Camera-less Smart Laser Projector

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Abstract

We introduce here our latest 'smart laser projector' prototype, i.e, a modified laser-based projector capable of augmenting all kind of surfaces while simultaneously using the laser as a scanning beam used for gathering information about that surface shape, texture, reflectivity, relative motion, etc. 'Augmenting' surfaces (including tables, desktops, walls and floors, but also human skin, paintings, market products on a shelf, etc) means here alphanumeric or iconic annotation, highlighting features invisible to the naked eye (for instance veins under the skin, small scratches or oily spots on surfaces), cueing (using flashes of light for marking secure perimeters or indicating dangerous obstacles) and line and contour enhancement for practical or aesthetic purposes. This device fits in many ways the definition of a 'smart projector' as described in [1] but presents a number of advantages with respect to the classical projector/camera configuration.

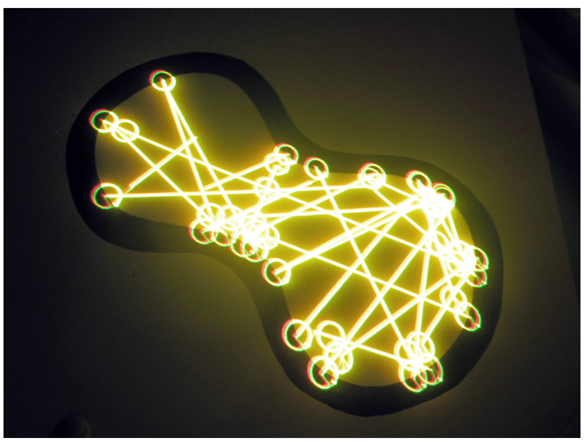

Figure 1: Combined green and red lasers trapped on a drawing

We demonstrate the prototype through a couple of interactive applications. The first was previously demonstrated on an earlier (bulkier) system [2]. The application is playful in nature and consists on generating a laser spot that seems alive as it keeps running on contours of drawings or bouncing on flat figures as well as over the edges of three-dimensional objects (Fig.1). The second application is a simulation of the refraction of light beams on a 2d surface, by simulating the Snell-law computed at the interfaces of gray level regions on a flat drawing - the gray level corresponding to a virtual refraction index (Fig.5).

1 Introduction

The 'smart laser projector' is basically a laser projector (capable of operating in raster scanning mode or vector mode), in which the illumination beam is capable of simultaneously sensing and scanning the surface (Fig.2). This paradigm presents a number of advantages with respect to the more classical 'projector-camera' setup used in sensor-enhanced displays [1]. Here, the sensing hardware and the projection hardware share the same optical path as well as part of the hardware (the lasers) and both sensing and displaying operations are realized simultaneously. The most important advantage is therefore that calibration (of camera and projector - i.e., computing intrinsic and extrinsic parameters) is not needed at all. Also, three dimensional coordinates of the point under illumination can be directly and very accurately known (thanks to laser-based rangefinding techniques) instead of inferred by triangulation. This means that there is no need to use a pair of stereo cameras nor structured light sources (or special markers on the real world). Besides, these three dimensional coordinates may not be needed at all while projecting using this device, since the measured property (color, reflectivity) at a particular point may be used to directly modulate the visible light. This would be the case in color-corrected images on a non-uniform wall-paper for instance. Another interesting example would be a smart laser projector version of the 'VeinViewer' system [3]. In the original system, an infrared camera is first used to discover subcutaneous veins, and then a DLP projector is used to highlight them (this time with visible light). In order to properly align the projection with the real position of the veins, it is imperative to know the position and orientation of the skin surface with respect to the camera. Since no stereo cameras are used, this means that the scanned limb must be physically constrained in the scanning region of the machine. This is not necessary while using a smart laser projector, since the infrared sensing beam is collinear with the illumination beam by construction. Additional advantages of the smart laser projector with respect to sensor-enhanced displays based on the camera-projector setup include:

- extremely large depth of focus: the laser-based display will stay in sharp focus over a large distance.
- variable resolution: the laser scanning step can be finer on regions of interest; alternatively, the projector can be used in vector-graphics mode, rendering non-pixilated imagery.
- simple and compact optical system: there is no 2d imaging optics, and hence no aberrations nor bulky optics. Indeed, using MEMS technology the system can be extremely compact and very rugged.
- projection at very long distance: when using vector-graphics mode, projection over surfaces hundreds of meters away is possible without unreasonable amounts of optical power. This is ideal for outdoor applications.

For these reasons, we envision a very large number of applications for the smart laser projector, including:

- Augmented architectural spaces. We are interested here on real-time detection of edges and corners, and augmentation of these edges with light from lasers - i.e, a non pre-calibrated laser-based version of works such as [4].
- Spatial cueing: Perspective enhancement is interesting from an aesthetic point of view (altering spaces by making them look larger or smaller, etc.), but can also be used to help people with or without visual or motor impairments, for instance by indicating the clear path while walking or driving thanks to dynamic lines or arrows on the floor. This will become practical if the sensing and displaying system can be made

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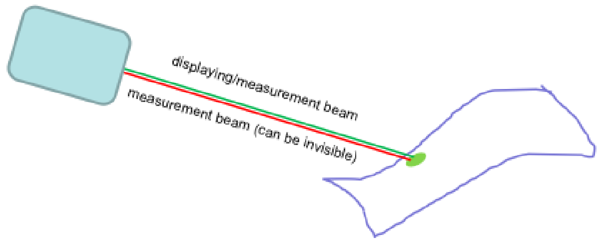

Figure 2: Principle of the smart laser projector: a single or multiple collinear laser beams perform simultaneous illumination and radiometric measurements

extremely compact and wearable, something that is straightforward in the case of a MEMS based smart laser projector.

- Translation of bar-code information into directly readable text. Since the laser can be used to scan the environment, it will be capable of recognizing printed codes (such as 1d or 2d bar codes). Once done, the laser can then be used to overlay information that is directly readable by a person (alphanumeric or iconic). This can be used to augment in an unobtrusive way the amount of information a potential buyer can get from a product on a shelf. By unobtrusive we mean that the information does not need to be present in a printed form (i.e., on a label), but also that the user does not need to wear any kind of head-mounted display to access this augmented reality environment. This concept is similar to that described in [5], with the advantages of not requiring a calibrated camera/projector pair, as explained above.

- Augmentation of paintings, mural advertisement and logos using laser light - without pre-calibration. Many applications can be foreseen for advertisement displays relying partly on printed material and partly on dynamic lighting.

- Automatic contrast compensation for printed material using an intelligent light source that can enhance readability of texts in uneven illuminated surfaces, or even in complete darkness (and in particular passive street signs and posts). This is possible because the active light mechanism used by the laser scanner does not need ambient illumination: this means that the scanner can 'see' and follow the contour of letters at night; at the same time, a visible beam of laser light make the letters appear clearer.

- Exo-displays: this would be a wearable device that project information in the physical space surrounding the wearer (including the user hand, see Fig.3). For this, scanning is necessary to find an appropriate surface, something that can be done by the laser projection system itself. Such wearable smart projector can be used to augment the surrounding with information only intelligible for the perspective of the user (by anamorphosing the alphanumeric data projected). An interesting field of application is on exo-displays for cars: the system could display or highlight signals directly on the road pavement, only intelligible from the perspective of the car driver.

- Entertainment: the laser light can interact with objects in real time; games such as pong, pinball, and air-hockey have been already demonstrated by us [2] and [6] (see Fig.4). It would be interesting to extend the range of the device so as to augment with laser much larger spaces - such as climbing walls,

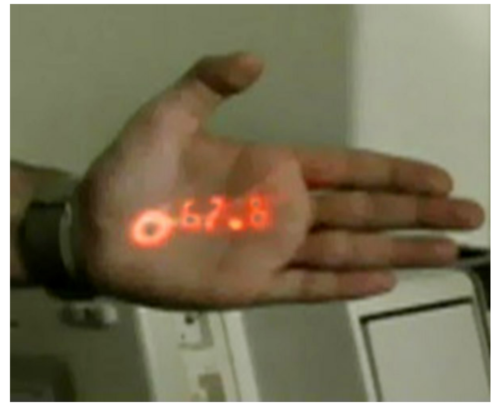

Figure 3: The palm of the hand detected and used on-the-flight as a projection display.

a whole football playground or even a ski slope. In the later case, the whole ski slope can serve as a gigantic dynamic display, where graphics can be drawn in response to the skiers' motion. Using laser projection - common in large scale audio visual shows - the graphics can be drawn from a single location onto an uneven surface in varying distance (something impossible to attain with standard projectors). Moreover, snow provides an excellent projection surface, giving high contrast imagery (obviously, the system would work best in low light environments).

- Medical imaging, biosensing and biometrics. The system could detect and highlight subcutaneous veins, by combining a visible laser with a near infrared laser. This would make for an extremely portable version of the "VeinView" device [3], with the advantage of fast and precise (quantitative) measurements (including heart rate, blood flow, and skin pigmentation) and more importantly, without the need to align the projection with the real objects. Variable wavelength and polarization can also be used to scan the skin surface for diseases such as melanoma (an intriguing possibility is the use of one of these laser beams for delivering simultaneous phototherapy). UV-wavelengths can also be used to detect the surface condition of teeth, thus indicating it to the user with visible light.

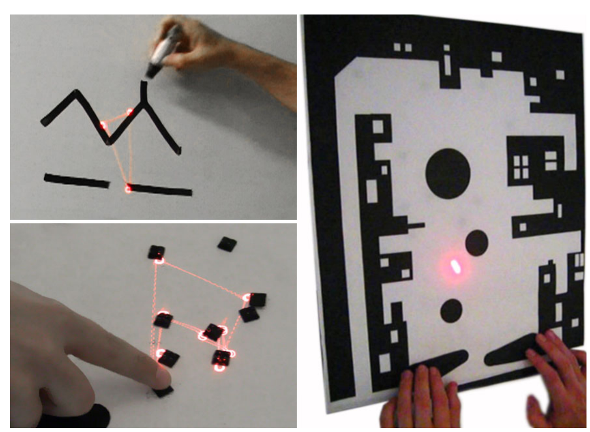

Figure 4: Example of drawings and games augmented with the laser

The design of the proposed laser-based 'sensing display' involves several problems among which the real-time extraction of relevant

3d features, radiometric properties, texture, speed and even temperature of the illuminated surface. We are particularly interested on designing a wearable, miniature 'sensing-projector' that can be attached to clothes or objects (including a car surface). This research builds on previous results on the 'smart laser scanner' project [7] and recent experiments on real-time scanning and projection of deformable surfaces using active lighting and a custom vision chip [8].

2 Previous work 'Sticky Light'

A previous system called 'sticky light' [2] demonstrated augmentation of drawing and logos (Fig.4), as well as interactive entertainment applications such as air (or rather *light*) hockey and pinball game, both playable with bare hands (scores were displayed in real time right next to the moving spot). These different applications were selectable through a small numeric pad, but even without changing the behavior of the light spot, the game could be modified by simply exchanging the graphic background. The quality of the laser light, and the fluidity of the motion made for a very unique experience.

Sticky-Light was essentially an art-installation promoting a reflection on the role of light as a passive substance 'used' for contemplating a painting or a drawing. Natural light, or an artificial spot of light is always necessary to illuminate what we want to see; in fact, the source of light is not really passive: it interacts and modifies the visual perception in an essential way. The installation amplified such effect: it gave the light spot new ways of interacting with the painting. It actually augmented the drawing content by scanning the lines and bouncing on the colors. By moving on the drawing, the light spot attracts the attention of the viewer. It actually forces the sight to follow the dynamic path taken by the light. The function of the laser scanner was therefore inverted: it no longer acquires information, but build upon an existing graphic design in order to create new dynamic visuals. While the eyes get the whole picture, the wandering of the light spot enables us to gain a deeper, sequential understanding of the shape.

Figure 5: The laser spot bounces on drawings and edges of 3d objects.

3 New prototype and apps

3.1 Bouncing on lines and edges

The new prototype is compact and portable and does not need a supporting table. We can therefore envision projecting on all kind of surfaces in the nearby environment. An interesting possibility is to project on people's clothes (Fig.5), or directly on their skin. Laser-augmented body painting would be possible, in which a dancer wearing a zebra-patterned outfit will be 'scanned' by a spot of light as he/she moves, as if explored by the needle of a phonograph, or as if turned on a lathe. Here, again, the function of the scanner is inverted. A 3d scanner normally captures the form of a shape that rotates on a specifically designed rotating plate, while in this new configuration, the act of 'seeing'(by the scanner) generates the motion (of the dancer) and modifies the shape of the observed object. The scanned material does not need to be just a black and white flat drawing; it can be virtually anything (a colorful tissue, a moving volume). What it's needed is that the scanned object present enough contrast for the scanning beam.

3.2 Ray-tracing

The new application demonstrated here consist of simulating the refraction of light beams as they 'travel' on a piece of paper with different colored regions (Fig.6). Besides the sheer playfulness, this application could be used for educational purposes on the topic of geometrical optics.

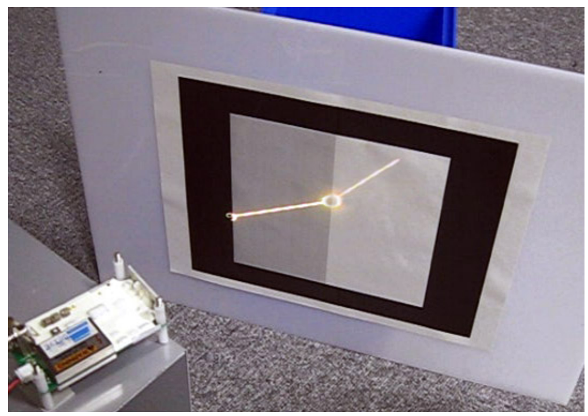

Figure 6: 2d ray-tracing with the smart laser projector. Note the scanning 'saccade' at the interface between gray areas, and the deviation of the 'beam' following a simulated Snell law.

4 Technical details

The system is based upon a 3d tracking technology previously developed in our lab called the 'smart laser scanner' [7]. The system uses a laser diode, a pair of steering mirrors, and a single *non-imaging* photodetector. The laser beam is able to detect contours in the very same way a blind person would use a white cane to stick to a guidance route on the street. The hardware is very unique: since there is no camera nor projector (with pixellated sensors or light sources), tracking as well as motion is extremely smooth and fluid. Moreover, several laser spots can be generated and controlled by a unique scanning head.

The new prototype system presented here uses a microcontroller both for steering the mirrors and for processing the photodiode signal. A modulated red laser beam is used for making reflectivity measurements as well as drawing. A collinear green laser provides a secondary color (in the near future we will use an RGB laser projector for completing the color palette, as well as color selective photodetectors - this means that the system will be capable of measuring, per-'pixel', the color profile of the surface under illumination and adjust the projected content accordingly).

The new Smart Laser Projector hardware comprises an Arduino Mega microcontroller, a custom made Lock-In amplifier, a laser head projector composed of two laser diodes (red and green) and a couple of galvano mirrors (Fig.7). The microcontroller generates a 100KHz square signal. This signal modulates the red laser beam and is also used by the lock-in amplifier as a reference signal. A lock-in amplifier acts as a pass-band filter with a very high Q-factor; usually it uses a pair of reference signals (in phase and quadrature) to compute the phase and amplitude of the signal. To simplify the hardware, and since the corresponding wavelength of the modulated AM signal is on the range of several hundreds of meters, we estimated that the phase is basically constant. Therefore, we calibrated once and set the phase of the mixing signals so as to obtain the larger response.

The microcontroller reads the lock-in amplifier output signal to discriminate between dark and bright zones (and a discrete number of gray levels). It also controls the position of the laser spot by generating analog signals driving the X/Y galvano-mirror pair. In the example of the bouncing application or the simulated refraction, the microcontroller will move the spot on a straight line until it detects a region with a marked difference on reflectivity; in such case, it generates a circular scanning saccade in order to compute the normal vector to the interface between the two different regions. From this information, it is straightforward to compute either the bouncing or the refracting direction.

5 Hardware and setup

The setup can be easily configured for interaction on an horizontal or a vertical surface. In the first case, the laser head can also be rotated to demonstrate drawing on clothes on people nearby. The system is compact and works autonomously (i.e. without a PC). The overall size is about 30x30x40cm (Fig.7).

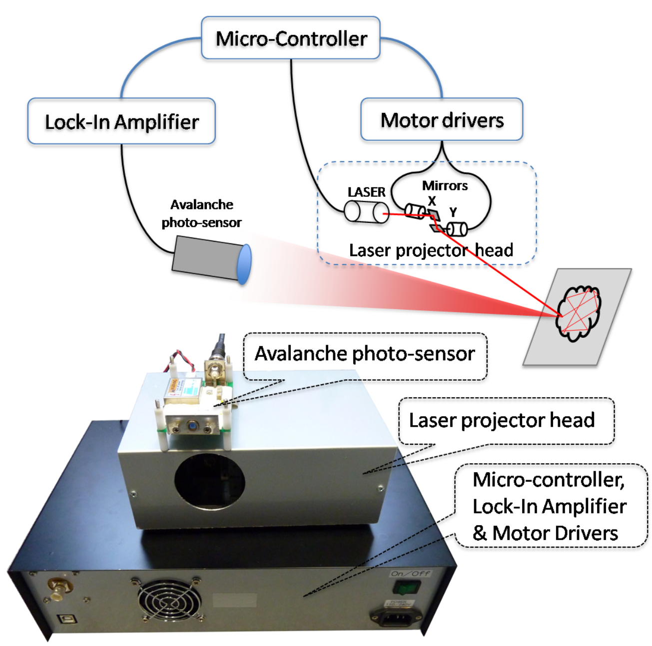

Figure 7: New compact and modular smart laser projector system.

6 Conclusion

We have demonstrated a portable prototype of a ‘smart laser projector’ having endless applications from entertainment, to human-computer interfaces to medical imaging. In the near future, we plan to demonstrate medical imaging applications (in the field of dermatology and phlebotherapy), as well as research on ways to rendering the whole system compatible with a hand-held instrument using MEMS technology.

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References

[1] O. Bimber, A. Emmerling, T. Klemmer, ”Embedded Entertainment with Smart Projectors,” Computer, vol. 38, no. 1, pp. 48-55, Jan. 2005

[2] A. Cassinelli, Y. Kuribara, S. Perrin and M. Ishikawa, Sticky Light showcased at Ars Electronica / Tokyo University Campus Exhibition(HYBRID EGO), Linz, Austria, 4-9 Sept. (2008), Campus Exhibition catalog. http://www.k2.t.u-tokyo.ac.jp/perception/StickyLight/

[3] R. K. Miyake et al, ’Vein imaging: a new method of near infrared imaging, where a processed image is projected onto the skin for the enhancement of vein treatment’, Dermatologic surgery: 2006 vol. 32 pp 1031-8. (The product is called ’VeinViewer’, from Lumintex Corporation, http://www.luminetx.com/).

[4] P. Valbuena, *Augmented Sculpture Series*, (www.pablovalbuena.com)

[5] P. Mistry, P. Maes. SixthSense - A Wearable Gestural Interface. SIGGRAPH Asia 2009, Emerging Technologies. Yokohama, Japan. 2009

[6] A. Cassinelli, Y. Kuribara, D.Manabe and M. Ishikawa, scoreLight, SIGGRAPH ASIA 2009, Art Gallery, Yokohama (2009). Art Gallery Catalog, p.15.

[7] A. Cassinelli, S. Perrin and M. Ishikawa, Smart Laser-Scanner for 3D Human-Machine Interface, ACM SIGCHI 2005 Portland, OR, USA April 02 - 07, 2005, pp. 1138 - 1139 (2005), www.k2.t.u-tokyo.ac.jp/perception/SmartLaserTracking/

[8] Y. Watanabe, A. Cassinelli, T. Komuro and M. Ishikawa. The Deformable Workspace: a Membrane between Real and Virtual Space, IEEE Tabletops and Interactive Surfaces, Oct. 1-3, Amsterdam, the Netherlands, (2008)