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Table-Top Projector-Camera System with Transparent Water Detection for Interactive Art

Takanori Koga and Takahiro Matsuo

***Abstract*—This paper describes a new projector-camera system which can be used for interactive arts utilizing transparent water as a medium between viewers and the arts. This system takes advantage of a shortwave infrared (SWIR) image for the transparent water detection. In particular, we present concrete specifications of the proposed table-top system and fundamental image processing techniques for real-time water blob detection and image projection to the blobs. Through the development of the system, we present a new way to use the SWIR image and show a novel interactive art utilizing transparent water as a medium.**

***Index Terms*—interactive art, shortwave infrared (SWIR), transparent water detection, infrared image processing, projector-camera system**

I. Introduction

In the field of interactive art [1–10], safe and close mediums such as wind and water are in the limelight recently to let viewers experience natural interaction with arts. For this purpose, there are many systems using wind [9]; and such systems have been studied well. On the other hand, few are known about the systems with fluid and transparent water; and most of those are based on indirect sensing with flow rate sensors. Thus, sensing and expression of transparent water still leave much matter to be studied. For example, [10] is a way to visualize transparent water by using heat images. However, it still needs work for application to interactive arts because it is difficult to control the temperature of the fluids constantly with a high degree of accuracy. Therefore, a new transparent water detection technique should be realized without using heat images.

To cope with this problem, in this study, we develop a table-top projector-camera system which realizes real-time transparent water detection and adaptive interaction with the viewers through projection mapping. In this system, short-wavelength infrared (SWIR) images [11, 12] are used for the stable detection of transparent water. In particular, we focused on the fact that water has high SWIR light absorption characteristics around 1450nm.

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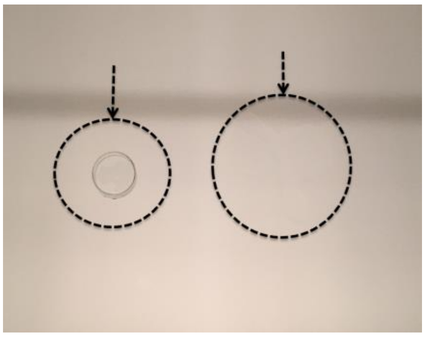
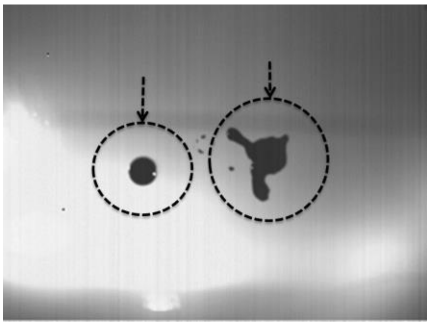


(a)



(b)

Figure 1. Imaging of transparent water blobs. The left and right circles point water in a petri dish and those on the table, respectively. (a) An image acquired with a CMOS RGB camera. (b) An image acquired with an InGaAs camera.

By using an indium gallium arsenide (InGaAs) imager [13–15] and a band-pass filter, water and damp of objects can be visualized distinctly. This is independent of the characteristics of the object and temperature of its surrounding environment. This paper describes concrete specifications of the system, image processing techniques, and an actual application of this system to an interactive art which realizes interaction between viewers and the art through touching with transparent water.

II. System Design

Figure 1(a) is an image of transparent water acquired with a CMOS RGB camera. Figure 1(b) shows the water blobs detected by using SWIR imaging. The water blobs were taken as the black regions because the proposed method utilizes absorption of SWIR light. This is a fundamental principle of the proposed system.

Figure 2(a) and 2(b) are a whole picture of the proposed system and the block diagram which shows processing flow, respectively. The measurement instruments are IR lights which emit infrared light over 820nm wavelength (2200K), an InGaAs imager which can detect lights from 1000nm to 1700nm wavelength and a band-pass filter with 1450nm center wavelength (full width at half maximum: FWHM=50nm), and a CMOS camera with 940nm long-pass filter. Those instruments were installed under and above the semi-transmissive table as shown in Fig 2(a). The table consists of an acrylic plate (1240x940x5mm) and a projection film. The development environments and concrete specifications of the workstation are as follows.

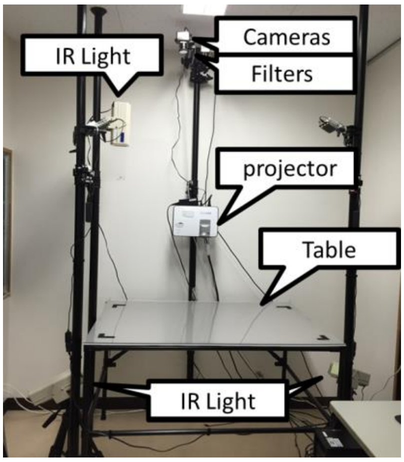
Computer: HP xw8600 Workstation
OS: Windows 7 Ultimate x64
Processor: Intel Xeon X5470 @3.33GHz (8CPUs)
Main Memory: 4GB
Graphic Board: NVIDIA Quadro FX 4800
Programming Language: C#
Development Environment: Unity 4.6.1
Software Libraries: OpenCVSharp, ArtCamSDK

As shown in the block diagram of Fig. 2(b), the acquired image streams are processed with fundamental algorithms such as histogram equalization, noise elimination, and morphological operation, etc. in order to extract the water blobs obviously. Finally, the detected blobs are expressed as a map data with solid model with a set of primitives in order to realize the real-time interactive projection mapping. We call this map an approximation map (A-MAP). The size of the image is 320x256. The image is processed by the following procedure to obtain the figures of the water blobs clearly as shown in Fig. 3(b) from Fig. 3(a).

1. The captured image by the InGaAs imager is converted from a 12-bit raw image into an 8-bit grayscale one. The contrast of the image is adjusted by the histogram equalization.
2. A median filter [16] with 5x5 filter window is applied to the grayscale image to remove impulsive noise. Then the image is binarized with an adaptive threshold.
3. A morphological operation (closing) [17] is applied to the image with a 4x4 square structural element to remove noise.
4. In order to obtain the A-Map, a majority decision is conducted for every 5x4 pixel blocks, and then the result is stored as a two-dimensional 64x64 lattice matrix as shown in Fig. 4(b) from Fig. 4(a). The A-MAP is used for recognizing the projection target area and for the calculation of the collision avoidance in the Boids algorithm explained in the next section.
5. The image acquired by the CMOS camera is used for generating a difference image between CMOS and InGaAs cameras. The image is used to distinguish between the water blobs and the other objects.

The image processing, the image projection, and overall control parts were integrated by using Unity [21]. Unity is an integrated development environment (IDE) mainly used for game development, and it adopts multi-platforms. Unity has

a



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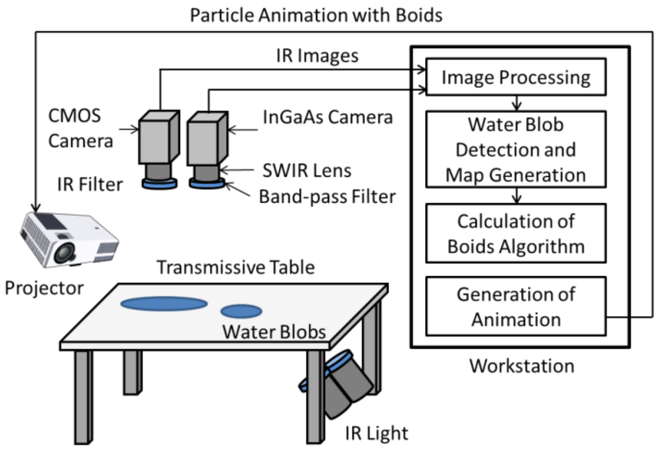
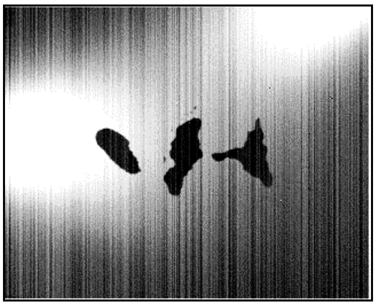
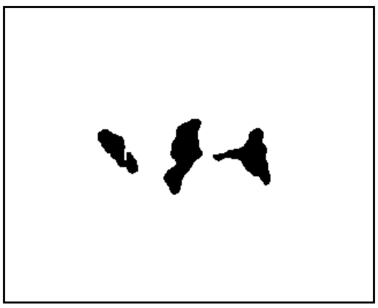


(b)

Figure 2. Overview of the proposed tabale-top projector-camera system. (a) Whole picture of the system. (b) Block diagram of the system.



(a)



(b)

Figure 3. (a) Acquired image with SWIR imaging. (b) Detected water blobs by the series of image processing.

vast of functions used to create multimedia contents such as rendering of three-dimensional (3D) objects, physical calculation, scene change, input interfaces, callback processing, communication between devices, etc.

Finally, by using the obtained A-MAP, the individuals of the flocks are controlled inside the projection region with Boids algorithm in order to generate interactive animation. Details of the processing blocks shown as "Calculation of Boids Algorithm" and "Generation of Animation" in Fig. 2(b) are explained in the next section.

III. APPLICATION TO INTERACTIVE ART

Figures 5(a)–5(c) show the actual interactive art created by using the proposed system. Figure 5(a) is a scene of test on the interaction with the A-MAP and Boids [18, 19] algorithm without graphical effect. Figure 5(b) shows the graphical animation of Boids with particle expression. Figure 5(c) shows an actual interaction between a viewer and the art. The viewer can change the figures of water blobs, and then the graphical animations with Boids projected onto the blobs are changed. Concretely, the animation represents the computer-generated fishes swim inside the water blobs with adaptive behavior. Furthermore, the viewer can create new flocks by making new water blobs by adding water or separating the blobs on the table. Indeed, the viewer can merge the flocks by aggregating the blobs. Naturally, the viewer can eliminate the flocks by removing the blobs.

Specifically, Boids is an algorithm for generating flocking animation such as birds, ants, and fishes, etc. The flocking animation can be naturally generated by just describing the following three rules.

1. Cohesion
   Each individual changes its moving direction to the center position of visible flocks.
2. Alignment
   Each individual aligns its direction and velocity with those of the surrounding and visible ones.
3. Separation
   Each individual keeps the gap with its surrounding ones.

Boids algorithm is easily extendable by adding new rules; and the flocks have diversity by adding new rules. In this study, we added the following two rules.

4. Wandering
   Each individual converges to a specific object. The position of the object can be set arbitrarily. By letting the object stroll around, wandering motion of the flocks is generated.
5. Collision avoidance
   Each individual maneuvers around the collisions such as the border.

In Boids, the position of each individual can be calculated by using velocities obtained by the aforementioned rules. The first three rules are original ones and the others are additional rules in this system. The coordinates and velocities of all the individuals are updated in every frame by the following procedure. After the calculation of velocity by the rules, {v1,…, v5} are normalized. Then the weighted sum of them

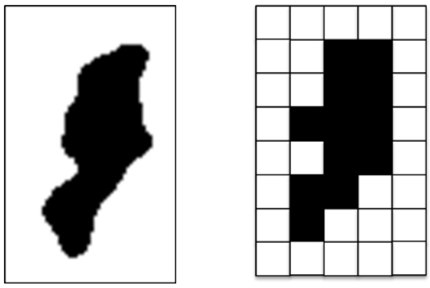
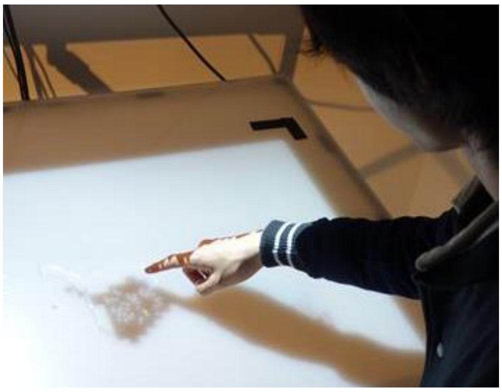


Figure 4. Approximation of a water blob with a coarse map. (a) Image of the detected blob. (b) Approximated water blob.



(a)

(b)

(c)

Figure 5. The developed interactive art. (a) Projection of the approximated map and the positions of boids for system test. (b) The Boids with particle expression. (c) Actual interaction by a viewer. The viewer can change the figures of the water blobs by touching.

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is calculated by using coefficients defined by a system designer. In this regard, a maximum velocity limit is set. In the actual calculation process, the following three matrices, i.e. Euclidean distance matrix, visibility matrix, and collision distance matrix are calculated. Finally, the fishes consisting the flocks are illustrated by using light particle [20].

Through the system development and its application, we confirmed that the real-time detection and visualization of transparent water blobs can be realized with the SWIR imaging technique, and some fundamental image processing techniques. Furthermore, we realized a new interactive art with this system. The proposed system can express one hundred individuals with 20 frames per second (fps) in average. This frame rate is enough for realizing fundamental interactive arts. In this regard, it is desirable to accelerate the processing speed to implement more individuals.

IV. Conclusions

In this paper, we proposed a table-top projector-camera system which realizes real-time transparent water detection and adaptive interaction with the viewers through projection mapping. Compared with the interactive arts with conventional mediums, our system and its application entails extraordinary experiences to the viewers by using safe and close transparent water. So far, the water detection with image processing has been realized by using heat images or colored water. On the contrary, the proposed system solved the problems of those systems, and it is easy to use the system in various environments and the viewers can touch the transparent water and interact the arts without psychological barrier.

In creation of media arts, especially interactive arts, the utilization of Unity is fruitful. This is because between artists' parts such as 3D modeling and art direction, etc. and engineers' ones such as system control, fundamental image processing, and implementation of algorithms can be obviously separated. Thus, the artists are not required knowledge on the detailed programming and can concentrate the design of art appearance, interaction, user interface and user experience, and art direction, etc.

The followings are limitations of the proposed system. In this study, we used halogen lamps with IR pass filters as IR lighting devices. Halogen lamps can emit bright light. However, they also emit non-negligible heat. This deliver a damaging blow to the IR filters. To use LEDs is a solution, however, SWIR LED is very expensive and they can emit very low power light. To cope with those problems, studies on the IR light is required more.

Future works are to develop and implement hand-tracking and gesture recognition algorithms in SWIR environment and to improve the expression of the interactive art. In order to generate more natural flocking motion, the parameters of Boids algorithm should be adjustment based on subjective evaluation.

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References

[1] D. Hudson and P. R. Zimmermann, *Thinking Through Digital Media Transnational Environments and Locative Places*, New York: Palgrave Macmillan, 2015.

[2] C. Paul, *Digital Art*, Thames & Hudson, 2008.

[3] O. Grau, *Virtual Art: From Illusion to Immersion*, The MIT Press, 2004.

[4] R. Dannenberg, J. Bates, "A model for Interactive Art", *Proceedings of the Fifth Biennial Symposium for Arts and Technology*, pp. 103-111, 1995.

[5] K. Brown (Ed.), *Interactive Contemporary Art: Participation in Practice*, I. B. Tauris & Company, 2014.

[6] T. Matsuo, S. Hirata, and T. Koga, Noctiluca, 2004 Asia Digital Art Award, 2004.

[7] K. Tobitani, E. Aiba, Y. Higashi, K. Aida, and N. Nagata, "Virtual Noctiluca: Media art of light and music through stream," *Journal of the Institute of Image Information and Television Engineers*, Vol. 68, No. 7, pp. J276-J284, 2014.

[8] M. Muller, D. Charypar, and M. Gross, "Rigid Fluid: Simulation for Interactive Applications," *Proceedings of SIGGRAPH '03 ACM SIGGRAPH 2003 on Computer Animation*, pp. 154-159, 2003.

[9] E. Sawada, S. Ida, T. Awaji, K. Morishita, T. Aruga, R. Takeichi, T. Fujii, H. Kimura, T. Nakamura, M. Furukawa, N. Shimizu, T. Tokiwa, H. Nii, M. Sugimoto, and M. Inami, "BYU-BYU-View-A Wind Communication Interface," *ACM SIGGRAPH 2007: Emerging Technologies*, 2007. DOI: 10.1145/1278280.1278282

[10] D. Iwai, I. Kanaya, S. Hiura, S. Inokuchi, and K. Sato, "Thermo Painter: A Tablet Type Input Device Using Thermal Vision and Ots Interactive Drawing System," *Journal of Information Processing Society of Japan*, Vol. 46, No. 7, pp. 1-12, 2005.

[11] W. S. Lau, *Infrared Characterization for Microelectronics*, World Scientific, 1999.

[12] F. Siebert and P. Hildebrandt, "Theory of Inferred Absorption and Raman Spectroscopy," *Vibrational Spectroscopy in Life Science*, Wiley, 2008.

[13] M. J. Cohen and G. H. Olsen, "Room-Temperature InGaAs Camera for NIR Imaging", *Proceedings of SPIE 1946, Infrared Detectors and Instrumentation*, 436, 1993. DOI:10.1117/12.158695

[14] T. Martin, R. Brubaker, P. Dixon, M.-A. Gagliardi, and T. Sudol, "640x512 InGaAs Focal Plane Array Camera for Visible and SWIR Imaging," *Proceedings of SPIE 5783, Infrared Technology and Applications XXXI*, 12, 2005. DOI:10.1117/12.603406

[15] M. H. Ettenberg, M. T. O'Grady, S.-C. Huang, and M. J. Cohen, "Miniaturized 320x256 Indium Gallium Arsenide SWIR Camera for Robotic and Unmanned Aerial Vehicle Applications", *Proc. SPIE 5074, Infrared Technology and Applications XXIX*, 353 (September 30, 2003); doi:10.1117/12.486329;

[16] T. Huang, G. Yang, and G. Tang, "A Fast Two-Dimensional Median Filtering Algorithm," *IEEE Trans. Acoust., Speech, Signal Processing*, Vol. 27, No.1, pp. 13-18, 1979.

[17] P. Soille, *Morphological Image Analysis: Principles and Applications, 2nd Edition*, Springer-Verlag New York, 2003.

[18] G. W. Raynolds, "Flocks, Herds, and Schools: A Distributed Behavioral Model," *Computer Graphics*, Vol. 21, No. 4, pp. 25-34, 1987.

[19] D. Terzopoulos, X. Tu, and R. Grzeszczuk, "Artificial Fishes: Autonomous Locomotion, Perception, Behavior, and Learning in a Simulated Physical World," *Artificial Life*, Vol. 1, No. 4, pp. 327-351, 1994.

[20] S. Koshizuka, H. Tamako, and Y. Oka, "A Particle Method for Incompressible Viscous Flow with Fluid Fragmentation," *Comput. Fluid Dynamics J.*, Vol. 4, pp. 29-46, 1995.

[21] Unity, http://unity3d.com (Dec 20, 2015)