SLFiducial detection: (a,b) find a topological structure that matches any of the stored into our subset database. (c) Find if the root tree node and it immediate node could be approximated to a square shape.

Tabletop's markers or fiducials are designed to encode an ID, and report their X and Y coordinates plus a rotation angle, being that data tracked only when the fiducial is on the surface. Fiducial are also widely used in Augmented Reality (AR) systems, where they are often applied to determine the 3D coordinates and orientation of a vector into the physical space, by using a 2D camera.

In this project we are using SecondLight, a novel tabletop tangible interface developed by Microsoft Research [5], which simultaneously combines DI[7] and FTIR[4]. Although SecondLight could employ several of the computer vision software systems already available for tabletop development none of them would allow taking full advantage from the very special affordances brought by SecondLight.

Fiducial Overview

Tabletop markers are used to encode an identification number and an orientation vector to extract its position and angle. Some of the most widely used include Dtouch [1], reacTIVision [6] and the ones used at based on topological adjacency region, encoding a binary sequence into its structure. On the other hand, pixelsense markers encode a binary number by a sorted circular path of dots, with a bigger one in the middle to point the centre.

The most widespread 6Dof fiducials are the ones used by ARToolKit[1], ARToolKit Plus[3] and ARTags [2]. These systems are all based on square shaped fiducials with a pattern in the middle (figure 1). The identification systems for the aforementioned tags are either based on Matrix-Patterns (figure 1, e and f) or on Pattern-Matching techniques (figure 1, d), both of which can proportionate wide subsets of fiducial ids.

Hardware setup

We use Secondlight (SL) to track markers, with a camera situated at the bottom of the table. Thanks to the SL switchable surface, at clear states of the surface, the system is able to see through; bringing us the possibility to track objects beyond the surface. Having two exposures per frame (on the surface and above it), and different lighting methods it is a challenge for finding the right 6DoF markers that could resist a high amount of camera noise while keeping a good balance between size and ID range.

SLFiducials

The method we propose for the new SL markers design, combines topological adjacency region for ID identification, and a squared shape for pose estimation (figure 2, a). These markers have a close relation with the reacTIVision ones and they use the same mechanism to get the fiducial orientation and identification.

Fiducial detection

To avoid false positives and make the system fast and robust, our fiducial finder algorithm proceeds as shown at figure 2 to detect a proper marker. Once the system knows it is a valid candidate, it estimates the fiducial pose by getting the orientation. Notice that once we have processed the adjacency tree [Figure 2, b] we have all the necessary data for the pose estimation step: The black end nodes of the tree point to the upper side of the fiducial square contour, and the contour edges four points, were extracted while

[1] http://www.hitl.washington.edu/artoolkit/

Method	time
SLVision with adaptive threshold	19
SLVision with simple threshold	4.8
ARToolkit (simplelite.exe)	17.54

Table 1. Amount of time in ms to process a frame by using different approaches and programs.

SLFiducial			ARToolkit	
Px. Size	F. Size	Results	Px. Size	Results
0.3	2	38%	2	0%
0.5	3.5	74%	3.6	15%
0.8	**5**	**98%**	5	78%
1.5	11	100%	11	100%

Table 2. Fiducial size and result comparison with different pixel sizes (Size in centimetres) from 1.7 meters distance.

applying the first square-shape approximation node check.

Robustness, id variations and size

As in reacTIVision, the robustness of our method relies on the rarity of the design of its markers. To improve this robustness we can perform two different checks. The first one is to compare the resulting encoded sequence of the adjacency tree with a database, enabling only the codes that we were to use (e.g. 0122111 in Figure 2, b). The second one is the quadrilateral approximation of its shape, thus discarding candidates which shape is not a square. This allows us to also use fiducials with a very simple topological tree (e.g. one only node).

The topological structure shown in [Figure 2, a] is defined by 5 leaf nodes with a 3-level depth tree. It also requires that the first node (the one at level 0) could be approximated with a quadrilateral. Given the markers size constraints, 5 is a reasonable number of nodes for SL. Using 5 nodes we could theoretically obtain 32 different markers (2^5), but since the order is not relevant and our method requires at least one black dot, we cannot obtain more than 5 variations. To increase the ID range of our fiducials without making bigger markers, we can simultaneously use fiducials with 5, 4, 3, 2 and 1 node. That would make a subset of 15 reduced markers, a number which can be doubled by inverting them (i.e. including their negative images).

Fiducial comparison and evaluation

In the following section, we discuss the results obtained by comparing the performance of our system with other 6Dof fiducial based tracking systems. These tests have been done with a SL surface working as usual, with the switchable display flickering at 60Hz. The computer was a DELL workstation with an Intel Xeon 2.53Mhz processor and 4GB of RAM running Windows7, and fitted with a 640x480 black and white FireWire camera with an infrared filter pointing to the surface and beyond.

Performance

To test [Table 1] our fiducials, we have developed SLVision. This vision system uses an adaptive threshold for tracking the fiducials at any distance, without worrying about the variations of incident infrared light. As justified before, we ran the SLVision test with a 15 item markers' dictionary. The Simplelite program we used for evaluating ARToolkit comes included with the ARToolkit libraries. It uses a simple threshold and it is set up for detecting only one marker (the marker "Hiro" [Figure 1, d]).

Size and range

As we have already stated in a previous section, the markers' size is an important design issue, and we should thus find a balance between size and fiducial effectiveness. On SL, this parameter will be determined by the minimum pixel size to be tracked from the largest possible distance (170 cm, given by the height reached by a user's arm).We ran some size tests for determining the proper size of our SL fiducials and compared these findings with different markers sizes. The experiment setup was composed by a tripod with and extensible mechanical arm handling the markers from a 1.5 meters distance from the floor. Once the marker was attached to the mechanical arm, we moved it around the camera field and counted the success rate throughout 1000 frames [Table 2].

ARToolkit	ARTooltik plus	SLFiducials
1 to ?	4096	30

Table 3. Range comparison. The bold ones are based on topological region adjacency.

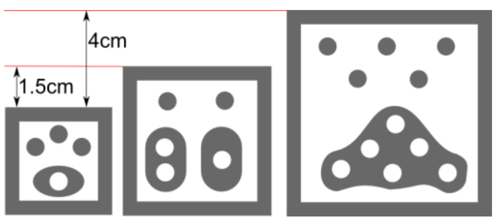

Figure 3. From left to right: 5 cm fiducial with 18 variations; 6.5 cm fiducial with 42 variations and 9 cm fiducial with 200 variations

From our tests we have detected that the minimum pixel size that our camera can track from a 170 cm distance is a square of about 0.3 cm side, so we decided to print all markers using nodes of 0.3, 0.5, 0.8 and 1.5 cm diameter width. It should be mentioned that because ARToolkit markers are based on image pattern detection, we cannot properly define the size of their pixels. In order to compare these markers with SL ones, we printed both marker systems at the same sizes.As shown in [Table 2] the optimal balance between sizes and success resulting from our experiments is attained when using 0.8 cm nodes. This setup produces 5 cm side markers which is an acceptable size for our system.

ID range is the maximum number of fiducial Id's that can be reached with a given fiducial design. [Table 3] shows a comparison between ID ranges of different fiducials. ARToolkit is the only one with an undefined range due to the difficulty to test it with all possible variations.Our system is the one with less ID variation, although this number could be increased by using larger markers.

Increasing the ID range on SLFiducials

As mentioned before, we can build bigger SLFiducials to obtain a bigger range variation, but marker real size is used to properly estimate the 3D pose of the fiducial and the system should know the size differences. By adding a new field on the SLVision topological structure matching table, the system, can access to the marker real size and make possible the coexistence of different marker sizes.On figure 3 we illustrate different marker sizes (the first one is the used on the evaluation) and its ID range variations.

Conclusions

We have developed a new topological region adjacency marker for the Microsoft SecondLight. Although these markers could be used for any augmented reality installation, they have been specially designed in terms of size and reliability, to take full advantage from the very special affordances brought by SecondLight, Adding 6DoF to tabletop markers substantially increases the interaction experience of this kind of interfaces pushing the tabletop tangible communication a step further.

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