Identifying Inexpensive Off-the-Shelf Laser Pointers for Multi-User Interaction on Large Scale Displays

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***Abstract*—We present a method for identifying inexpensive, off-the-shelf laser pointers in a multi-user interaction environment on large-scale displays. We identify a laser pointer's personality, a measure of its output in a particular context. Our method requires a set of inexpensive and unmodified green lasers, a large screen, a projector, and a camera with an infrared (IR) filter. The camera detects the IR spillover from the green laser beam, while ignoring color information projected onto the screen. During a calibration phase, a radial histogram of each laser's IR spillover are used to represent the laser's personality. Our system is able to identify the spots of a specific laser, allowing multiple users to simultaneously interact in the environment. In addition, we present a series of applications that take advantage of tracked and identified laser pointers to demonstrate large-scale, multi-user interactions.**

Keywords–Systems, man, and cybernetics; User interfaces; Human-computer interaction.

I. INTRODUCTION

Multi-user, large-scale interfaces, in which individual users are identified and tracked, present a challenging and worthwhile design problem. Collaborative problem solving is oftentimes easier to accomplish when sharing a large projection surface than when operating on individual screens (such as with mobile devices), and user interaction and U.I. design is simplified if all users operate on the same display. In applications in which efficient interactivity between users is important, laser pointer devices are preferable to stationary pointer devices, such as mice [1]. In most cases, the challenge of identifying individual users is tackled by physically modifying laser pointers, an effective yet often-times costly and time-consuming solution. To circumvent these drawbacks, we present the idea of describing a laser by its personality, a measure of the shape and intensity of a laser pointer's leaked infrared (IR) light, which allows us to track and identify an off-the-shelf laser pointer among a group of others for the purpose of multi-user collaborative applications.

Our contributions are:

- The *laser pointer personality*, the signature shape and intensity of a laser point's infrared light leakage, and the laser pointer personality system used to identify laser pointers by their personalities.
- Several multi-user applications that demonstrate the utility of the personality system.

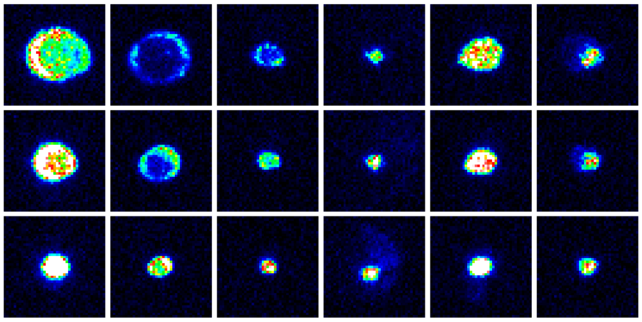

Figure 1. False color renderings of the IR spill from 6 inexpensive green laser pointers.

The rest of this paper is organized as follows. Section II describes the laser personality system. Section III discusses accuracy test results. Section IV discusses various applications that take advantage of the laser personality system. Section V closes the article.

A. Related Work

Single laser point detection is accomplished in two main ways: brightness filtering and IR filtering. Olsen and Nelson detect a laser spot on a large display screen with a two-pass system that detects red brightness with an applied convolution filter [2]. Oh and Stuerzlinger allow for multiple laser points by applying a threshold to the brightness field of the image [3]. The same technique is applied by Davis and Chen in their LumiPoint system [4]. However, depending on the brightness of the laser spot with respect to the rest of the image, this can create trouble due to its context sensitivity. Ahlborn et al. [5] present a system using multiple camera views, in which the background image is filtered out. IR filtering is employed by work by Qin et al. [6], Angelini et al. [7], and Cheng et al. [8].

In addition to laser spotting, one challenge in multi-user laser pointer systems is pointer identification. One method is to dynamically change the number of lasers present in the system at any given point in time, and to track an IDed laser spot across frames with predictive measures, such as the Kalman filter [9] [10] [8]. Another method involves the use of time division multiplexing, or the application of a laser blinking pattern, to identify a particular laser, as employed by Vogt et al. [11] [12], as well as Pavlovych and Stuerzlinger [13]. Francisco de la O Chavez et al., present a system whereby users can operate the electronic devices and appliances in their homes with a laser pointer [10]. Qinet al., present a system in which a special laser pointer is used to project several beams whose orientations indicate the angle of rotation along the beam axis of the laser [6]. Biet al. present the uPen, a laser pointer outfitted with right- and left-click buttons, designed to mimic computer mouse functionality [14]. Shizukiet al. present a series of gestures used with a laser pointer, and a series of applications using them [15]. In some applications, single laser pointer identification is all that is necessary, such as that by Miksiket el al. [16]. Each of these systems involves specialized hardware, and such additional cost. Our system requires only an I.R. filtered camera and cheap laser pointers.

II. LASER POINTER PERSONALITY SYSTEM

To detect the current position of each laser pointer dot, we use a 1280 x 960 pixel monochrome, 33fps video camera. An IR pass filter in front of the camera blocks all visible light (from the projector), so we can robustly detect the bright points of IR light from the laser. We specifically use green laser pointers because the green light is produced indirectly from an infrared laser diode, and some of the infrared light remains for our detection. Most inexpensive green lasers do not include an IR filter to block this light.

We begin with a simple calibration step to determine the pixel to pixel correspondence between our camera and the 1920 x 1080 projector and projection surface, and to collect intensity data on all lasers in the system. Our system has been tested on screens as tall as 18 feet (2.44 meters). Calibration consists of hovering each laser point on several known locations on the screen for a period of time. When tracking multiple lasers simultaneously, we use the Kuhn-Munkres, a.k.a. Hungarian Algorithm [17] [18] [19] to match the lasers from frame to frame. This method produces a pairing that efficiently minimizes the sum of the distances between the positions of each laser across the two frames. We also considered using a Kalman filter [9] to track smoothly moving laser dots, but our early experiments indicated this was complicated to tune for the accelerations of the laser dots at corners or tight turns and ultimately not necessary.

In addition to the centroid of the laser spot we also extract the intensity and size of the detected IR spill to calibrate laser intensity data for identification. Inexpensive lasers exhibit unique IR spillover, as shown in Fig. 1, and this is fairly consistent for each device (once the laser has warmed up for about 15 seconds, and as long as the batteries are reasonably fresh), allowing us to track and identify the lasers over time. The pattern of spill from the laser varies most with distance of the laser to the screen. The top row of images in Fig. 1 were collected with the laser 15 feet from the screen, the middle row at 10 feet, and the bottom row at 5 feet.

We call this signature the lasers personality. During the calibration phase, we capture several frames worth of this intensity data at each of the calibration points for each laser. We examine the blob of light and calculate a radial histogram of the intensity values of the blob. In practice, 20 bins (representing a radius of 20 pixels) is sufficient to capture the uniqueness of a laser spots shape. Note that the calibration can be performed simultaneously for many lasers (with 1 person per laser), and takes less than a minute. Sample laser personality data is presented in Fig. 2.

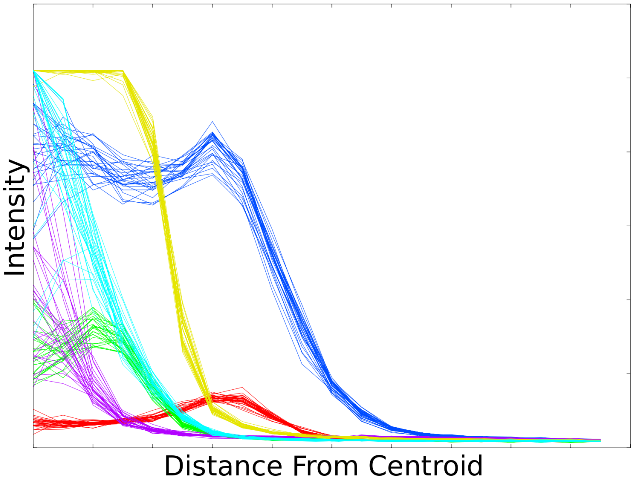

Figure 2. 30 personality measurements for each of 6 lasers from a single calibration screen location.

A. *Identifying Laser Spots: Matching Personalities*

Once calibration is complete, the system is able to match any laser spot on the projection surface with one of the calibrated lasers. When a laser spot is detected, its personality is calculated, and matched with that of one of the known lasers.

For efficiency, we utilize two passes to process the camera image. In a first coarse pass, we examine every nth pixel in the camera image and all pixels greater than a pre-set intensity threshold continue to the second pass. In the second pass, a generous window around each remaining pixel is examined. We collect all nearby pixels above the threshold and extract the largest connected component. The centroid of this component is set as the laser spot position. We then compute the histogram of pixel intensities shown in Fig. 2, matching the personalities using the sum of squared differences between the detected and known personalities.

It is important to note that the apparent laser intensity varies spatially for each laser due to a number of additional variables, including: distance from laser to screen, distance from screen to camera, and camera vignetting. We normalize for these variations by averaging all of the intensity data for all of the lasers collected at each of the calibration grid points, and normalize the input by dividing it by the spatial average. We use barycentric coordinates and interpolation to normalize laser points between calibration grid locations. Camera position normalization is especially crucial when the camera is placed at an extreme angle to the screen, and thus experiences significant perspective distortion. When multiple lasers are simultaneously detected on the screen, we leverage temporal coherence to disambiguate lasers with somewhat similar histogram personalities. We employ the Kuhn-Munkres algorithm to assign unique labels to all detected points; that is, no two lasers will be assigned the same ID, even if they both select the same ID as their first choice.

III. ACCURACY TESTS

The tests were performed using six lasers (given IDs 1-6) in the 19 x 23 space. The space was divided into a series of

TABLE I. RESULTS FROM ACCURACY TESTS.

Laser	**a) Single Pos.**		**b) Arc Mov.**		**c) Line Mov.**		**d) Walking Path**		**e) All Lasers**	
1	100.00	100.00	96.54	98.27	53.88	74.14	51.13	68.49	99.79	100.00
2	100.00	100.00	100.00	100.00	90.43	95.21	78.65	86.25	99.07	100.00
3	95.85	100.00	70.96	73.48	35.14	48.65	60.50	96.10	83.49	98.75
4	92.79	100.00	77.40	100.00	80.41	100.00	83.02	100.00	99.61	99.78
5	99.67	99.67	100.00	100.00	57.99	92.57	82.95	94.26	99.80	99.92
6	90.33	96.03	93.89	95.91	72.56	79.70	91.81	94.86	84.08	99.90
Min:	521		347		230		645		968	

testing locations at discretized 22.5 arcs with radii of 5', 10', and 15' from the center of the projection surface. The results are presented in Table **??**. Five accuracy tests were run in total, described below.

- **a) Stationary Test -** judge how well lasers could be matched to the calibrated data while stationary.
- **b) Arc Walking Test -** judge how much side-to-side movement affected the overall accuracy of the identification system.
- **c) Straight Line Walking Test -** judge how much distance from the screen affected the overall accuracy of the system.
- **d) Path Walking Test -** provide an overall averaging of the previous two tests, and to mimic movement expected by users in real-world environments.
- **e) All Lasers Simultaneous Test -** assess how accurately the laser identification system performed when several lasers were on the screen at once.

For each test and for each laser two percentages are reported: the percentage of frames in which it was correctly identified as its primary ID (left column), and the percentage of frames in which it was identified as either the primary or secondary ID (right column). The minimum number of frames collected for each test is reported along the bottom row. All units are percentages of frames.

Overall, our laser identification system is most effective when lasers remain in the general area from which their calibration data is collected while the system is in use. It is rare that a laser is mislabeled in this instance. However, when moving from place to place, the shape of the laser spot can change dramatically, and so the personality can as well. This explains the poor performance of lasers in general in tests c) and d).

These tests bring to light two noteable shortcomings of our identification system that will be tackled in the future. The first is that position is important when comparing a laser spot to a given set of laser personalities, and a lasers personality changes over the time of its use due to warming and battery drain.

IV. APPLICATIONS

We have implemented a series of five applications that effectively take advantage of multi-user interfaces for visualization, education, and problem-solving. The common thread among each of the applications is its use of input from several different users to achieve a common goal, e.g. exploration of a data visualization or solving a puzzle. Our applications are a multi-user painting program, a puzzle solving program, a terrain and hydrography data visualization tool, a graph visualization tool, and an infrastructure map visualization tool.

Figure 3. A visualization of the puzzle application.

The first application is a standard paint program, which allows any number of users to paint on the screen using the laser pointer as a brush, selecting color and size at will. Users hover over buttons to choose color and brush The puzzle solving program reads in an image and breaks it into n equally-sized rectangular textured tiles, randomizes them, and displays the new order on the screen, seen in Fig. 3. In the figure, five users (each represented by his own color) attempt to solve a 7x5 piece puzzle. The five images represent five points in time during the solving of the puzzle. Each border between two tiles that should not be adjacent is greyed out (top left image), but once a tile is placed next to its proper neighbor, the border fills in (middle image). Each laser point creates a trail of a unique color as it moves across the projection surface, providing feedback to individual users. The common goal of the users of this application is to reassemble the original image by clicking and dragging the tiles.

In addition, we have implemented a visualization tool for terrain hydrography. The goal of the application is to allow for the exploration of terrain hydrography data by multiple users through a laser pointer interface, utilizing the work of Metz et al. [20] and OCallaghan and Mark [21]. The application consists of a data view and a graphical user interface side-by-side, in which modes are selected in the GUI through dwell-selection. In addition to selection of modes, the laser pointers are also used to interact directly with the 3D terrain data and camera view.

We have also developed a graph visualization tool that allows users to explore data organized by nodes and edges. Our application takes as input node and connectivity information. Laser points which dwell on a node for a period of time grab the node, indicated by the laser trail turning green, and can drag the node to a new location. The graph will rearrange itself based on a mass-spring simulation, minimizing the energy in the system.

Our final application is a visualization, exploration, and editing tool for infrastructure data. The data are organized as a spatial graph of interconnected nodes and arcs in several different infrastructure systems: electric power, telecommunications, transportation, etc. The tool is used to visualize the complex network along with vulnerabilities during hurricane and flooding scenarios (e.g., where are ambulances re-routed if a local hospital is flooded). Images of all applications and videos of the system in use are available upon request.

V. CONCLUSION

Multi-user interaction on large-scale displays is a powerful collaborative tool with several applications. In this paper, we have presented a method for identifying off-the-shelf laser pointers in an inexpensive and simple manner by calibrating each laser pointers IR spillovers intensity histogram, called the lasers personality, allowing for closest-neighbor matching of data points. The system requires only a calibration step to set up, and once it is complete multiple users can interact with interfaces in a large-scale environment. Applications tailored to multi-user collaborate problem solving efforts are presented in this paper that take advantage of our systems ability to identify laser points to explore data, manipulate data, and solve problems in a group environment. Our method is inexpensive, accurate, simple, and scalable to large screen displays.

While the system works well when users do not change how far they are from the projection surface (sufficient for many applications), there are times when this is not enough. One clear extension to this work is the introduction of continuous calibration, in which calibration data is updated as the lasers are used to account for changes in environment, including the position of the users. Additionally, the next step of adopting the system for general use is a detailed user study, which we plan to conduct in the near future. And we will extend our suite of applications for a broader audience.

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