Tracking 3D Puzzle Pieces for Collaborative Learning Environments

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Children naturally learn about their world by manipulating objects within it. Playing with blocks and puzzles helps to develop their understanding of spatial relationships and other mathematical concepts. Using physical objects also allows them to work and learn in groups. Yet sometimes they need outside intervention from an adult or knowledgeable guide to help them learn more and stay engaged longer. Unfortunately, instructors often have too many students to give each one adequate attention. Our work focuses on developing computer-based "guides on the side" that can "watch" as children play with physical puzzles, and offer help or suggestions as needed. Our approach is to use the physical puzzle pieces as parts of a tangible interface. With our system, children are free to explore and collaborate without a computer, yet they can benefit from the computer's instruction as they need it. We have successfully implemented and tested a 2D Tangram puzzle using this approach [Scarlatos 2002].

In this sketch we present our most recent work, which extends these ideas to the third dimension and applies them to a Soma Cube puzzle. This work is unique in that we are tracking multiple wireless 3D objects, in a small space, simultaneously. Here, we present two approaches to this problem. We have also developed a novel representation for the state of the 3D puzzle, which we describe, This representation enables our system to select appropriate hints, give encouragement as progress is made, and offer congratulations when the solution is found.

1. Seeing Puzzle Positions

Our first approach is to use computer vision to track the position and orientation of the puzzle pieces. Pairs of digital cameras capture stereo views in color. To help distinguish the pieces from one another, we painted them with distinct fluorescent colors (fig. 1). We selected these colors based on their distribution in YUV space. We then used reflective tape to mark the edges of the pieces. With the light source mounted near the cameras, these edges stand out in stark contrast to the rest of the environment.

We work with the images in two parts. First, we use the luminance (Y) values of the images to find the corners of the puzzle pieces. We achieve this with a Sobel gradient filter and Harris corner detection. Second, we use the chrominance (UV) values to determine which puzzle pieces the corners correspond to. We then correlate these corners in the stereo images to derive 3D coordinates. Finally, we translate, rotate, and scale the coordinates to achieve the best match with our internal representation of the puzzle piece, which yields its orientation [Trucco and Verri 1998].

2. Sensing Puzzle Positions

Our second approach is to use sensors within the puzzle pieces to detect their condition. We extended Anderson et al.'s approach for computational building blocks [2000] by using wireless communications to transmit information about the state of each puzzle piece. Each piece of the Soma cube contains a Basic Stamp, current sensors, and a radio frequency (RF) transceiver. A current sensor detects when a circuit is completed by two puzzle pieces touching (fig. 3). By placing distinct resistors at each possible circuit, we can tell which sides of which pieces are adjacent to each other. With additional resistors, we can detect relative orientation as well. This adjacency information is transmitted to the computer via the RF transceiver. The setup of the leads on the outside of the pieces ensures that every adjacency will be sensed by the two pieces.

3. Representing Puzzle State

In order to respond appropriately to what the children are doing, we need a rotation- and translation-invariant representation of the state of the puzzle. We have two ways of representing this state. First, we represent each pair of touching puzzle pieces with a substring indicating: a) the labels of the pieces and their touching faces, b) a relative orientation angle, and c) their topological relationship (e.g. meets, intersects, contains). These resulting substrings are then sorted and concatenated to produce a unique string representing the precise state of the puzzle. Second, for puzzles that have multiple solutions, we represent clusters of touching pieces with a voxel model whose coordinate frame corresponds to the local coordinates of the piece with the lowest-valued index.

4. Acknowledgements

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5. References

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Figure 1. Single snapshot of Soma Cube puzzle pieces.

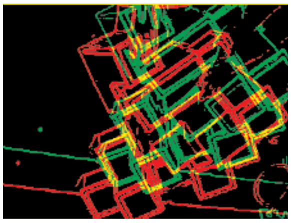

Figure 2. Edges detected in a stereo pair.

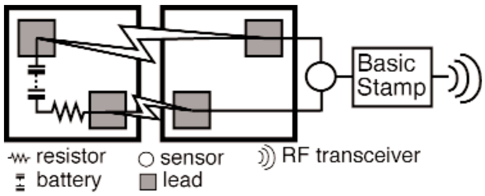

Figure 3. Touching surfaces complete the circuit.