Learning Environment based on an Interactive Projection Table for Children

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***Abstract*—This paper proposes a tabletop learning environment for children. Some physics-based phenomena such as reflection and refraction of light are difficult for children to understand. Our interactive projection significantly help children understand behaviors of light through watching simulated light particles and interacting with them by moving real objects on the table. Our system consists a PC, video projector, and depth sensor. Depth-based object detection is performed with each of captured frames at 60 FPS. In the prototype of our implemented system for learning behaviors of light, simulated light particles reacts in realtime with actual objects moved by a user hand, which would greatly help people including children understand behaviors of light such as propagation and reflection. Our future work includes to conduct a series of user experiments in local museums to evaluate usability of the proposed system. Development of other learning applications are also of high importance.**

***Index Terms*—tabletop interface, behavior of light, learning for children**

I. Introduction

A wide range of digital devices allow us to enhance various learning experience in school, home and special-purpose facilities such as museums and galleries. It is known that people's attention increases when they are supplied with multimodal and multimedia information while learning. We propose an interactive projection table for children to learn some kind of phenomena that we encounter at very special circumstances. Our applications include behaviors of light, and objects behaviors in gravity field. Though these phenomena are well-described with physics equations, they are remarkably difficult to understand for children. An interactive experience with real objects with simulated behaviors are far easy to well-understand these rules in physics.

Our applications are not limited to physics but could be extend to other fields such as

- learning Foreign language words by selecting alphabetical objects,
- nature observation by moving a mock magnifying glass, and
- computational thinking such as sorting algorithms by automatically counting the number of object exchange while sorting.

In this paper, we mainly set our focus on learning application for behaviors of light.

Fig. 1. ”A table where little people live” by teamLab [3]

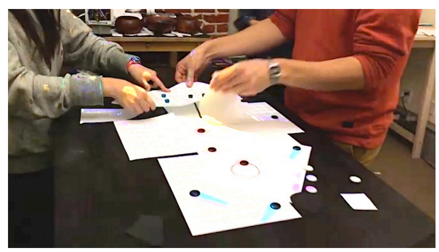

Fig. 2. Multi-user interactive table called “La TABLA” equipped with a projector and camera [4].

II. Related work

Learning environments with interactive objects have been widely studied for decades. Support system for urban planning [1] and landscape analysis [2] based on Tangible User Interface (TUI) are some of leading work in this field. teamLab Inc., a Japanese digital media company, offers and exhibits hundreds of digital interactive systems and exhibits around the world. Their system is usually set in a dark place and typically consists of a set of video projectors, touch sensors, RGB cameras and depth sensors. ”A table where little people live” is one of such installations. Projected little people on the table top of this product react with real objects placed by children interested in interacting with this world [3].

Multi-user interactive environment named ”La TABLA” is proposed [4], [5]. Due to use of an inexpensive projector and webcam, their system works fine with a white objects or sheets of papers, placed on a black table.

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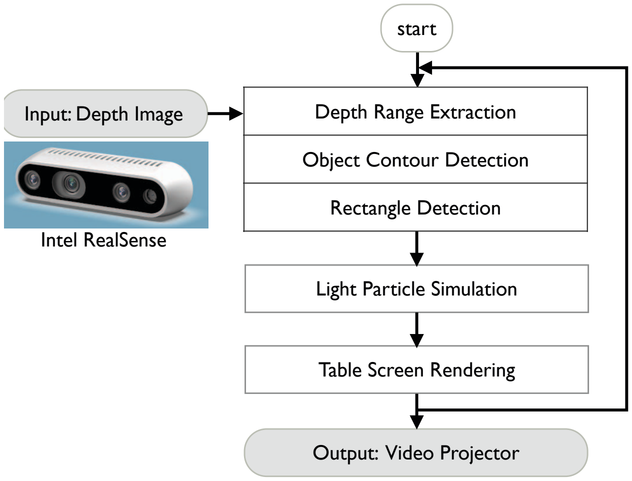

Fig. 3. The processing flow of the proposed interactive projection table with a depth sensor and projector.

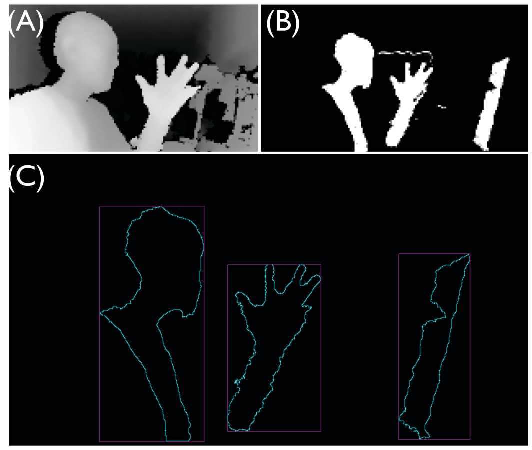

Fig. 4. Object detection example with a depth sensor. (A) a depth image, (B) regions with a specific depth range, and (C) their contours.

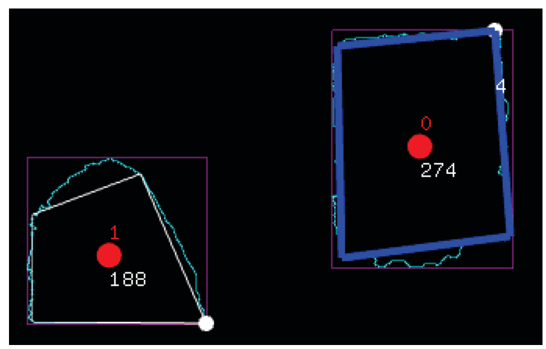

Fig. 5. Rectangle object detection

III. Basic Design of the Proposed System

A. Overview

Our system employs a depth sensor RealSense (D415 or D435) from Intel Inc. and a video projector. The use of depth sensor, not a RGB camera, significantly increases the usability and object recognition stability of our projection table because the input is hardly affected by the projected colored images on objects and the table surface. If input images were to be captured with a RGB camera, they would require a complex process to subtract projected color patterns on the objects and table.

The processing flow for an application (behaviors of light described later) is shown in Fig. 3. The depth sensor captures a depth frame of objects on the table. Color images are captured for a logging purpose in experiments but not used for object recognition in our system. The connected components in the captured depth frame are then detected to find objects in the scene followed by rectangle detection. This process finds rectangular objects moved and placed by children. Behaviors of light is simulated as a set of propagating or reflecting photons (light particles), moving at a much slower velocity than that of actual light. The photons are rendered at their locations to finish the output image to be projected on the table.

We implement the proposed method with openFrameworks [6], an open source library widely used for multimedia software development or so-called creative coding. Unlike a similar framework Processing [7] which is also popular and implemented with Java language, openFrameworks is written in C++ language, which offers much higher performance suitable for various realtime interactive systems. Due to a powerful RealSense sensor connected via USB 3.1, our system runs at a sufficiently high frame rate of 60 frames per second (FPS).

B. Object detection with a depth sensor

Table I lists widely used depth sensors with the first best-selling depth sensor for consumers, Kinect from Microsoft Inc. Though these are called sensors, they are really powerful calculating devices that compute and estimate depth images based on the sensed values. Currently popular sensors RealSense D435 and D415 from Intel Inc., have much higher resolution and wider depth field of view [8]. We are currently using D415 that shows better recognition results in our experimental settings.

Fig. 4 shows an example of object contour detection. The depth sensor captures a depth frame that consists of 640×360 of unsigned 16 bit values ((A) in the figure. Our system does not require the full resolution with 1280×720 available with that sensor, but requires lower computational costs. Reducing the resolution of captured depth frame is a effective way to achieve that with roughly the same level of recognition performance. Depth images contain absolute values in millimeters and we extract a narrow range of values that correspond to objects atop the surface of our table. In Fig. 4 (B), depth values between 50 and 60 (cm) from the

TABLE I
DEPTH SENSOR COMPARISONS

	RealSense D435	RealSense D415	Microsoft Kinect V1
Depth resolution	1280 × 720	1280 × 720	320 × 240
Depth field of view (deg.)	87 × 58	65 × 40	57 × 43
Ideal range of depth (m)	0.3–3.0	0.5–3.0	0.8–4.0
Depth value	16 bit integers	16 bit integers	8 bit integers
Connection	USB 3.1	USB 3.1	USB 2.0

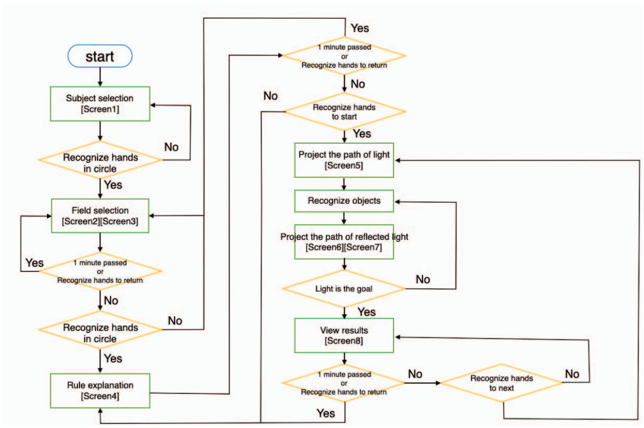

Fig. 6. State transition diagram of the proposed system for learning behaviors of light

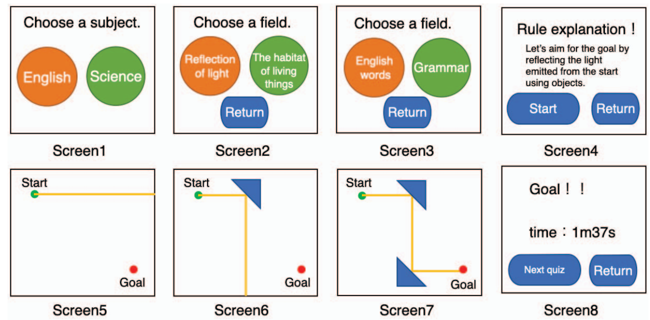

Fig. 7. Screen transition examples of the proposed system for learning behaviors of light

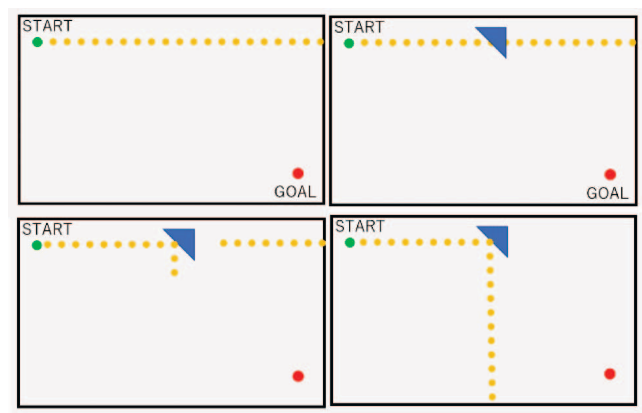

Fig. 8. Concept illustration of learning reflection of light

sensor are extracted and colored in white. The contours are detected by performing connected component labeling and contour tracing technique. We perform rectangle detection on these counters found so far. This can be done by simplifying contours and checking whether the simplified contour satisfies the following conditions or not.

1) it has four vertices,
2) it is convex,
3) it is not too small,
4) and none of 4 angles is steep ($\cos\theta < 0.1$ for each angle).

In the case shown in Fig. 5, only the right-side contour is recognized as a rectangle. The two red circles represent the center of mass of each objects, red numbers are the region IDs, and white values show the number of line segments that form the contour before the simplification process.

IV. Application Design

Our prototype application is for learning behaviors of light and illustrated with its state transition diagram in Fig. 6. Screens design corresponding those states are shown in Fig. 7.

Designs of projected patterns are illustrated in Fig. 8 and Fig. 13. In both of these modes, the user is asked to make the light reach the goal point by changing the locations and directions of objects placed on the table. Such objects used for interactions are drawn in blue triangles in these figures. In Fig. 8, the ray of light gets reflected by the blue triangle. This gamification increases the interact of children in learning behaviors of light.

A series of screenshots from our working prototype is shown in Fig. 9. These are not photographs of projected patterns onto a table but captured screen frames from our system because tabletop projection is still under development. Each of images (a)–(e), four sub-images atop of the main screen consists of, from left to right, a color image, infrared (IR) image, 8-bit depth image with brightness normalization, and 16-bit depth image with a specified range of values highlighted. The last one is used to recognize objects in our algorithm.

In our system for learning behaviors of light, a ray of red light, which is represented with hundreds of small red circles, keeps coming in from the left. Users interact with

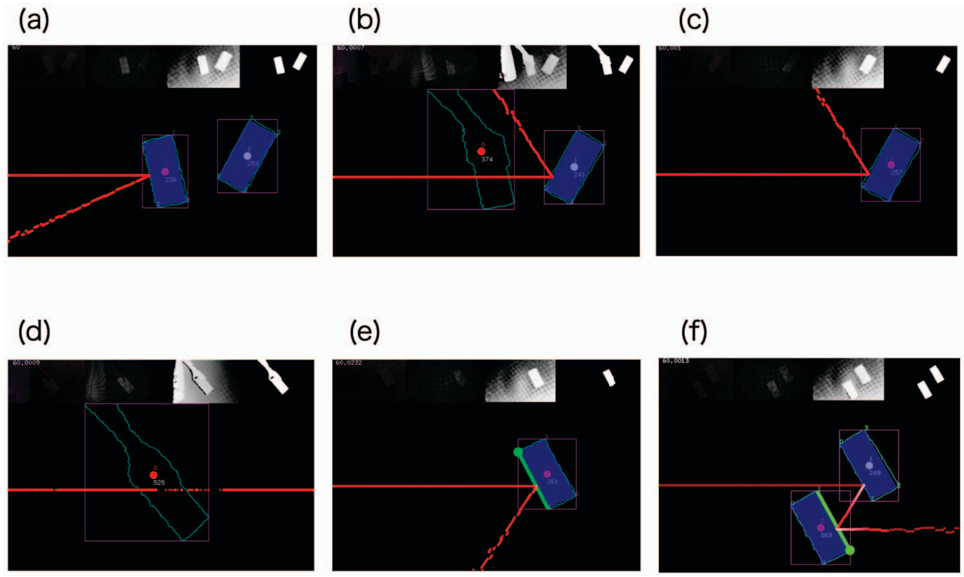

Fig. 9. Screenshots from our prototype of learning system for behaviors of light. (a) the rectangular object on the left reflects the ray of red light incoming from the left, (b) the user removes the left object on the table, (c) the remaining rectangular object on the right starts reflecting the light, (d) the user changes the direction of the remaining object, (e) the reflection direction changes according to the object, and (f) the first object is placed again to reflect the incoming ray from the left. In each of images (a)–(f), what located at the top are, from left to right, color image, Infrared (IR) image, depth image, and depth with a limited range of values for object detection.

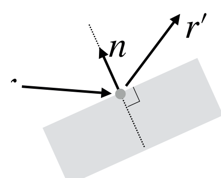

Fig. 10. The law of specular reflection and our definition of vectors

this ray of light by placing or moving white rectangular objects (Styrofoam bricks). Such a object placed to block the propagation of the ray causes a change in its direction (reflection) following the law of reflection.

Physically speaking, the law of specular reflection in a uniform medium (Fig. 8) is as follows

$$\boldsymbol{r'} = \boldsymbol{r} + 2(\boldsymbol{n} \cdot \boldsymbol{r})\boldsymbol{n}$$

with the direction of the ray $\boldsymbol{r}$ incoming to a point on the surface, the direction of the reflected ray $\boldsymbol{r'}$ outgoing from that point, and the surface normal unit vector $\boldsymbol{n}$ outward the surface, and the inner product $\cdot$. This phenomena is much easily understood if it's illustrated in a diagram, and becomes even more easier with interactive simulation of real objects.

In our current implementation, two types of display setting are being examined as shown in Fig. 11. In our first type, contents are displayed on the surface of a large LCD, and they are projected on the surface with a short-focus projector in our second type.

Fig. 11. Two types of display settings in our prototype (left: on the surface of a large LCD, and right: with a short-focus projector)

Fig. 12 illustrates one of problems with our current implementation. Though the object (the white rectangle on the right) is placed on the surface of the table and keeps still, its detected contour shows small continuous vibration that leads to a variance in the reflection angle at the surface of this object. We require some technique to stabilize the reflection angle with a placed still object.

Fig. 13 shows a conceptual illustration of a more complex case with a simulated prism. The ray of light shows spectroscopic propagation with the prism (white triangle in the figure), which divides the white ray into three rays in red, green and blue. These are three components of light color. The use of a prism increases the complexity of reflection patterns, which makes this application more suitable for adult users. Users including children experience behaviors of lights in a much easier way to interact with than with lights in the real world.

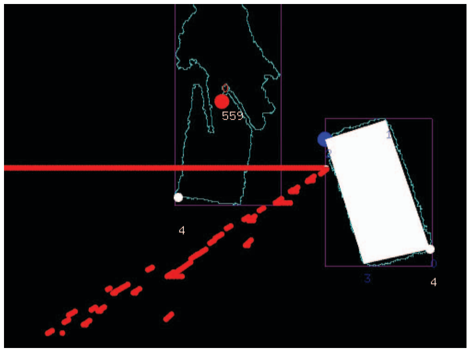

Fig. 12. Instability of simulation of reflected ray of light

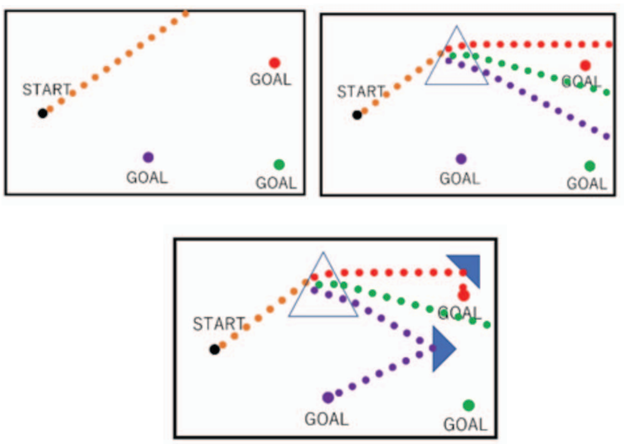

Fig. 13. Concept illustration of learning spectroscopy of light with a prism

V. Summary

We proposed an interactive projection table for children to learn various kinds of subjects and contents. One of such applications is about behaviors of light, which could be understood without complex physics equations. We are currently completing the development of our prototype by implementing a matching mechanism between locations of real objects on the table and those of projected patterns. Our future work includes the completion of the prototype development followed by user experiments to assess the usability and effectiveness of the proposed system. Local museums express their interest in our prototype and its user studies.

References

[1] H. Ishii, J. Underkoffler, D. Chak, E. Ben-Joseph, L. Yeung, "Augmented Urban Planning Workbench: Overlaying Drawings, Physical Models and Digital Simulation," Proc. IEEE & ACM ISMAR 2002.

[2] B. Piper, C. Ratti, and H. Ishii, "Illuminating clay: a 3-D tangible interface for landscape analysis." Proc. SIGCHI Conference on Human Factors in Computing Systems (CHI '02), ACM, pp. 355–362, DOI:https://doi.org/10.1145/503376.503439

[3] teamLab Inc., "A Table where Little People Live," https://www.teamlab.art/w/kobitotable/

[4] C. Gingold and L. Iannini, "La TABLA," http://tablaviva.org

[5] C. Gingold, La Tabla implementation and documents, https://github.com/chaimgingold/Tabla/

[6] openFrameworks, https://openframeworks.cc/

[7] Processing, https://processing.org/

[8] REALSENSE, Intel Inc., https://www.intelrealsense.com