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See-Through Medical Examination: Visual Support for Medical Consultation by using Projector-Based Augmented Reality and Thermal markers

Jeremy Bluteau†‡, **Itaru Kitahara**†*, **Yoshinari Kameda**†,
Haruo Noma*, **Kiyoshi Kogure*** and **Yuichi Ohta**†
†University of Tsukuba, 1-1-1 Tennoudai, Tsukuba, Ibaraki, 305-8573, Japan
‡ Universite Joseph Fourier, Domaine Universitaire BP 53, Grenoble, 38041, France
* ATR, 2-2-2 Hikaridai, Keihanna Science City, Kyoto, 619-0288, Japan
{jeremy| kitahara|kameda|ohta}@image.esys.tsukuba.ac.jp, {noma|kogure}@atr.jp

Abstract

This paper presents a system that allows patients and physicians to experience better communication during medical consultations using Augmented Reality (AR) technology. This AR system can superimpose augmentations (i.e., human body components) onto the real patient's body. This annotated information would form the cornerstone for collaborative work between the two actors. We focus on the advantages of projector-based technology and the ARToolKit. Our technique, based on thermal markers (i.e., using human body temperature as a source of information) is used for tracking the location of pain in the patient through the projected augmentations. The second aim of using thermal markers is to protect the patient's privacy. The required calibration method between thermal-camera and projector is also presented. The feasibility of the system is demonstrated through development of a complete application.

Key words: Augmented Reality, Medical Consultation, Collaborative Work, Thermal Marker, Health Science

1. Introduction

In medical consultations, communication is one of the most important factors between a doctor and a patient. In the direction from the patient to the doctor, information about the patient's status must be collected as accurately as possible to construct a precise interpretation of it. In the other direction, the patient must be able to receive comprehensible information to give his informed content without any misunderstanding. In both directions, clear communication is essential. A collaborative work exists based on the patient's body (if we disregard psychological consultations).

Two problems need to be solved. The first is: how can the physician bring medical knowledge and his interpretation in a simple way, even if the patient has no anatomical knowledge? The second problem is: how can the patient explain to the doctor the feelings that are difficult to localize and specify? Theses two main problems are summarized in Fig. 1.

Fig. 1: Difficulty of the communication between patient and doctor

Augmented Reality (AR) has potential to be a convenient tool for human communication that allows the user to see the real world with virtual objects superimposed upon it. AR is based on mixing a live video stream from a camera with computer-generated graphical scene elements [Azu97]. This kind of AR technique is helpful for general medical visualization tasks, mainly in surgical applications [Baj92] [Stat96] [Fuc98] [Goe03], or for training applications [Sie04] [Goe03], however, there does not yet appear to have been approaches proposed that apply collaboration between live video and computer-generated elements. In the fully Virtual Reality world, some experiments have been carried out involving patient and doctor interaction [Joh05], but it is still important to conduct medical examinations on real patients' bodies, because diseased parts will always be with us. On the other hand, if we realized a system that utilizes a patient's body information (e.g., appearance and shape), privacy issues must be carefully considered. People usually do not want to be in hospital, thus they might be quite reluctant to have their personal information taken down without any clear merit.

This paper introduces our trial to provide a prototype system for a see-through medical examination, which is based on AR technology, and that respects patient privacy.

2. See-through medical examination

During the examination, the confidential relationship between patient and doctor must stay strong. However, electronic devices used in AR systems such as Head-Mounted Displays (HMD) or connecting wires makes their communication difficult [Tak02]. To make things worse, it would not be possible to observe the patient torso from the patient's point of view with a HMD. We have tried to find the best solution in regard to this principle of prior relationship.

2.1. Choice of Display device

Computer graphics (CG), which enhance communication between patient and physician, must be visible to both of them. We choose to directly display theses CG images by an LCD video projector onto the patient's body, because HMDs or Hand-Held Displays are not acceptable in regard of image clarity price and the prior relationship between patient and physician. In our study, we consider the human body as nearly flat; therefore projection does not need to be adjusted with respect to patient shape. Furthermore, the projection on the patient's body brings forth new information in the consultation: for example, pain can easily be located. The patient just needs to point out the pain's position on his/her body to display a relation with virtual images. Thus, the physician's explanation becomes more concrete by assimilation. In the case of projection on the anterior of the face around the head, the use of a mirror can be useful.

By employing such a projector-based system, not only the patients themselves, but also accompanying people (e.g., family or friends) can share the same augmented information while the medical consultation proceeds. Although immersion in such a system may exhibit some lack of clarity due to shadows and occlusions, ergonomic, safety and human factors are maintained [Ras01] [Ina00]. Thus, some applications using projection can also be realized, especially in medical research [Tac03].

2.2. Real-time object tracking

We need to accurately estimate the position of the patient in order to superimpose the CG at the correct place. Our tracking system allows the exact position of the patient to be known in the 3D world. Although magnetic tracking devices are accurate, they can interfere with other sensitive medical equipment. Our tracking system, on the other hand, is based on ARToolKit[1] [Bil99]. There are already many practical examples of using this software library in medical applications [Fis04]. The ARToolKit video tracking libraries calculate the real camera position and orientation relative to physical markers in real time. Previous medical researches used ARToolKit, but only on stationary patients (under anesthesia or fixed on structures). In our research, the target can move, and the marker can also be masked temporary by the video projector. Simply adapting the ARToolKit, however, is not enough; we also need to take movement and location estimation errors due to distance (more than 1 meter) in account [Mal02].

2.3. Marker detection in the Projector-Based AR environment

Using a projector has the drawback of the projected data overlapping the ARToolKit marker. This leads to difficulties in detecting the marker with a camera. In conventional projector-based AR systems, ARToolKit markers are placed on the area where the projected objects remain while the system is running [Ash03]. However, in our system it might not be feasible to keep the patient immobile during the medical consultation: it is better to place the marker in the projected area to reduce calibration error.

2.4.Privacy protection

In conventional AR systems, detection of ARToolkit markers is realized by a color video camera. As noted above, the patient may not want to be filmed due to his/her partial nudity or just to preserve his/her own privacy. This issue gives us one of the strongest motivations for finding a solution. It would not be an exaggeration to say that practical application of our system depends on whether we can solve this problem.

2.5.Our proposed solution

The solution not only to solve the detection conflict but also to preserve privacy issue is provided by thermal markers [Kit05], where, instead of using a color video camera and printed AR-Toolkit markers, a thermal video camera and thermal-markers are used. As Fig. 2 shows, the thermal marker is expressed by the temperature difference generated by partially covering the surface of the body with thermal barrier material.

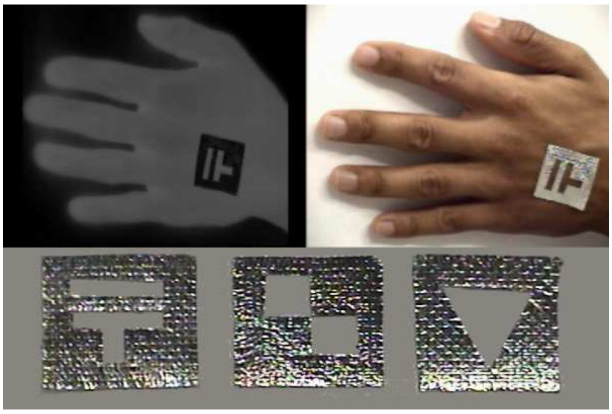

Fig. 2: Top left: thermal video capture of a thermal marker; Top right: Color video capture of the thermal marker; Bottom: Examples of thermal markers for skin

Thermal markers are used for identifying person, but they can also be used to localize a position. As thermal video data are invisible, it is nearly impossible to identify a person in this way. Fig 3 shows how difficult it is to recognize a face on such images. This means the privacy of the patient is totally preserved. Moreover, thermal video cameras are not sensitive to visible light wavelengths so the projector will not interfere with this method of detection.

Fig. 3: Thermal image

Our complete system is illustrated in Fig. 4. The patient, wearing an attached thermal marker, is captured by a thermal camera. A computer generates CG models of organs or body components, calculating the geometric relationship between the camera, the projector and the patient, and projects the CG image onto the patient's body. Finally, the patient can receive a more effective medical consultation by sharing not only his/her external but also internal information with the doctor.

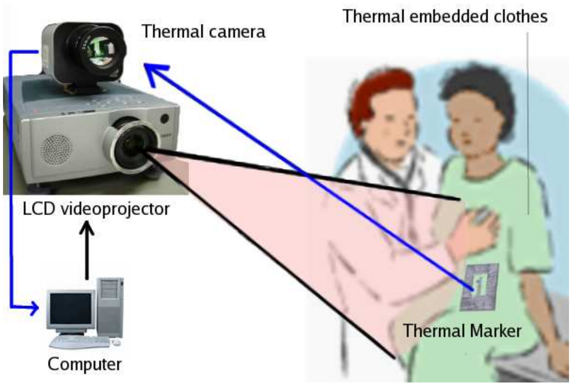

Fig. 4: Overview of see-through medical examination system

3. Theoretical approach

In this section, we describe each developed method to realize our proposed system.

3.1. Thermal recognition

As presented by [Kit05], the ARToolKit assumes the visible light image to be the input information, while we capture and input an infrared image. Since infrared radiation is much weaker than visible light, we preprocess the input infrared image to enhance contrast. Since this filter is applied to gray-scale images, we need to convert it. The gray-scale intensity of pixel (i,j) in RGB is given by Equation (1). This equation is largely used to produce the best quality of gray by reducing the importance of the green value. The NTSC standard for the luminance equation is given in Equation (2).

$$I_{ij} = 0.333 * R + 0.333 * G + 0.333 * B \quad (1)$$

$$I_{ij} = 0.299 * R + 0.587 * G + 0.114 * B \quad (2)$$

A contrast filter stretches the gray levels to obtain optimal repartition. The gray level of a pixel in the output image O is computed from the gray level of the corresponding pixel in the input image I as describe in Equation (3), using I_{max} and I_{min}, the extreme values of input image I.

$$O_{ij} = \frac{I_{ij} - I_{min}}{I_{max} - I_{min}} * 255 \quad (3)$$

Other powerful filters have been tested and have been shown to provide superior recognition results for the ARToolKit's detecting function. The threshold gray levels filter converts the input image to a binary image as described in Equation (5) using Equation (4).

$$t = I_{min} + \frac{I_{min} + I_{max}}{2} \quad (4)$$

$$O_{ij} = \begin{cases} Imin & if I_{ij} < t \\ Imax & othewise \end{cases} \quad (5)$$

3.2. Location estimation error

ARToolKit calculates the position of the camera with precise X- and Y-planar coordinates, though the Z-coordinates are only estimates from the shape and other parameters of the marker. This often leads to a localization error on localization, which affects the global position of the projected computer graphics. Moreover, if no markers are recognized, no position can be given. Consequently, we decided to provide several markers to minimize the probability of visibility loss.

To solve theses problems, we have implemented two different algorithms. First, to minimize the location estimation error that increases with distance, a threshold comparison has been implemented with the following algorithm:

```
// initialize the previous position
if (previous_position == NULL)
    previous_position = (0.0,0.0,0.0);
endif
//test if we need to calculate
if ( abs ( previous_position – current_position)>
threshold)
    previous_position = current_position;
end if
```

```
// display the Computer Graphics at previous_position
displayCG();
```

Then, to improve the lack of marker visibility, we introduce a second algorithm:

```
found = false;
i = 0;
while(not found and i < marker_count)
    if(marker(i) is visible)
            found = true;
            // load marker specific
            // translation constants
            loadMarkerTranslation(i);
    else
            //increment i
            i = i+1;
    end if
end while
// perform threshold algorithm
thresholdAlgorithm();
```

3.3. Format of Computer Graphics

Many anatomical models of different organs are currently being developed, though their formats vary greatly depending on the application field for which they have been designed[1].Thanks to Internet, however, the VRML model is becoming a standard[2]. In its second version, interaction models (manipulation, animation) are beginning to appear. This means that our application can include animation.

3.4. Calibration between a Thermal Camera and a Projector

In ordinary use of the AR-Toolkit, it is not necessary to calibrate the capturing equipment and the displaying equipment (e.g., a color camera and a LCD monitor), because the video capturing and CG projecting processes share an identical coordinate system. However, in our system it is physically not possible to perfectly align both coordinate systems. Therefore, we have to compensate for the difference between the projective geometries of the two sets of equipment with a calibration process. A conventional projector-based augmented-reality system calibrates the relative projective geometry between the capturing and projecting equipment by capturing specific calibration patterns that are projected by a projector [Ash03a]. However, in our system it is not possible to capture the projected calibration patterns, since a thermal camera cannot see visible light. Instead of using the visible calibration pattern, we calculate the calibration with a trial-and-error correction method.

[1]http://www.med.ub.es/~aprats/sae/html-uk/links.htm#galeriaimagenes
http://shape.cs.princeton.edu/search.html
[2]http://www.web3d.org/

In capturing a thermal marker, the relative projective geometries between the thermal camera and the world coordinate determined by AR-Toolkit, are calculated. In the first trial-and-error step, the system projects a CG model onto the captured 3D space while assuming that the video capturing and CG projecting processes share the same coordinate system. As a result, the projected CG model is not correctly mapped onto the real world, as shown in Fig. 5.

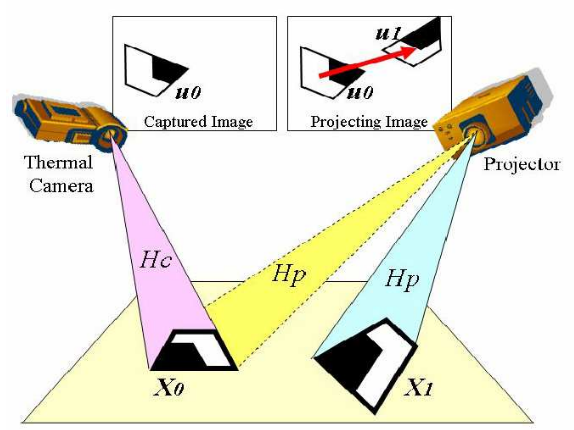

Fig. 5: Trial-and-error correction calibration method

We compensate for the displacement in an error-correction step. A thermal marker *Xo* is observed in *uo* of a captured thermal image, then a projector projects a CG model of the captured thermal marker as if the view volume of a projector and a thermal camera completely overlap. The position of the thermal marker in the projecting image is also *uo*, and the projected marker on the plane in the real world is *X1*. Here, we assume that *X0* and *X1* are coplanar. More precisely, both *X0* and *X1* are on one plane where the height value is zero (*XZ-plane*). By using the corresponding vertices' 2D coordinates of *X0*, *X1* and *uo*, homography projective matrixes are calculated. As illustrated in Fig. 5, the homography matrix between the thermal camera plane and the *XZ-plane* is *Hc*, while that between the projector plane and the *XZ-plane* is *Hp*. The projective transformations are explained in the following equations.

$$X_0 = H_c u_0 \quad (6)$$

$$X_1 = H_p u_0 \quad (7)$$

To compensate for the difference between *X0* and *X1*, the projector has to project the thermal marker onto *X0*. Equation (8) is the equation of the projection.

$$X_0 = H_p u_1 \quad (8)$$

Equation (9) is derived by integrating Eqs. (6) and (8).

$$u_1 = \left(H_p\right)^{-1} H_c u_0 \tag{9}$$

Finally, the displacement between *X0* and *X1* is corrected by transforming the projected image with Equation (9).

As long as we compensate for the displacement by homography projection, it is not possible to calibrate 3D CG objects onto the real 3D world. We can estimate the extrinsic parameters (i.e., position and orientation) of a thermal camera and a projector to decompose projective matrixes, and calibrate the equipments in 3D world with using the extrinsic parameters. However, estimated results might be affected by the observation conditions. On the other hand, our application system aims to display the human components onto the body surface, so, basically, we do not have to align the CG model while maintaining 3D geometric consistency, because it is impossible to map the texture information onto real human organs.

4. Pilot system development

We have implemented a pilot system to demonstrate the feasibility of our proposed see-through medical examination.

4.1. System Specifications

Our system consists of these commercially produced electronic devices:

Table 1: Specifications of Used Equipment

	Specifications
LCD-projector	Canon LV-5100 LCD-projector. Can display images thrown 1.4 to 6.7 meters with brightness of 700 ANSI lumens.
Thermal camera	Avio IR-30 camera for thermal acquisition
Video capture card	Bt878 video capture card for plugging into the thermal camera.
Graphic board	An ATI 3D Rage Pro AGP video card.
Processor	Intel Pentium III (CPU), 1 GHz

The software is written in C/C++ programming language on the Linux platform because the ARToolKit is also written in C. Linux Fedora Core 3 is our operating system.

The thermal markers are shaped by cutting out urethane foam-coated aluminum foil. Their size is 3 cm square. Adhesive material is coated on the reverse side so that the markers can stick to human skin or clothes.

4.2. Implementation of Image filters

Contrast and threshold filters are used to improve the detection rate of markers from a captured thermal video. Detection results from these different filters are shown in Fig. 6, where the gray dispersion levels are clear in the screen shots. The contrast filter stretches the dispersion to cover a larger part of gray spectrum, while the threshold filter summarizes the gray levels. We thus get low gray intensity, which helps the ARToolKit's detection function.

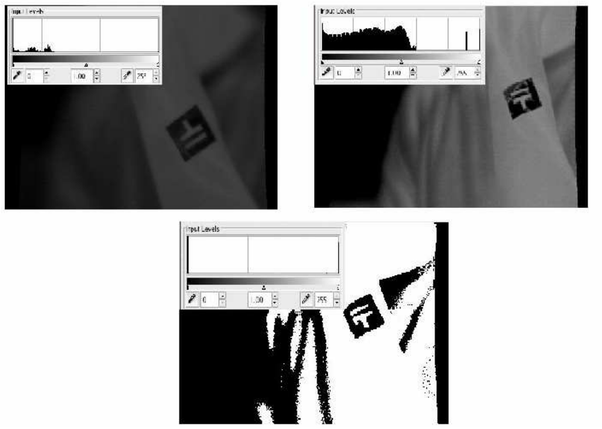

Fig. 6: Left: thermal capture without filter; Right: with contrast filter; Center: with threshold filter.

4.3. Implementation of trial-and-error correction calibration method

In the calibration process it is necessary to project an image onto the patient body at the acquired marker position. At first, the system displays the image where it sees this marker as the trial-and-error step. Then, we correct the position by overlapping the real position with the projected image in the error-correction step. This step is graphically described in Fig. 7, which shows compensation for the displacement of positions between the real marker and the projected one.

Fig. 7: Left: CG overlapping without calibration; Right: with calibration, the real marker and the projected one are overlapping.

4.4. Final results

Experimental results show that our system can overlap different human components onto the patient's body where thermal-markers are placed. The positions are processed to be visible and known by the system. Finally, the system displays images via the LCD-projector at about 10 frames per second with a capture definition of 640x480 pixels in "Full" resolution mode. Comparatively, basic ARToolKit applications have a frame rate of 15 frames per second with our device configuration. Final results are shown in Figs. 8 and 9.

Fig. 8: Overlapping of lung (top) and skeleton torso (bottom) over clothes.

In Fig 8, computer graphics of a torso skeleton and lungs are projected over the patient's clothes. The marker is not visible due to the opacity of the t-shirt. However, our solution allows for the marker to be hidden for a short time. This solution is the best one if the patient does not want to be naked, because his or her privacy is completely maintained.

As Fig. 9 shows, CG of the heart and top of the digestive system are displayed directly onto the patient's skin. The patient's position is given by the adhesive marker fixed on the body. The bottom picture shows that the problem of overlapping the marker with the superimposed CG is solved. The physician can also choose different anatomical layers depending on the depth location of the body components. The patient can then point out the location where the pain is physically located, enabling the physician to give more comprehensible explanations.

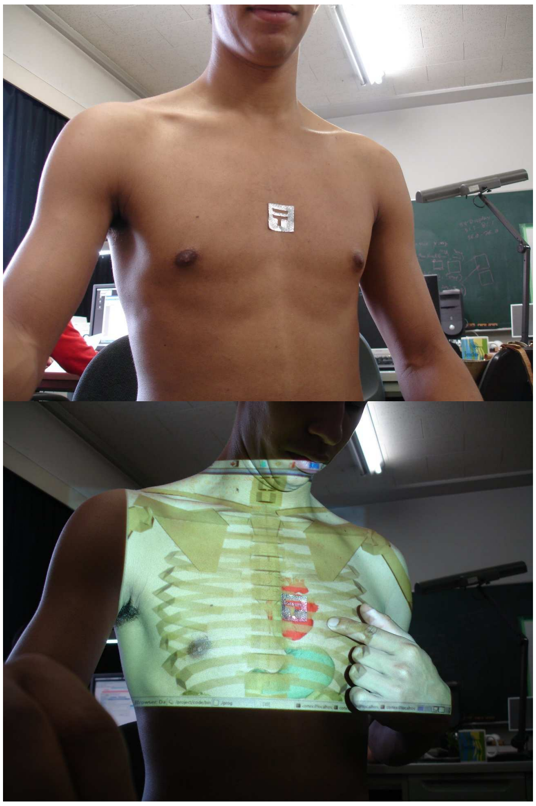

Fig. 9: Marker placement (top); and overlapping of heart and digestive system onto skin (bottom).

5. Conclusion

We have presented a novel approach of using the Augmented Reality (AR) technique for medical applications. Unlike other researched medical systems applying AR, we provide information to increase the collaboration between patient and physician. In fact, our solution is based on relatively cheap devices. Better oriented 3D models, with animation, will improve the usability of the system. In addition, an ergonomic interface is needed to obtain a usable and commercially viable product. We also plan to boost the efficiency of the 3D augmentations by improving the accuracy and reducing the latency of the tracking system. This will lead to an original method for designing AR applications. Our technique needs to be tested further and certified for medical use. Even though the system is still under development, our project's results indicate the system shows great potential for solving many practical problems in medical consultations.

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References

[Azu97] R.T. Azuma: *"A Survey of Augmented Reality."* Presence: Teleoperators and Virtual Environments 6, 4 (August 1997), 355 – 385.

[Ash03] M. Ashdown and P. Robinson: *"Experiences Implementing and Using Personal Projected Displays."* In IEEE International Workshop on Projector-Camera Systems, (Procams 2003).

[Ash03a] M. Ashdown and R. Sukthankar. *"Robust calibration of camera-projector system for multi-planar displays."* Technical Report HP Labs HPL-2003-24, January 2003.

[Baj92] M. Bajura, H. Fuchs, and R. Ohbuchi: *"Merging Virtual Objects with the Real World: Seeing Ultrasound Imagery within the Patient."* In Proceedings of SIGGRAPH '92 (Chicago, IL, July 26-31, 1992). In Computer Graphics 26, #2 (July 1992): 203-210.

[Bil99] M. Billinghurst, H. Kato, S. Weghorst, and T. A. Furness. *"A mixed reality 3d conferencing application."* Technical report, Human Interface Technology Laboratory, University of Washington, 1999.

[Fis04] J. Fischer, M. Neff, D. Freudenstein, and D. Bartz. *"Medical Augmented Reality based on Commercial Image Guided Surgery."* In Eurographics Symposium on Virtual Environments (EGVE), June 2004.

[Fuc98] H. Fuchs, M. Livingston, R. Raskar, D. Colucci, K. Keller, A. State, J. Crawford, P. Rademacher, S. Drake and A. Mayer: *"Augmented reality visualization for laparoscopic surgery."* In Proceedings of Medical Image Computing and Computer-Assisted Intervention '98 (MICCAI '98), volume 1496 of LNCS, pages 934-943, October, 1998.

[Goe03] G. Goebbels, K. Troche, M. Braun, A. Ivanovic, A. Grab, K. von Lübtow, H.F. Zeilhofer, R. Sader, F. Thieringer, K. Albrecht, K. Praxmarer, E. Keeve, N. Hanssen, Z. Krol and F. Hasenbrink: *"Development of an Augmented Reality System for intra-operative navigation in maxillo-facial surgery."* In 2. Jahrestagung des Gesellschaft für Computer-und Roboterassistierte Chirurgie (CURAC), November 2003.

[Gra03] R. Grasset and J.-D. Gascuel. *"Réalité Augmentée et Environnement Collaboratif : Un Tour d'Horizon."* In: "AFIG '03 (Actes des 16èmes journéees de l'AFIG)", December 2003.

[Ina00] M. Inami, N. Kawakami, D. Sekiguchi, Y. Yanagida, T. Maeda and S. Tachi, Visuo-Haptic Display Using Head-Mounted Projector, Proceedings of IEEE Virtual Reality 2000, pp.233-240, 2000.

[Joh05] K. Johnsen, R. Dickerson, A. Raij, B. Lok, J. Jackson, M. Shin, J. Hernandez, A. Stevens and D.S. Lind : *"Experiences in Using Immersive Virtual Characters to Educate Medical Communication Skills."* In Proceedings of IEEE Virtual Reality 2005 (VR 2005).

[Kit05] I. Kitahara, M. Ito, H. Noma, K. Kogure and N. Hagita, *"Thermal-ID: A Personal Identification Method Using Body Temperature."* Adjunct Proc. of The 3rd International Conference on Pervasive Computing (Pervasive 2005) Advances in Pervasive Computing, pp. 69-72.

[Mal02] P. Malbezin, W. Piekarski and B. Thomas: *"Measuring ARToolkit accuracy in long-distance tracking experiments."* In: 1st Int'l AR Toolkit Workshop. (2002).

[Ras01] R. Raskar, G. Welch, K.L. Low and D. Bandyopadhyay: *"Shader Lamps: Animating Real Objects with Image Based Illumination"*, Eurographics Workshop on Rendering, June 2001.

[Sie04] T. Sielhorst, T. Obst, R. Burgkart, R. Riener and N. Navab. *"An augmented reality delivery simulator for medical training."* In International Workshop on Augmented Environments for Medical Imaging - MICCAI Satellite Workshop, 2004.

[Stat96] A. State, M. Livingston, G. Hirota, W. Garrett, M. Whitton, H. Fuchs and E. Pisano *"Technologies for Augmented-Reality Systems: realizing Ultrasound-Guided Needle Biopsies."* In Proceedings of SIGGRAPH '96 (New Orleans, LA, August 4-9, 1996). In Computer Graphics Proceedings, Annual Conference Series, 1996, ACM SIGGRAPH, 439-446.

[Tac03] S. Tachi, *"Telexistence and Retro-reflective Projection Technology (RPT),"* Proceedings of the 5th Virtual Reality International Conference (VRIC2003) pp. 69/1-69/9, Laval Virtual 2003, France, May 13-18, 2003.

[Tak02] M. Takemura,Y. Ohta,*"Diminishing Head-Mounted Display for Shared Mixed Reality,"* IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR 2002), pp. 149-156. Oct. 2002.