

Visual Support for Medical Communication by Using Projector-Based Augmented Reality and Thermal Markers

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Abstract

This paper presents a system that allows patients and physicians to experience better communication during medical consultations using Augmented Reality (AR) technology. The AR system can superimpose augmentations (i.e., human body components) onto the real patient's body, and such annotated information serves to form the cornerstone for collaborative work between the two actors. We focus on the advantages of projector-based technology and 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 system's feasibility is demonstrated through development of a complete application.

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

1. Introduction

In medical consultations, communication is one of the most important issues 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 consent without any misunderstanding; in both directions, clear communication is essential. This means that 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? These two problems are summarized in Fig. 1.

Another serious problem concerns rehabilitation exercises for patients with artificial joints that join displaced bones, where the joint's range of movement is misunderstood. Even though the patients might work hard to rehabilitate themselves, daily progress is usually small, and as a result it is difficult to notice its effectiveness. Consequently, patients often struggle to maintain their motivation since rehabilitation exercises require great mental strength. If patients can visualize the condition of their body, for example the hip, knee and shoulder bones, with their own eyes, they will become more acutely aware of the performance limitations to their joint movements, thereby reducing the problem of joint dislocation. If patient can compare himself with his old self who had not undertaken any rehabilitation in a few days ago, it is quite easy to realize the progress brought by rehabilitation exercises.



Fig. 1: Difficulty of communication between patient and doctor

Augmented Reality (AR) has the 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 com-

puter-generated elements. In a fully Virtual Reality world, some experiments have been carried out involving patient and doctor interaction [Joh05], but it is still important to conduct medical communication on real patients' bodies because diseased parts will always be with us.

On the other hand, if we do realize a system that utilizes a patient's body information (e.g., appearance and shape), privacy issues must be carefully considered. Most people usually do not want to be in hospital, thus they might be quite reluctant to have their personal information collected without any clear merit.

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

2. Visual support for medical communication

2.1. Choice of Display device

During communication, 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 effective 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 an HMD. We have been working to find the best solution in regard to this principle of prior relationship.

Computer graphics (CG) for enhancing communication between patient and physician must be visible to both of them. We choose to directly display these CG images using an LCD video projector onto the patient's body, because HMDs or Hand-Held Displays are not acceptable in regard to image clarity and the prior relationship between patient and physician.

In our study, we consider the human body to be an almost flat surface; therefore, the 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.

Such a projector-based system enables not only the patients themselves, but also accompanying people (e.g., family or friends), to share the same augmented information while the medical consultation proceeds. Although immersion in such a system may result in 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

To superimpose the CG at the correct place, we need to accurately estimate the patient's position. Our tracking system allows the exact position of the patient to be known in the 3D world. Magnetic tracking devices, although accurate, can interfere with other sensitive medical equipment, whereas our tracking system operates based on ARToolKit¹ [Bil99], which does not produce any harmful effects on medical instruments, since the required input information is a video stream that can be extracted in a completely passive way. 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 studies have 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 temporarily by the video projector. Simply adapting the ARToolKit, however, is not enough; we also need to take into account movement and location estimation errors due to distance (more than 1 m) [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.

¹ <http://www.hitl.washington.edu/artoolkit/>

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 ARToolkit 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. The thermal video camera employed in our proposed system observes far-infrared radiation (heat rays). In the field of medicine, this kind of observation system is called thermography, and it is already widely used, which means it is not difficult to install the camera system into the current medical environment.

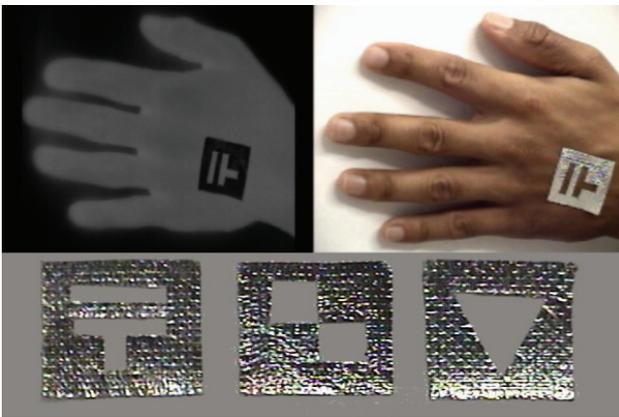


Fig. 2: Top left: thermal video capture of a thermal marker; Top right: Color video capture of the thermal marker; Bottom: Examples of thermal markers for skin

Thermal markers are used for identifying individuals, but they can also be used to localize a position, though because thermal video data are invisible, it is nearly impossible to identify a person in this way. Figure 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.

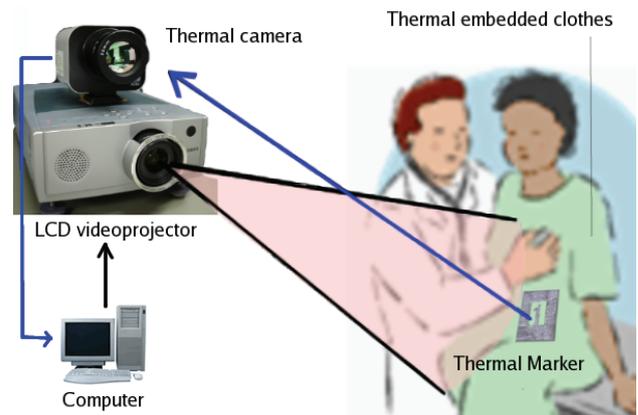


Fig. 4: Overview of see-through medical communication system

3. Theoretical approach

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

3.1. Thermal Marker

The two-dimensional barcode, typified by QR code, is a well known medium [QR]. The two-dimensional barcode is described with a fine black and white waffle pattern. However, since the infrared radiation the system uses is much weaker than visible light, it is difficult to scan such fine patterns in thermal images. Our system

expresses identifying information using the ARToolkit. With this toolkit the user can arbitrarily set the size of a two-dimensional marker to correspond to the resolution of the capturing infrared camera. Since the toolkit can handle such scannable characters as a two-dimensional marker (e.g., alphabetical character, digit, or symbol), it has another merit in that users can easily monitor the operation on their own.

As shown in Fig. 2, the two-dimensional Thermal markers are shaped by cutting out urethane foam-coated aluminum foil patterns. We place the cutout foil on the human body to block off bodily heat, producing a temperature difference between the covered region and uncovered region, and this difference causes changes in the intensities in the captured infrared image. The system extracts the subject's identification information to determine the two-dimensional marker's identity using the changes in intensity.

3.2. Recognition Thermal Marker

The ARToolKit provides a function to detect the two-dimensional marker from the input image. With this function it is possible to automatically extract the identification information. However, our proposed method still has a problem; the ARToolkit assumes the visible light image to be the input information. On the other hand, our method captures and inputs the infrared image as the input. Since infrared radiation is much weaker than visible light, the contrast ratio between the region of the marker and the region of the body surface might not be enough for ARToolKit's detecting function. We solve this problem by preprocessing the input infrared image to enhance contrast.

When detecting the two-dimensional Thermal-ID marker, the contrast of the foreground region is more important than that of the background. We enhance the contrast of only the foreground region with the following steps. (1) Segment the input image into foreground and background regions. In our proposed method, the capturing camera is assumed to fix on the environment. Therefore, a background subtraction operation is valid. (2) Survey all pixel values in the foreground region to detect the maximum value I_{max} and the minimum value I_{min} . (3) Enhance the contrast of the foreground region to calculate the normalized pixel values I from I_{org} with Eq. (1). In this case, we express the pixel value with an 8-bit gray-scale.

$$I = (I_{org} - I_{min}) \times \left(\frac{255}{I_{max} - I_{min}} \right) \quad (1)$$

3.3. Location estimation error

ARToolKit calculates the camera's position 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, which affects the global position of the projected com-

puter 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 these 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();
```

3.4. 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 designed². Thanks to the Internet, however, the VRML model is becoming a standard³. In its second version, interaction models (manipulation, animation) are beginning to appear. This means that our application can include animation.

² <http://www.med.ub.es/~aprats/sae/html-uk/links.htm#galeriainagenes>
<http://shape.cs.princeton.edu/search.html>

³ <http://www.web3d.org/>

3.5. Calibration between a Thermal Camera and a Projector

In ordinary use of ARToolKit, it is not necessary to calibrate the capturing equipment nor 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.

In capturing a thermal marker, the relative projective geometries between the thermal camera and the world coordinate determined by ARToolKit 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.

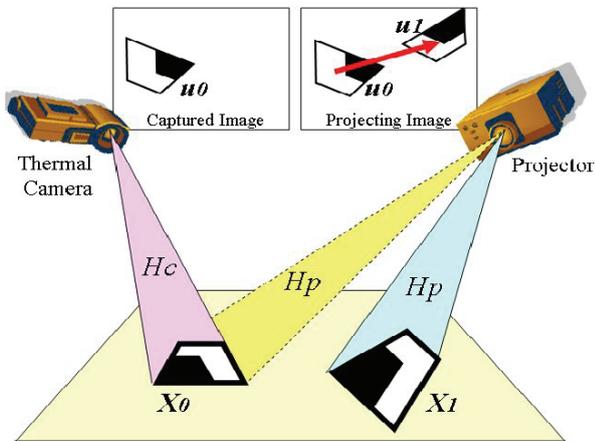


Fig. 5: Trial-and-error correction calibration method

We compensate for the displacement in an error-correction step. A thermal marker X_0 is observed in u_0 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 u_0 , and the projected marker on the plane in the real world is X_1 . Here, we assume that X_0 and X_1 are coplanar. More precisely, both X_0 and X_1 are on one plane where the height value is zero (XZ -plane). By using the corresponding vertices' 2D coordinates of X_0 , X_1 and u_0 , homography projective matrixes are cal-

culated. As illustrated in Fig. 5, the homography matrix between the thermal camera plane and the XZ -plane is H_c , while that between the projector plane and the XZ -plane is H_p . The projective transformations are explained in the following equations.

$$X_0 = H_c u_0 \quad (2)$$

$$X_1 = H_p u_0 \quad (3)$$

To compensate for the difference between X_0 and X_1 , the projector has to project the thermal marker onto X_0 . Equation (4) is the equation of the projection.

$$X_0 = H_p u_1 \quad (4)$$

Equation (5) is derived by integrating Eqs. (2) and (4).

$$u_1 = (H_p)^{-1} H_c u_0 \quad (5)$$

Finally, the displacement between X_0 and X_1 is corrected by transforming the projected image with Eq. (5).

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 the 3D world 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 communication.

4.1. System Specifications

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, measuring, 3 cm x 3 cm, are shaped by cutting out urethane foam-coated aluminum foil. Adhesive material is coated on the reverse side so

that the markers can stick to human skin or clothes.

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

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 the gray spectrum, while the threshold filter summarizes the gray levels. We thus obtain a low gray intensity, which assists the ARToolKit's detection function.



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



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

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

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

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. These 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 640 x 480 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.

Figure 8 shows computer graphics of a torso skeleton and lungs 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.



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

As Fig. 9 shows, a CG of the heart and top of the digestive system is displayed directly onto the patient's skin, with the patient's position 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 of the body components in question. The patient can then point out the location where the pain is physically located, enabling the physician to give more comprehensible explanations.

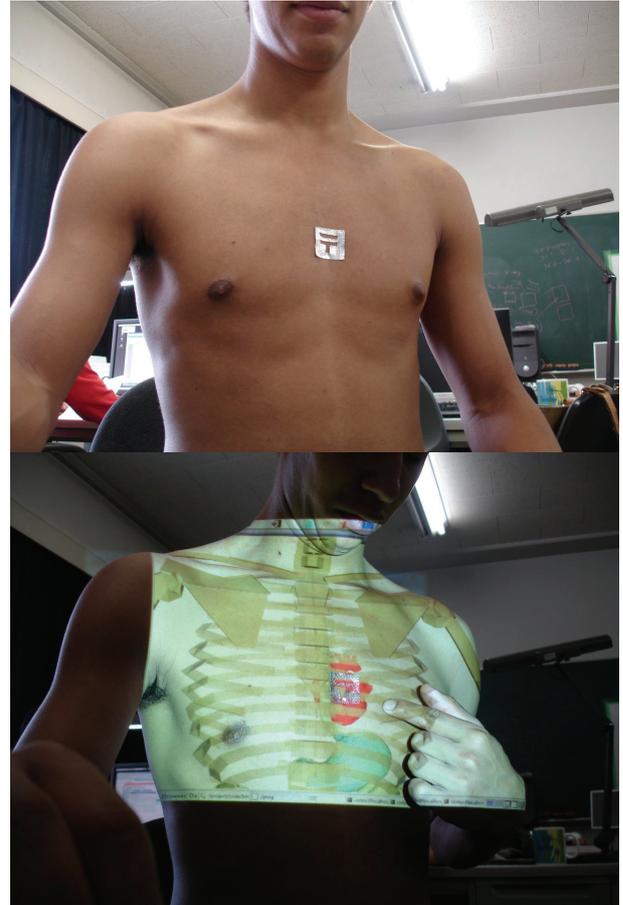


Fig. 9: Marker placement (top); and overlapping of heart and digestive system onto skin (bottom).

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 it shows great potential for solving many practical problems in medical consultations.

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