University of Tsukuba, Japan
at Computer Vision and Image Media Laboratory

Bluteau Jeremy
Information Technologies for Health
Technologies de l'Information pour la Santé

Internship report - 4th year

Augmented Reality and Collaborative Work in Patient-Physician relationship

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with appendices

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French Résumé

Ce rapport présente les résultats d'un stage de seconde année d'école d'ingénieur Polytech'Grenoble, département Technologies de l'Information pour la Santé. Ce stage de trois mois, a été réalisé à l'université de Tsukuba, au Japon. Il expose l'emploi de la Réalité Augmentée (AR) pour améliorer la communication lors d'une consultation médicale. Notre système de réalité augmentée peut projeter de nouvelles informations (i.e. des composants du corps humain) directement sur le corps du patient, tout en préservant son intimité. Ces informations sont la base d'un travail collaboratif entre patient et médecin. Nous nous focalisons sur les avantages d'un système à base de video projecteur et de marqueurs thermiques (i.e. en utilisant la température corporelle comme source d'information). Les aspects théoriques et techniques engagés dans ce projet seront présentés. La faisabilité du système est démontrée à travers le development d'une application logicielle. La publication en relation avec ce projet est aussi présentée.

Acknowledgment

No work comes into being without special roles of many people.
First, I'd like to thank Pr. Ohta, coordinator of the Laboratory of Computer Vision and Image Media, for the reception in his laboratory. For all people of my university and university of Tsukuba who help me to realize this internship at the other side of the World, I give my thanks : Gheeraert Etienne, Akimoto Katsuhiro, Duhamel Brice, Tabuteau Angélique, Calabrese, Pascale, Neau Frederique, Jambon Francis and Baconnier Pierre.
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Glossary

3D : *three-dimensional* - is often related to a stereoscopic display that exploits binocular vision. Three-dimensional objects have volume and may be measured and described using three orthogonal directions.

AR : *Augmented Reality* - is a field of computer research which deals with the combination of real world and computer generated data. At present, most AR research is concerned with the use of live video imagery which is digitally processed and "augmented" by the addition of computer generated graphics. Advanced research includes the use of motion tracking data, fiducial marker recognition using machine vision, and the construction of controlled environments containing any number of sensors and actuators

CG : *Computer Graphics* - is the field of visual computing, where one utilizes computers both to generate visual images synthetically and to integrate or alter visual and spatial information sampled from the real world. This field can be divided into several areas: real-time 3D rendering (often used in video games), computer animation, video capture and video creation rendering, special effects editing (often used for movies and television), image editing, and modeling (often used for engineering and medical purposes). Development in computer graphics was first fueled by academic interests and government sponsorship.

GANTT chart : *GANTT chart* - is a popular type of bar chart, showing the interrelationships of how projects, schedules, and other time-related systems progress over time. In project management, a GANTT chart can show when the project terminal elements start and finish, summary elements (shown) or terminal element dependencies (not shown).

HHD : *Hand Held Display* - is a small portable device that can display information. Cellular phone or PDA are HHD.

HMD : *Head Mounted Display* - is a device that one wears on one's head to have video information directly displayed in front of one's eyes. HMDs are often used for simulating virtual reality environments.

LCD projector : *Liquid Cristal Display projector* - is a device for giving presentations generated on a computer. They are the modern equivalent to the slide projector and overhead projector used in the past. LCD projectors place a small LCD panel, almost always color, in front of a bright lamp, with the imagery on the LCD being provided by an attached computer or other video source. LCD projectors tend to be smaller and much more portable than older systems.

PDA : *Personal Digital Assistant* – is hand held device that was originally designed as personal organizers, but became much more versatile over the years. One major advantage of using PDAs is their ability to synchronize data with desktop, laptop and other computers.

Introduction

I have performed a three months internship in Japan, as a part of my fourth year of *Information Technologies for Health* formation.

First, I will expose the context of my internship. After a short presentation of Japan, I will present the University of Tsukuba. Finally, I will introduce the Computer Vision and Image Media laboratory, where I accomplished this internship.

Project's context

Information Technologies for Health Department (TIS) is a part of Polytech'Grenoble, the engineering School (French “Grande Ecole”) of the Joseph Fourier university in France. The knowledges acquired comes from three categories : computing, instrumentation and measurements, and biology and medical sciences. Engineering for the Health sector is an emerging field. The engineer must have a central role between the health world and the computing and instrumentation world. As one objective of this formation is the practice of technical knowledges, students undertake two company (or laboratory) internships. One at the end of the fourth year, the other at the end of the fifth year.

This internship belongs to the first category, and may validate my fourth year in TIS department. The project of my internship include aspects of biological and medical sciences, augmented by the use of software engineering and development. Moreover, to develop and promote relationships on international market, this project was conducted in Japan. The choice of Japan is vigorously correlated to advance technologies of this country.

Japan and Medical Applications

Japan (in Japanese *Nihon* or *Nippon* , 日本 - stand for sun/day and root - country of rising sun) is an est-Asian country (Fig. 1). Japan is a volcanic archipelago incorporated by several thousand small islands between the Pacific Ocean and the Japan see. Japan consist of four main islands, Kyûshu, Shikoku, Hokkaidô and Honshû. This last one, is the biggest, on which are the cities of Nagoya, Kyoto, Ōsaka and Tokyo (東京). Tokyo is now the biggest town in the world (with more than 30 million inhabitants in 2002 if we include Yokohama and Kawasaki). At the top of advance technologies, this town has a developed economy, even it's remains the same currently.

Fig. 1 - Map of Japan

Medical and Health sector are not kept down from this movement. Main distributors for health systems comes from Japan, and lost of researches are provided in this country.

University of Tsukuba

Tsukuba (つくば市) is a planned city located about 60 km north-est far from Tokyo. The city was founded on November 30, 1987 as a "Science City". It is home to more than 60 research institutes, including the University of Tsukuba, the KEK high-energy research center, and the main research center of the JAXA (ex-NASDA) space agency. Mount Tsukuba, particularly well-known for its toad-shaped Shinto shrine, is located near the city.

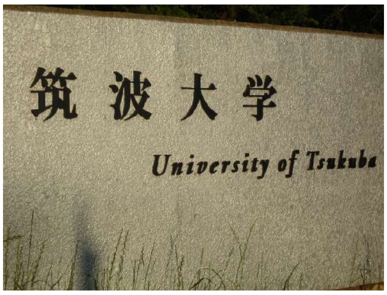

Fig. 2 - Entrance stone of the University of Tsukuba

The University of Tsukuba (Fig. 2) has vocation not only to emphasize education but also to encourage research since its foundation. Because faculty do not belong to an educational system but to a research system, it is assured of being able to conduct interdisciplinary researches. Not only faculty but also graduate students figure prominently in research. Since the foundation of the university, graduate schools have maintained two parallels graduate programs: master's programs to create professionals with academic and technical expertise; and consecutive 5-year doctoral programs to create independent researchers. This University provide not only scientific courses or researches. Range of studies in the University of Tsukuba is quite large, from Medical Science to Art Design or Sport. International exchanges in every fields improves the level of learning, enriches education and trains people to have a more international outlook. The University of Tsukuba accept foreign professors, conducts exchange programs with foreign universities and actively encourage foreign inbounds (about 570 foreign professors and 550 foreign student in 2004).

Computer Vision and Image Media Laboratory

This laboratory is a part the College of Information Sciences. It caters undergraduated and graduated students who want to acquire knowledge and skills in the specific area of computer vision and Image media. Projection on curve screen by several projectors, getting information from several video surveillance cameras, improving new algorithms for computer vision, augmented reality applied for helping drivers in crossroads or guiding users in an unknown environment are some examples of researches conducted in this laboratory. Even if this laboratory do not have a specific medical or health domain, the technologies handled in this laboratory can directly find an application in these sectors. As well, video capture systems are used in laparoscopic explorations, Augmented Reality (AR) technologies are employed in very new research in medicine. My internship is a good opportunity to apply these techniques for health and knowledges can be brought mutually.

Report scheme

First, the presentation of the subject of my internship, with problematics and objectives, will be described. Methodologies of management for this project will be founded in the second part of this report. All mains aspect of the project management will be exposed in this passage. Then, the system will be described in details, with innovations of this work. Others encountered problems would be the highlight point of the next subdivision. This section will deals with several different difficulties and their solutions. Finally, the results of this internship will be provided in the last section of this report.

Subject Presentation

Problematics of my Internship

The way of practicing medicine has steadily evolved for about an half century. About 60 years ago, the physician decided almost alone of the treatment of his patient (Fig. 3). The patient had to trust in his doctor. Since, engineering for health has made a lot of progress in order to lead the doctor to a good diagnosis. Actually, it's possible to provide a surgery with more accuracy than ever (Fig. 4). Researches continue in this way, by providing more and more ergonomics solutions (Fig. 5) [Fis04][Fuc98][Goe03].

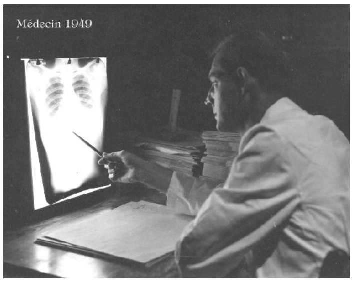

Fig. 3 - Physician in 1949

Fig. 4 - Computer Guided surgery
(http://www.praxim-medivision.com/)

But in most of current 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 consent without any misunderstanding. Thus, actual laws give the responsibility of collecting this informed consent to physicians. Some software help to provide such kind of knowledges[1]. In both directions, clear communication is essential. A collaborative work exists based on the patient's body (if we unaware 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 ? (Fig. 6).

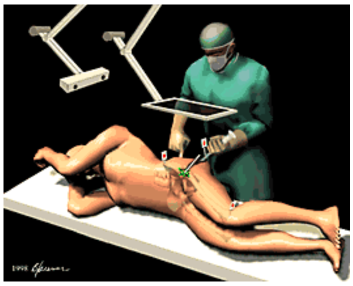

Fig. 5 - Future in surgery
(http://www.mrcas.ri.cmu.edu/)

Fig. 6 - Difficulty of the communication between patient and physician

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 AR technologies for collaborative work in medicine [Gra03]. In the fully Virtual Reality world, some experiments have been carried out involving patient and doctor interaction [Joh05], but they have only a training goal for new physicians.

1http://www.natom.com/

I tried to adapt AR technologies to solve these two problems and then, simplifying the communication between physician and patient by providing the “physician vision” to the patient. To realize this system, we used the patient's body information (i.e. appearance and shape) to display at the right place anatomic augmentations. Privacy issues must be carefully considered. People might be quite reluctant to have their personal information taken down without any clear merit, even his medical secret exists. Thanks to the laboratory, I had the opportunity to design by myself this subject.

Objectives

The objective of this internship is to produce a collaborative work system, using AR technologies, and provide augmentations (e.g. models of organs, bones, vessels,...) for the patient and the physician, in real time, without disturbing the current prior relationship.

As the term of this stage was quite short, these objectives were split in two main steps. First was to get a video of the patient, to get models of organs from web-database or patient's X-Ray images, to generate augmentations from these data and then, display the augmented images on the computer screen. This first step is presented in Fig. 7.

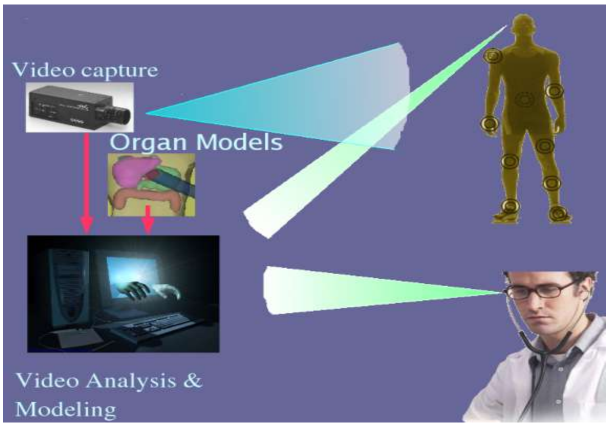

Fig. 7 - Overview of “On screen” configuration.

To increase the efficiency of AR, the results of augmentations could be projected on the patient body. The patient see directly on his skin, the components of his body. It is, then, a powerful way to understand the physician explanations by assimilation with the localization. On another side, the pain could easily be located. The figure 8 below, present an overview of this step. This phase require to solve a lot of new problems such as calibration between projector and video capture. As this step is time consuming, it was not included in the project management schedule at the beginning.

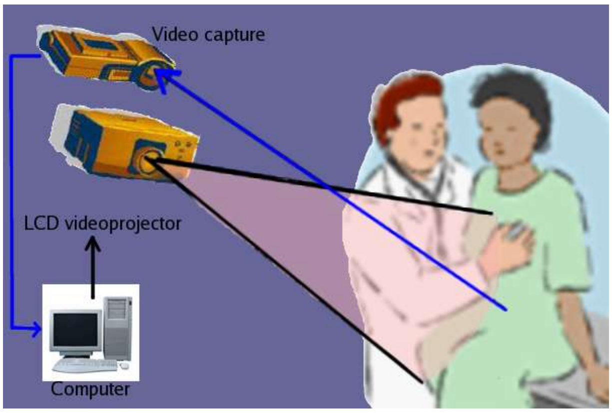

Fig. 8 - Overview of projector-based configuration.

Another objective on the entire project is to keep the privacy of the patient. The patient may not want to be filmed due to his/her partial nudity or just to preserve his/her own privacy.
This report presents a prototype system for a see-through medical examination, which is based on AR technology, and that respects patient privacy.

At least, one other major objective of this internship was to discover the Japanese culture and way of working. I have tried to impregnate myself by this environment by visiting lot of different places and seeing lot of peoples in Japan (cf appendices C).

Methodologies and steps in work : Project management

Management of a project determines its feasibility and its proceeding. The definition and respect of the project management schedule conduct project to its end or not. The main goal of this tool is to predict and help performing all steps, and also recognize all unforeseeable tasks.

GANTT chart

As this project did not involve many people, the methodology applied was simple. In bigger project, it would have been more complex. The schedule of the project was defined in a GANTT chart. The first definition of project tasks is sum up in table 1. This schedule is closely correlated with used technologies, presented in section *"System Overview"*.

Table 1. Initial project Tasks

WBS	Name	Start	Finish	Work
1	Arrival	May 10	May 11	1d 6h
2	Subject Specification	May 11	May 13	1d 6h
3	Meeting for completion of project agreement	May 20	May 20	
4	Understanding Camera behavior	May 13	May 20	4d 3h
5	Understanding AR Toolkit and OpenGL	May 13	May 20	4d 3h
6	Programming Localization of Patient	May 20	Jun 3	8d 6h
7	Research the Organ Database	Jun 3	Jun 10	4d 3h
8	Organ Overlay	Jun 10	Jul 1	13d 1h
9	Back ending of the project	Jul 1	Jul 15	8d 6h
10	Report Writing	Jul 1	Jul 15	8d 6h
11	Realization of oral presentation	Jul 15	Jul 22	4d 3h
12	Oral Presentation	Jul 22	Jul 22	
13	Departure	Jul 22	Jul 29	4d 3h

These tasks are organized as presented in the following GANTT chart below (Fig. 9).

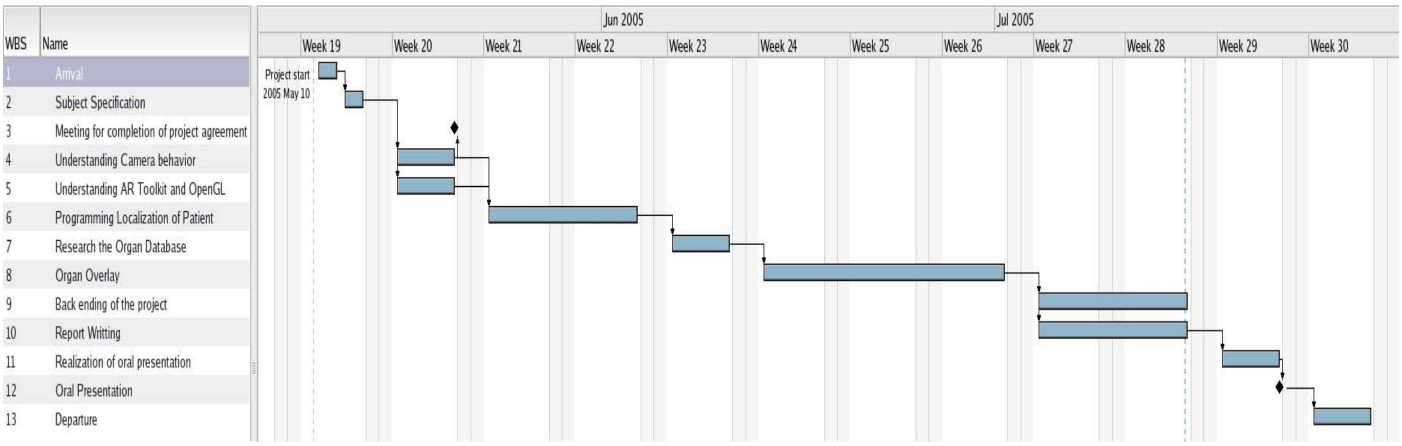

Fig. 9 - GANTT chart, first definition.

During the project, this schedule has change to integrate some modifications. The number of task increased, including the redaction of a publication (cf appendices) and the implementation of the second objective of the project (i.e. projecting augmentations onto the patient's skin). This change occurs on June, 17th in week 24, at about an half of the project. This adaptation appears because the first objective of the project was achieved. New tasks are shown in table 1 below.

Table 1. Final project Tasks

WBS	Name	Start	Finish	Work
1	Arrival	May 10	May 11	1d 6h
2	Subject Specification	May 11	May 13	1d 6h
3	Meeting for completion of project agreement	May 20	May 20	
4	Understanding Camera behavior	May 13	May 20	4d 3h
5	Understanding AR Toolkit and OpenGL	May 13	May 20	4d 3h
6	Programming Localization of Patient	May 20	Jun 3	8d 6h
7	Research the Organ Database	Jun 3	Jun 10	4d 3h
8	Presentation of Research Subject to the Lab	Jun 7	Jun 7	
9	checkpoint with Professor	Jun 17	Jun 17	
10	Industrial Virtual Reality Expo	Jun 24	Jun 24	
11	Implement use of Thermal detection	Jun 20	Jul 1	8d 6h
12	Writing a paper for ICAT2005	Jun 20	Jul 7	12d 2h
13	Paper submission for ICAT2005	Jul 8	Jul 8	
14	Organ Overlay	Jun 10	Jul 1	13d 1h
15	Back ending of the project	Jul 1	Jul 13	7d
16	Report Writing	Jul 1	Jul 15	8d 6h
17	Realization of oral presentation	Jul 15	Jul 22	3d 6h
18	Seminar	Jul 22	Jul 24	2d 5h
19	Oral Presentation for the Lab	Jul 26	Jul 26	
20	Departure	Jul 27	Jul 27	

The new tasks arrangement is shown in Fig. 10 (a real size copy of this chart is available in appendices C). The progression of each task can be evaluated and displayed in the GANTT chart for illustrate the progression of the project. For example, we can see that the writing of the report has been delayed by about one week, due to highest priority given to the redaction of the publication.

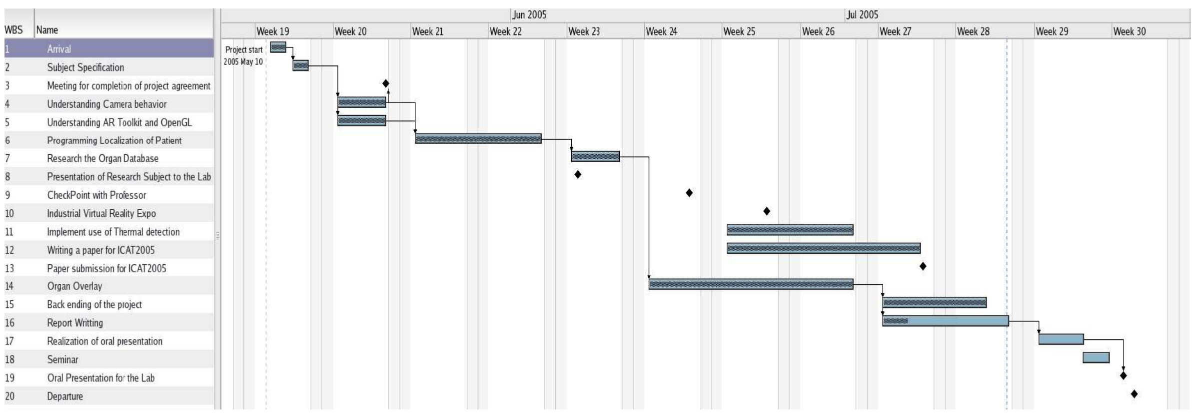

Fig. 10 - GANTT chart, final definition.

Files Management

Files management is one of the technical part of project management which bring some concrete solutions for the safety of the project. As computer are often subject to crash or data loss, all the project files (i.e. source code, documentation, presentations, images,...) are managed under a concurrent version system (CVS). This system keep and administrate, on a central server, an unique version of a project. It gives the possibility to restore previous version of these files.

Website

Providing information to all intervenors is also a crucial point in a project. These news are given by two specific ways : the mail for all the important and non preemptive task, and a website. The choice of these solutions was given by practices of the laboratory and by the distance (i.e. time zone differential and different schedule) of each intervenors. This website broadcasts some crucial information like progression in the project, encountered problems and their solutions, but also results. This website was updated twice a week during the project. A screen shot of the website is illustrated in Fig. 11.

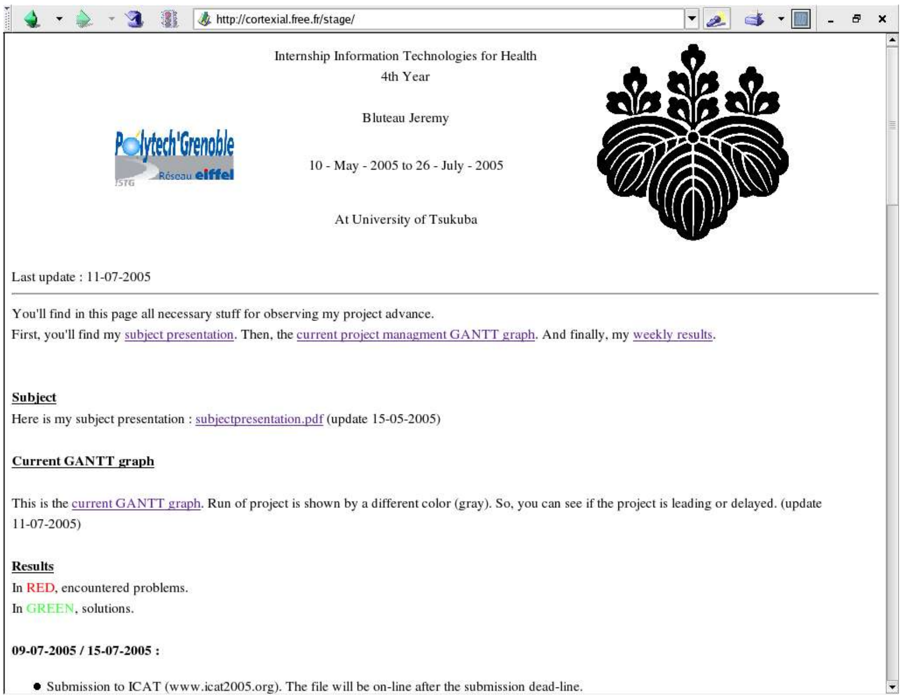

Fig. 11 - Screen shot of the website used for broadcasting information.

System overview

In this section, the hardware and software components of the system are described. It is composed of the following hardware components :

- Personal Computer (PC) under Linux – Intel Pentium III, 1GHz (Processor)
- Graphic board - ATI 3D RAGE Pro AGP Video card
- Video capture card - Bt878
- Color Camera – Sony EVI-D100
- Thermal camera – AVIO IR-30
- LCD Projector – Canon LV-5100 , 700 ANSI Lumens for 1.4 to 6.7 meters
- Thermal marker shaped by cutting out urethane foam-coated aluminum foil.

Our complex can use color video camera with printed markers OR thermal camera, with thermal markers and LCD projector. The choice of the devices depends on the display way for augmentations (i.e. on the computer screen or on the skin of the patient). The system, which display augmentations on the patient's skin or patient's clothes, is shown in Fig. 12. The patient, wearing an attached thermal marker, is captured by a thermal camera. A computer generates Computer Graphics (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, directly on his/her body.

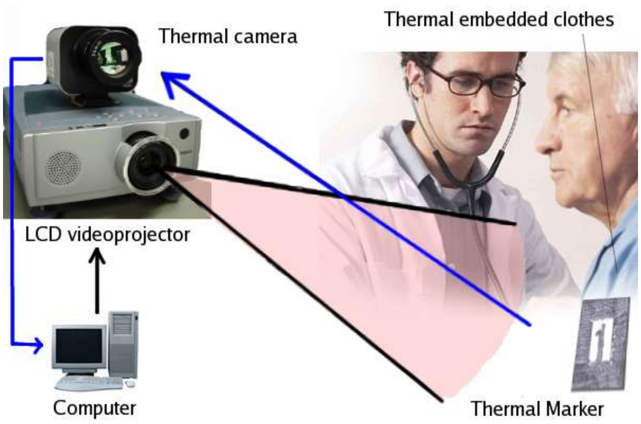

Fig. 12 - Layout of full projected-based system.

Following software components are involved in our system :

- ARToolKit
- Texture Loading class from Damiano Vitulli (www.spacesimulator.net, 2002)
- Font display class from Soji Yamakawa (http://homepage3.nifty.com/ysflight/uglyfont/uglyfonte.html, 2005)
- Access functions to a SONY EVI camera from Pic Mickael, (AIST Japan, 2002).

Those components are described in more detail in the following sections.

Computer configuration

The choice for computer hardware configuration is correlated with the devices involved in the system. Only the Operating System (OS) (i.e. Linux) was preferred by the laboratory for homogeneity. For plugging the color camera and the thermal camera, a video capture card was needed, we choose a Bt878 video capture which is a common one.
As our system requires 3D calculations, a 1GHz processor, with ATI 3D RAGE Pro video card has been chosen. These components could be replaced by equivalent system.

Display system for augmentations

Computer Graphics (CG), which enhance communication between patient and physician, must be visible to both of them. Thus, patient-physician privileged relationship must stay strong. AR technologies often use Head Mount Display (HMD) or Hand Held Display (HHD) to increase the integration of augmentations [Azu97]. A HMD is a device that one wears on one's head to have video information displayed in front of eyes. Lots of device like Portable Digital Assistant (PDA) or cellular phone belong to the second category. Even if theses techniques are powerful for AR, they are not adapted to a medical consultation context. HMD need lots of wires and simple things like observing your own torso via this device won't be possible, due to its weight and its shape. HHD are generally very small, old people or children will not be capable to use them. Thus, they need some learning to handle.
We choose to display these CG by a LCD video projector onto the patient's body or patient's clothes. The projection onto the patient brings new information in the consultation : the patient just need to point out the pain’s position on his/her body to display a relationship with virtual images. By employing such a projector-based system, not only the patients themselves, but also accompanying people (i.e. 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 projector-based system exist in medical research [Tac03]. In our project, we consider the human body as nearly flat; therefore projection will not exactly fit the patient body, but its shape. In the case of projection on the anterior face especially around the head, the use of a mirror can be useful.

Tracking system : ARToolKit

In the context of a real consultation, we need to accurately estimate the position of the patient in order to superimpose the CG at the correct place. Although magnetic tracking devices are accurate, they can interfere with other sensitive medical equipment. Our tracking system is based on ARToolKit [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 (Fig. 13). It is written in C/C++.

Previous medical researches used ARToolKit, but only on stationary patients (under anesthesia or fixed on structures). In our project, the target (i.e. patient) can move.

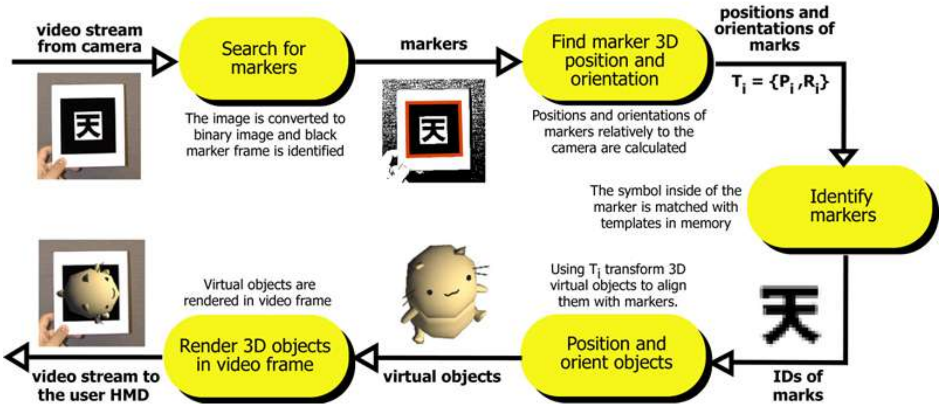

Fig. 13 - ARToolKit's steps to perform marker tracking in real time.
(http://www.hitl.washington.edu/artoolkit/)

In addition, the use of color video camera in pair with an LCD-projector do not allow the ARToolKit to detect the marker. Examples of this conflict are demonstrated in figures 14 and 15. Figure 14, demonstrates how projected computer graphics can disturb the vision of the camera. The projected image overlap the marker and then, the captured image will not have any recognized marker.

The second example, in figure 15 shows the difficulty of finding the “right” marker if we project a similar virtual object. The ARToolKit, as our eye, recognize the two markers as similar, and then, can give two different positions for the same kind of marker. Even if this case is rare, it could append in calibration step for example.

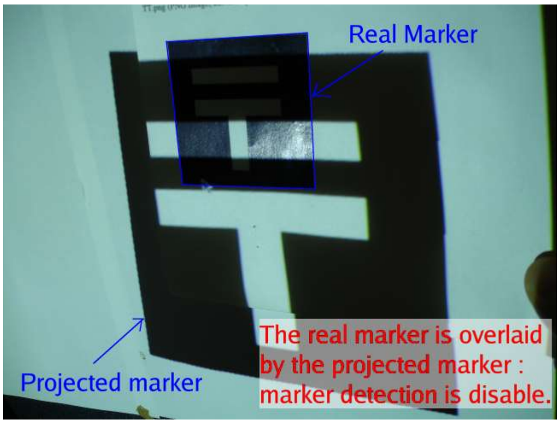

Fig. 14 - Overlapped marker conflict.

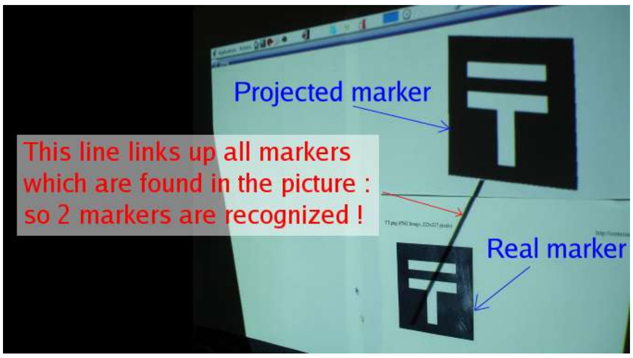

Fig. 15 - Marker illusion conflict.

In conclusion, simply adapting the ARToolKit, is not enough. We had to find a solution to solve these conflicts.

Thermal solution

It would not be an exaggeration to say that practical application of our system by displaying the augmentations onto the patient depends on whether we can solve the conflict between color video camera and video projector or not.

The solution to solve the detection conflict is provided by thermal markers [Kit05]. Instead of using a color video camera and printed ARToolKit markers, a thermal video camera and thermal-markers are used. As shown in Fig. 16. Information is expressed by the temperature difference generated by partially covering the surface of the body with thermal barrier material.

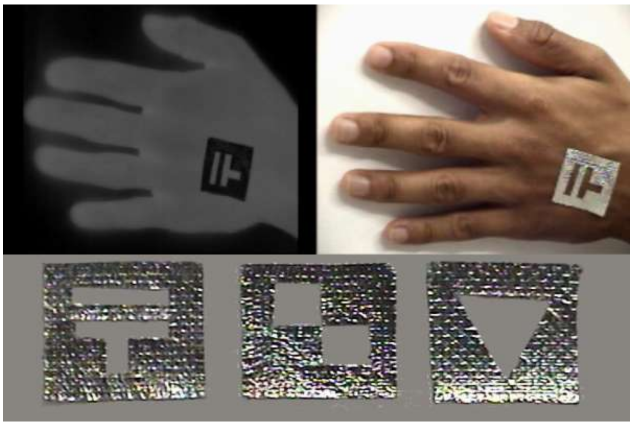

Fig. 16 - Thermal markers.
Top left: Thermal video capture of Thermal marker
Top right : Color video capture of Thermal marker
Bottom : Example of Thermal marker on skin

Thermal markers were used to identifying person by [Kit05], whereas they can be used to localize a position. In addition, thermal video camera is not sensitive to visible wavelength of light, so the projector will not interfere with this system of detection.

Other software components

Nowadays, writing a software from its beginning is not the right way to construct an application. Re-usability has become the main word of software development.

Font display component

Our application will use ARToolKit. This software library uses OpenGL technology. In our case, to display some information to the user of our system, we want to print instructions in the screen. Unfortunately, there is no easy way to display font in OpenGL. You have basically three ways to draw text using OpenGL (Raster fonts, Geometric fonts, Textured mapped fonts). As a beginner in OpenGL programming, I choose to use a simple Geometric font display class designed by Soji Yamakawa.

Bitmap texture loading component

Another way of broadcasting information to the user is to print pictures on the main screen. To do this, you need to load these pictures as textures. Deplorably, inflow of different images format complicate a lot this task. That why a texture loading class from Damiano Vitulli is used.

Camera Access function component

To improve the usability of the system, the user will not stop his/her action to adjust the focus, or the position of the camera every time. So, as the color video camera can be controlled through the RS-232C serial port, a library providing the access functions has been used. This software part has been developed by Pic Mickael, AIST Japan in 2002. We would have developed the same control enhancement for thermal video camera, but it is not authorized by hardware.

All these software components, including the ARToolKit library, are written in C or C++. and are connected to our program as described in the following UML schema (Fig. 17). Some wrapping components have been design to match our needs.

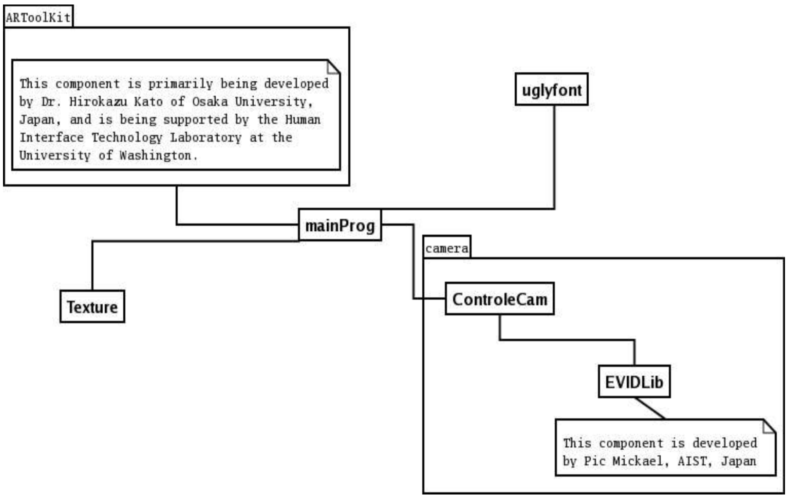

Fig. 17 - UML schema : main packages and software components involved in the application.

Other encountered problems

As previously exposed, in the fully Virtual Reality world, some experiments have been carried out involving patient and doctor interaction [Joh05], but Augmented reality and collaborative work in patient-physician relationship appears not to have been approaches. In that case, we had very few register mark to help us. So we face some novel problems. In this section, we describe the other encountered problems during the project.

3D human models

Many anatomical models of different organs are currently being developed, though their formats greatly depending on the application field for which they have been designed. For example, *The Visible Human Project®* is an outgrowth of the National Library of Medicine's plan. It is the creation of complete, anatomically detailed, three-dimensional representations of the normal male and female human bodies. Acquisition of transverse CT, MR and cryosection images of representative male and female cadavers has been completed. The male was sectioned at one millimeter intervals, the female at one-third of a millimeter intervals. This database is really interesting and safe, but the specificity of the files format and the mass of information disable its usability in our project. We choose the provide a large and simple 3D format for the models of our application, allowing future imports. Thanks to Internet, the VRML model is becoming a standard. Almost all 3D software modeler can export models in VRML. **Blender** is the open source, cross platform suite of tools for 3D creation. This software was used to mix some existing 3D models form several format (3DStudio Max, Maya,..). The main drawback of our solution is the lack of reliability in the founded 3D models, but they have the advantage to be free. Models can be found on the website listed in table 3.

Table 3. Reluctant website for 3D models

Name	URL
3D Visible Human Project	http://www.npac.syr.edu/projects/3Dvisiblehuman/VRML/VRML2.0/MEDVIS/
Anatomical Chart Company	http://www.anatomical.com/
CHS - Center for Human Simulation	http://www.uchsc.edu/sm/chs/gallery/gallery.htm
Human Anatomy On-Line	http://www.innerbody.com/htm/body.html
Human Brain Project Repository	http://hendrix.ei.dtu.dk/vrml/vrmlhome.html
Medicine en 3 Dimensions	http://perso.infonie.fr/cordial/indexe.htm
Museo de Anatomía	http://www.ucm.es/info/museoana/
Princeton shape retrieval and analysis group	http://shape.cs.princeton.edu/search.html
Radioanatomie	http://www.med.univ-rennes1.fr/cerf/edicerf/RADIOANATOMIE/TABMAT.html
the eSkeletons Project	http://www.eskeletons.org/
the Visible Human Project Visible Gallery	http://www.nlm.nih.gov/research/visible/visible_gallery.html
Workshop Anatomy for the Internet	http://www.uni-mainz.de/FB/Medizin/Anatomie/workshop/englWelcome.html

In second version of VRML, interaction models (manipulation, animation) are beginning to appear. This means that our system can display animated augmentations. We can imagine seeing a normal digestive passage and an abnormal as an explanation in a consultation.

Privacy

In medical consultation, the patient often want to preserve his/her own privacy. In spite of that, 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. This problem deals with ergonomic and human factors and may lead to the reject of the system by many users.

Fig. 18 - Preservation of privacy in thermal images.

Unfortunately, the use of a color video camera is required in a context on screen display (without projector). This context of utilization is under medical secret, but some patient may be opposed.

This issue gives us one of the strongest motivations for finding a solution for the projector-based system. By using a thermal video camera, the privacy of the patient is keep free. Moreover, we don't need to project the patient image and augmentations (in screen display we need to project patient image), but only virtual objects. As thermal video is eyes invisible information, it is nearly impossible to identify a person (Fig. 18).

Thermal image filtering

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. ARToolKit recognition function deals with gray-scale images, we convert it before applying the filter.
The gray-scale intensity of pixel (i,j) in Red Green Blue (RGB) is given by equation (1).

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

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).

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

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 Imax and Imin , the extreme values of input image I.

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

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).

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

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

Results of these different filters are shown in Fig. 19. We can see the gray dispersion levels under the screen shots. With contrast filter, the dispersion is stretched to cover a bigger part of gray spectrum. With threshold filter, the gray levels are summarized. We get few gray intensities, and then, it helps the ARToolKit's detection function.

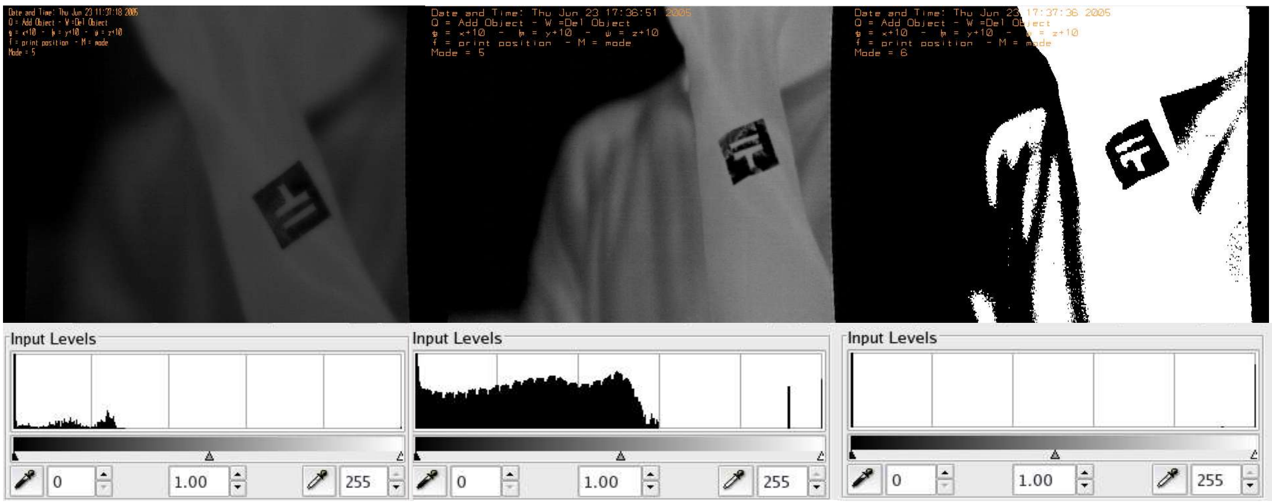

Fig. 19 - Result of Image Filtering.
Left : thermal capture without filter. Center : with contrast filter. Right : with threshold filter.

Calibration between projector and thermal-markers

In ordinary use of ARToolKit, it is not necessary to calibrate capturing equipment and displaying equipment (i.e., a color camera and a LCD monitor), because video capturing process and CG projecting process share the completely same coordinate system. However, in our system, it is physically not possible to align the both coordinate systems same. Thus, we have to compensate the difference between projective geometry of two equipments by a calibration process. Projector-based augmented reality system calibrates relative projective geometry between capturing and projecting equipments with capturing specific calibration patterns which are projected by a projector [Ash03a]. In our system, it is not possible to capture the projected calibration patterns, since a thermal camera can not see visible light. In addition, we did not find any paper dealing with this combination between thermal camera and LCD-projector. So, we have implemented a calibration method for this combination. Instead of using the visible calibration pattern, we calculate the calibration with a trial-and- error correction method.

With capturing a thermal marker, the relative projective geometry 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 to the captured 3D space while assuming that video capturing and CG projecting processes share the same coordinate system. As the result, the projected CG model is not correctly mapped onto the real world, as shown in Fig. 20.

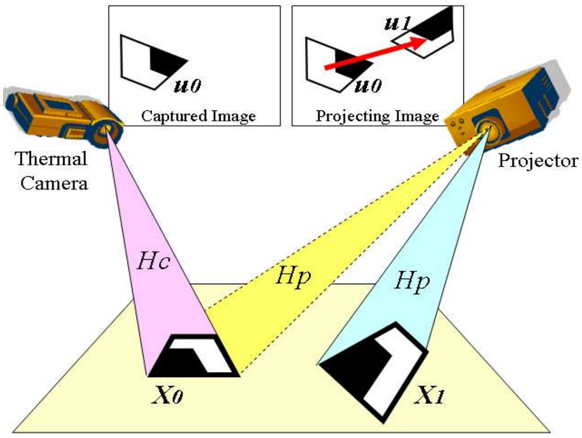

Fig. 20 - Trial-and- error correction calibration method

We compensate the displacement in 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 overlapped. The position of thermal marker in the projecting image is also ***uo,*** and 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*). With using the corresponded vertices's 2D coordinates of ***X0***, ***X1*** and ***uo***, homography projective matrices are calculated.

Finally, the displacement between ***X0*** and ***X1*** is corrected by transforming the projected image. As long as we compensate 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 matrices, and calibrate the equipments in 3D world with using the extrinsic parameters. However, estimated results might be affected by the observing condition. On the other hand, our application system aims to display the human components on surface of the body. So, basically, we do not have to align the CG model with keeping 3D geometric consistency, because it is impossible to map the texture information onto the real human organs.

The system will display the image where it “see” this marker through thermal camera. Then, we correct the position by overlapping the real position with the projected image. This step is illustrated by Fig. 21.

Fig. 21 - Calibration process.
CG overlapping before calibration(left) and after calibration (right)

Results

One of this internship objective was to implement an application demonstrating the feasibility of my proposed use of augmented reality in patient-physician relationship.
In a first part, the prototype system will be presented. Then, the publication related on this system will be exposed.

Prototype system

Our system can overlap different human components onto the patient's body where thermal-markers are placed. The position is defined to be visible and known by the system (i.e. calibrated). Finally, the system display images via the LCD-projector at about 10 frames per second with a capture definition of 640*480 in Full resolution mode. Comparatively, basic ARToolKit's applications have 15 frames per second with our device configuration.
The application try to be as simple as possible by providing a friendly interface (Fig. 22).

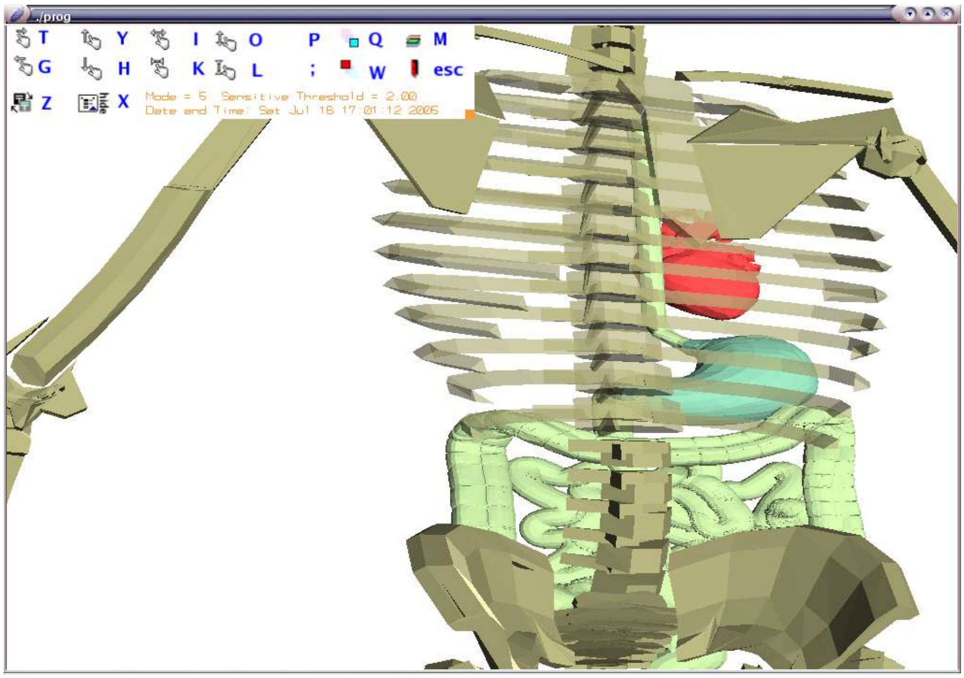

Fig. 22 - Main interface of application.

The legend of the application, shown in Fig. 23, provides informations with pictures, allows its use by foreign languages people, and can be hidden too. Computed values are display in this legend, for accuracy of visibility. For example, the green square (at bottom right) indicates that a marker is found. Orange denotes that calculation of the placement, to correct the position of the augmentations placement, is in process. Red stands for lack of detection of the marker.
The sensibility threshold for movement detection can be adjusted. The user is allowed to choose which layer of augmentation he wants to display. For example, you may want to show the thoracic cage first; in a second view, lungs just beneath the ribs, and then the heart deeper inside the body.

Fig. 23 - Ergonomic Legend

The calibration mode is also available in the legend. It turns the application in the calibration mode, illustrate by Fig. 24. The user see directly the picture of the pattern to fix onto the real pattern. This calibration step is described in Fig. 21, p 21.

During the loading of the application, some short message provide the state of each step of loading. In appendices C.


Fig. 24 - Interface in calibration mode

Final in situ results are shown in Figs. 26 and 25. In figure 26 (left), Computer Graphics of torso skeleton and lungs are projected over the patient clothes. The marker is not visible due to the opacity of the t-shirt. However, our solution allows to hide marker for short time. This solution is the best one if the patient do not want to be naked, because his privacy is completely maintained.
In Figure 26 (right) CG of heart and top of digestive system are displayed directly onto the patient's skin. The patient can then point out the location where his pain his physically located and the physician can expose in details his explanations. The position of the patient is given by the adhesive marker fixed on the body (Fig. 25).

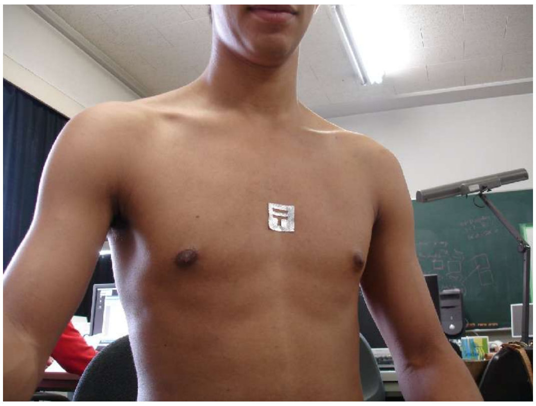
Fig. 25 - In situ marker placement.

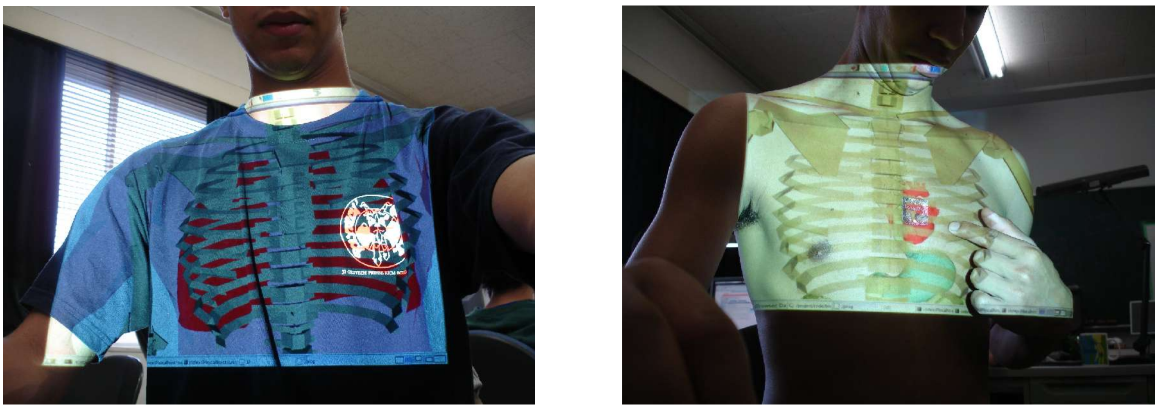
Fig. 26 - In situ augmentations.
Overlapping of lung and ribs over clothes (left) and Overlapping of heart and digestive system onto skin (right).

The source code of the project has also been documented with Doxygen. The documentation, in HTML, allows future development of this application. Wizard assistant could be implemented to guide the user through the calibration process. Preview of each layer in the interface would be useful for the physician. Moreover, others 3D models should be created, with specific learning goal.

Publication

Research output is crucial for the University, the department, and the individual. Writing a publication is an opportunity to publish a work to a specific domains, and then improve the all field evolution.

International Conference on Artificial Reality and Telexistence (ICAT) is the oldest International Conference on Virtual Reality and Telexistence. ICAT 2005 will not only look for innovations in the technology itself, but also explore novel ways to transfer and express information and creative ideas to the society and people.
One of the biggest and unexpected result of this internship is the submission of a publication to ICAT. This paper is currently under review. If it will be accepted, a poster presentation or a demonstration of this project will be provided at this conference. This paper can be found in appendices .

Conclusion & balance of this internship

This three months in Japan has been a really amazing opportunity to realize my fourth year of Polytech'Grenoble internship. By integrating the laboratory of Computer Vision and Image Media at University of Tsukuba, I have learn a lot of things. This laboratory gave me the chance to design my own subject, which is Augmented Reality and Collaborative Work in patient-physician relationship. The aim of this subject was to facilitate the communication, especially to get patient's informed consent, by providing the “doctor vision” to the patient. These augmentations are basically provided by Augmented Reality technologies. The realization of this project conduct me to learn 3D Image processing, particularly OpenGL, and also developing a software in C/C++ language. Knowledges from Information Technologies for Health department were included to design a medical specific application. Moreover, specific contributions from the laboratory, such as thermal marker tracking, help this project to ends.
The developed system can overlap different human components onto the patient's body. The patient can move freely according to the real time tracking system. Thus, privacy of the patient remain free by the use of a thermal system. Furthermore, the system display images via a projector, on the patient's body.
But the development of this application is only the visible part of the iceberg. As this project is made of several new techniques, it conducts me to write a publication for ICAT, with is now being reviewed. Learning how writing a publication bring me a lot of new knowledges of research environment. It has also given to me the chance to publish a paper before ending of my scholar path.

Finally, by traveling in Japan, I discovered a completely novel culture, with different habits, exotic landscapes, uncommon food and unique people. This international exchange enriches my education and improve my international outlook. It has boost my desires to enrich my way of being by several different cultures.

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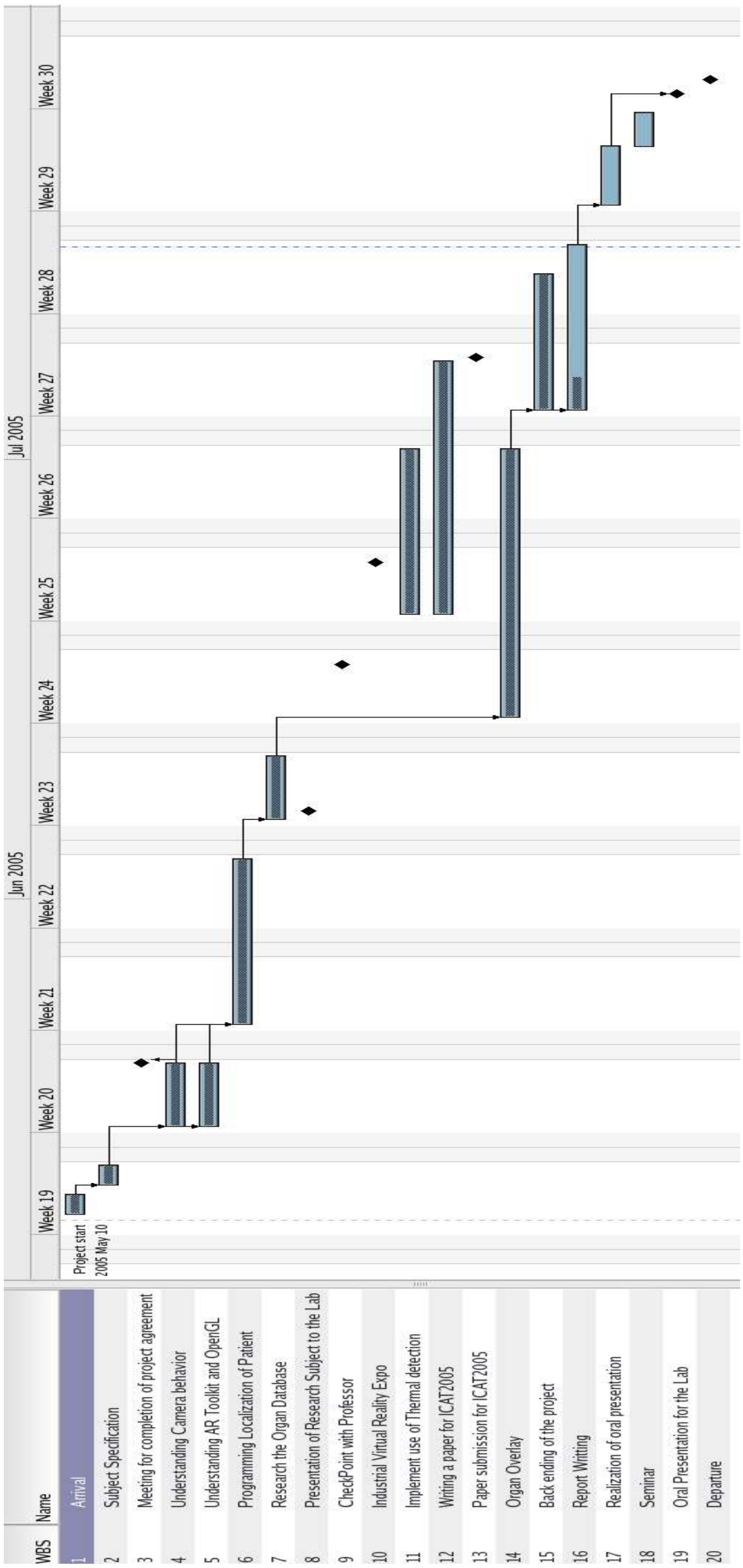
Appendices

List of appendices



Appendix A - GANTT chart of the project.

```
cortex@localhost:/project/code/bin
File Edit View Terminal Tabs Help
[cortex@localhost bin]$ ./prog


*** Loading Camera Parameters ***
--------------------------------------
SIZE = 640, 480
Distortion factor = 317.500000 192.000000 26.300000 1.009989
780.54604 0.54781 304.64423 0.00000
0.00000 762.30679 208.68123 0.00000
0.00000 0.00000 1.00000 0.00000
--------------------------------------
FittingMode (Z): COMPENSATED IMAGE
ProcMode (X)    : HALF IMAGE
DrawMode (C)    : TEXTURE MAPPING (HALF RESOLUTION)
TemplateMatchingMode (M)    : Color Template
MatchingPCAMode (P)    : Without PCA


*** Loading Color Camera-controls ***
Error EVILib Receiver(void *): Unknown message received from camera
Error EVILib Open(int, char *) AddressSet
Error cam1 SERIAL PORT Open
Camera registered - control not enable


*** Loading VRML and Markers Objects ***
Opening model file Data/object_data_vrml
About to load 4 models.
Model 1:    Wrl/human_top.dat
VRML id - 0
Model 2:         Wrl/lung.dat
VRML id - 1
Model 3:     Wrl/skeleton.dat
VRML id - 2
Model 4: Wrl/skeleton+digestive+heart.dat
VRML id - 3
Object count = 4


*** Loading Textures files ***
Texture Data/patt.bmp loaded as 0
Texture Data/legende.bmp loaded as 1
Texture Data/legende1.bmp loaded as 2
```

Appendix B - Software Loading trace.

Appendix C - Samples of the Japanese culture.

ICAT 2005
December 5-8, Christchurch, New Zealand

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.

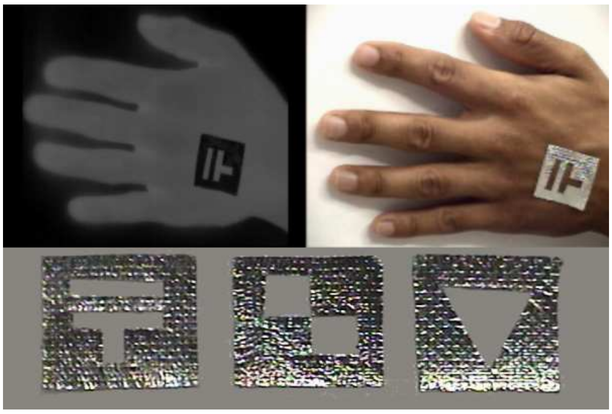


Fig. 2: Top left: thermal video capture of a thermal marker; Top right: Color video capture of the thermal marker; Bottom: Examples of thermal markers for skin

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.

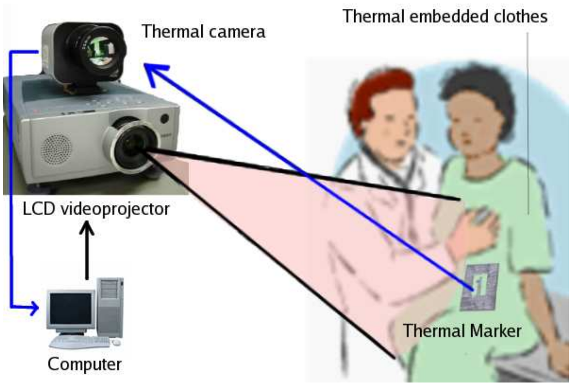


Fig. 4: Overview of see-through medical examination system

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.

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.

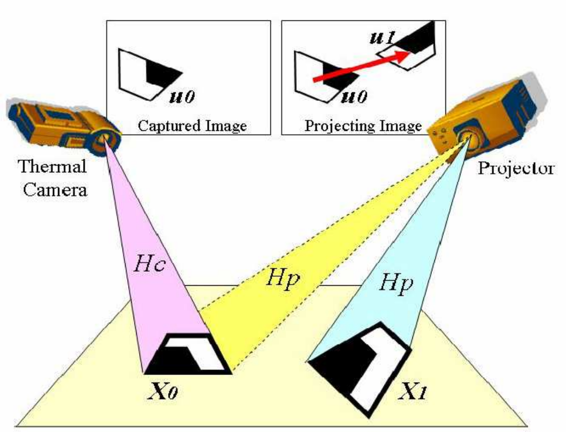


Fig. 5: Trial-and-error correction calibration method

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.

$$X_0 = H_c u_0 \tag{6}$$

$$X_1 = H_p u_0 \tag{7}$$

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.

$$X_0 = H_p u_1 \tag{8}$$

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

[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/

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

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.

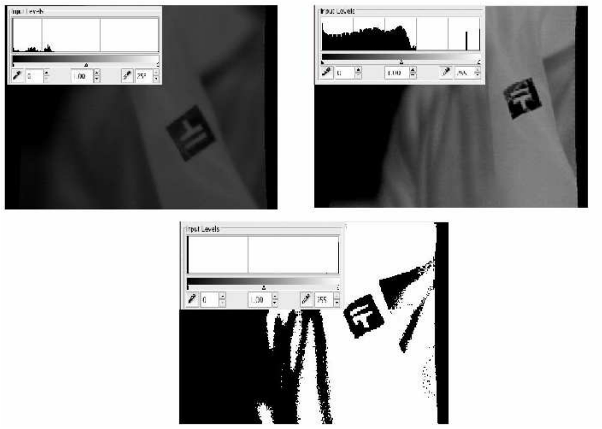


Fig. 6: Left: thermal capture without filter; Right: with contrast filter; Center: with threshold filter.

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.

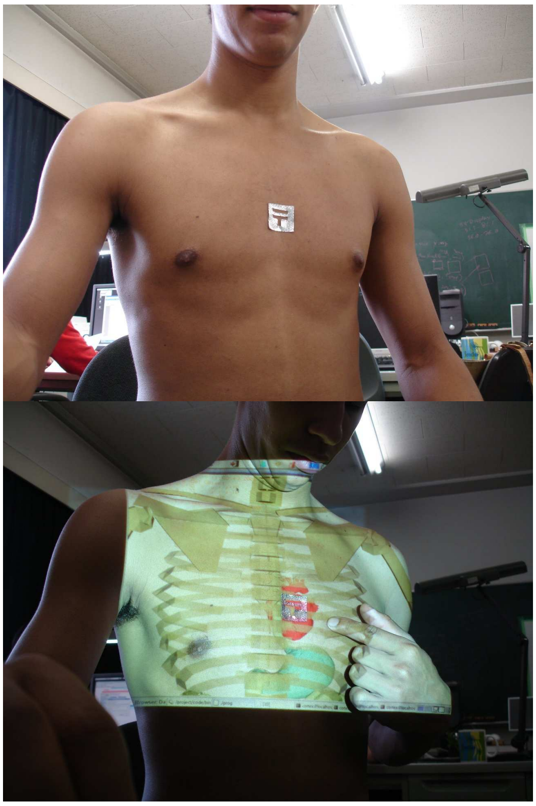


Fig. 9: Marker placement (top); and overlapping of heart and digestive system onto skin (bottom).

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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Augmented Reality and Collaborative Work in Patient-Physician relationship

Bluteau Jeremy fourth year of Information Technologies for Health

University of Tsukuba

Address:	1-1-1, Tennodai, Tsukuba, Ibaraki, JAPAN Zip code :305-8577
Phone :	029-853-6240 or 6766
Fax :	029-853-6240
Email :	info@intersc.tsukuba.ac.jp
URL :	http://www.tsukuba.ac.jp/eng/

Administrative coordinator : Dr. AKIMOTO Katsuhiro

Phone :	+81-29-853-5274
Fax :	+81-29-853-5204
Email :	akimoto@esys.tsukuba.ac.jp

Computer Vision and Image Media Laboratory director : Pr. OHTA Yuichi

Phone :	+81-29-853-5515
Fax :	+81-29-853-5207
Email :	ohta@iit.tsukuba.ac.jp

French coordinator : Pr. CALABRESE Pascale

Phone :	+33-(0)-456520060
Fax :	+33-(0)-476-63-71-86
Email :	Pascale.Calabrese@imag.fr

Title : Augmented Reality and Collaborative Work in Patient-Physician relationship.

Abstract :

This report presents the result of a fourth year internship of Information Technologies for Health, Polytech'Grenoble, at University of Tsukuba, Japan. It exposes the use of Augmented Reality (AR) technology to improve better communication during medical consultation. Our AR system can superimpose augmentations (i.e. human body components) onto the real patient's body, while keeping his privacy free. This annotated information would form the cornerstone for collaborative work between Patient and Physician. We focus on the advantages of projector-based technology and thermal markers (i.e. using human body temperature as a source of information). Theoretical and Technical solutions for designing this system are also presented. The feasibility of the system is demonstrated through development of a complete application. The publication related on this project is also presented.