

# The Visible Korean Human Phantom: Realistic Test & Development Environments for Medical Augmented Reality

Christoph Bichlmeier<sup>1\*</sup>, Ben Ockert<sup>2\*\*</sup>, Oliver Kutter<sup>1\*\*\*</sup>, Mohammad  
Rustaei<sup>1</sup>, Sandro Michael Heining<sup>2†</sup>, and Nassir Navab<sup>1‡</sup>

<sup>1</sup>Computer Aided Medical Procedures & Augmented Reality (CAMP), Technische Universität  
München, Germany

<sup>2</sup>Trauma Surgery Department, Klinikum Innenstadt, LMU, München, Germany

**Abstract.** This paper reports on the preparation, creation and first applications of the Visible Korean Human Phantom - VKHP that provides a realistic environment for the development and evaluation of medical augmented reality technology. We consider realistic development and evaluation environments as an essential premise for the progressive investigation of high quality visualization and intra operative navigation systems in medical AR. This helps us to avoid targeting wrong objectives in an early stage, to detect real problems of the final user and environment and to determine the potentials of AR technology. The true-scale VKHP was printed with the rapid prototyping technique "laser sinter" from the Visible Korean Human CT data set. This allows us to augment the VKHP with real medical imaging data such as MRI and CT. Thanks to the VKHP, advanced AR visualization techniques have been developed to augment real CT data on the phantom. In addition, we used the phantom within the scope of a feasibility study investigating the integration of an AR system into the operating room.

**Key words:** Medical Augmented Reality, Focus & Context AR Visualization, Test Beds for Augmented Reality

## 1 Introduction

In this paper, we propose a new genre of phantoms. The Visible Korean Human Phantom - VKHP provides a realistic environment to develop and evaluate future visualization techniques and surgical navigation systems taking advantage of augmented reality technology.

Beside the close collaboration among physicians, engineers and computer scientists within an interdisciplinary lab space, which we call *Real World Lab*, to

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\* bichlmei@cs.tum.edu

\*\* ben.ockert@med.uni-muenchen.de

\*\*\* kutter@cs.tum.edu

† sandro-michael.heining@med.uni-muenchen.de

‡ navab@cs.tum.edu

investigate the needs of the final user and the potentials of new technology, we determined the importance of a realistic phantom for developing and evaluating our approaches as an important factor for progressive research. Experimental arrangements such as cadaver, animal or in-vivo studies to develop, showcase and evaluate AR technology are expensive, difficult to be justified and hard to obtain. Custom-made phantoms are often presented by the community to simulate a minor anatomic part or conditions. However, this can either produce artificial problems that are not present on real conditions or important issues are disguised. Both lead consequently to a non optimal system design and configuration.

It is extremely difficult, maybe even impossible, to build a phantom that corresponds to the physical properties of the human anatomy. Different companies like Gaumard, Laerdal or Meti offer manikins simulating different training environments for teaching medical emergency teams and particular medical situations like birth simulation. However, there is no solution yet on the market that provides a mannequin coming with real imaging data sets that is adapted to the needs for AR applications.

Many applications follow the strategy of using CT or MRI imaging data of unrealistic, custom-made phantoms to design a navigation or visualization system. Quite often, the produced phantoms and corresponding imaging data are capable of evaluating a certain task such as accuracy and time duration of instrument guidance. However, such imaging data excludes information that can be used in real conditions or includes information that misleads the user and results into distorted results that can not be projected onto real medical cases.

For instance, Sauer et al. [14] use a cantaloupe and a box filled up with mashed potatoes for the evaluation of AR guided needle biopsy. Birkfellner et al. [4] present a phantom skull with jelly that "was covered with polypropylene dust in order to make the jelly opaque" to simulate navigated neurosurgery. Traub et al. [16] built a wooden box for navigated surgical drilling that is equipped with metal spots serving as target spots and filled up with silicone. Sielhorst et al. [15] took a CT scan from a thorax phantom with nothing except a plastic spinal column inside the body to evaluate the quality of depth perception of different visualizations modes. We [1] built a phantom for pedicle screw implantation in spine surgery consisting of replaceable vertebrae. The CT scan of vertebrae surrounded by silicone and peas was then used for the evaluation of an AR navigation system.

Cadaver and animal studies come close to the real conditions in the OR. However, only few researchers having access to interdisciplinary facilities report on such lab and evaluation environments [17, 6, 3]. For the major part of the community, such experiments are not accessible at all. Only few groups report on evaluations on real patients [10, 4, 7, 5]. Unfortunately, this most realistic test bed for medical AR applications is far from being frequently accessible for continuous development.

## 2 Method

A major research topic in medical augmented reality addresses the improvement of visualizing medical imaging data superimposed on the patient. Naive superimposition of virtual anatomy on real objects such as the patient skin would result in misleading depth perception since the visualized data then appears to be outside rather than inside the body. We investigated a promising approach to provide the user of a video-see through head mounted display (HMD) [3] with an intuitive view through the transparent skin into the patient's body. For this reason the transparency of the skin region within the video images are manipulated due to geometric properties of the skin taken from the CT scan, the observer's position and view direction. They carried out a phantom, a cadaver and an in-vivo study and presented the results at [3]. Regarding the expensive preparation and execution of these studies shows that there is a major need for new test bed solutions.

A new approach for real-time visualization [11] and new graphics hardware allows us to augment a similar AR scene with direct volume rendering of CT data. Regarding consecutive and progressive development and evaluation of this high quality rendering approach, an earlier used thorax phantom [15, 3] can not measure up to the potentials of new rendering features anymore. Cadaver as well as volunteers can still serve for feasibility studies, however, both can not be provided for a permanent testing environment.

### 2.1 Visible Korean Human Phantom

Beside the *Visible Human Project* (Caucasian) (VHP) and the *Chinese Visible Human* (CVH) [18], the *Visible Korean Human* (VKH) [13] project provides full body imaging data consisting of MRI, CT and a photographic data set. We created a phantom from the CT data set of the VKH and prepared a set of operation sites for frequent applications in trauma surgery such as hip, shoulder, spine and neurosurgery. Such operation sites can be used for training surgeons in standard procedures within an almost realistic setting and developing new solutions for AR based image guided surgery in different surgical disciplines.

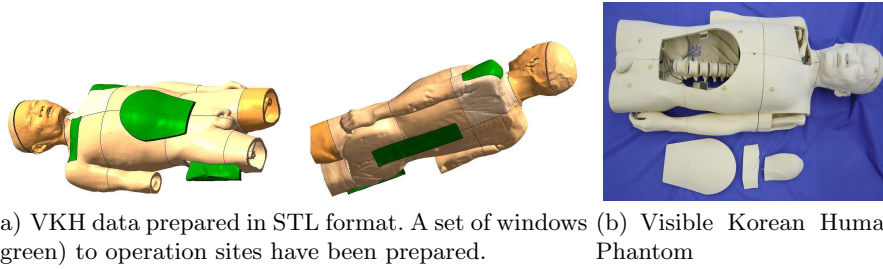
Five removable windows were fabricated into the phantom's skin (see Fig. 1(a)). This includes a 30x10 cm approach at the back of the phantom for the simulation of dorsal instrumented spine operations, for instance vertebroplasty, kyphoplasty or pedicular screw implantation and fixation. In addition, windows were integrated at the proximal shoulder and the proximal femur for internal osteosyntheses procedures, for instance plate and screw fixation. At the right clavicular region a 10x3 cm approach was built in to allow intramedullary clavicular fixation as well as intrathoracal drain application. Bearing in mind the soft tissue preparation defect, all drill and fixation steps can be obtained and guided by a navigation system.

The VKHP consists of the skin and bone structure from the CT scan, which is suitable for providing a test bed for different procedures in navigated hip, shoulder, spine and neurosurgery. First, CT data of the VKH was prepared using

the software 3-Matic and Mimics of Materialise <sup>1</sup> to create surface models of the anatomy to be printed in 3D. The required surface model format is STL <sup>2</sup> to be applicable for rapid prototype 3D printers. The virtual phantom was divided into components of maximum size of 700mm x 380mm x 590mm for the printing machine. In general, there are machines on the market that provide bigger print volumes. However, the components were prepared to be removed and plugged together for being able to adjust the VKHP according to a particular application and also for sharing parts of it among different lab spaces.

Our true-scale *Visible Korean Human Phantom* (VKHP) (see Fig. 1(b)) ranging from the head to the hips was printed from the prepared STL data (see Fig. 1(a)) with additive rapid manufacturing technique, *selective laser sintering*, by the company FIT <sup>3</sup>. The VKHP has been printed in layers (150  $\mu\text{m}$  steps). Depending on the quality of the STL surface data, a theoretic level of detail of 0.7mm can be achieved.

To enhance the realism of the skin, the phantom was coated with skin colored powder, which also avoids non realistic specular highlights on the raw material.



**Fig. 1.** The Visible Korean Human Phantom (VKHP) prepared with different operation sites for future experiments related to different procedures in navigated hip, shoulder, spine and neurosurgery.

## 2.2 Registration

The used tracking system localizes objects like surgical instruments and the patient equipped with a tracking target of passive infrared retro-reflective marker sets [3]. For high quality registration of the virtual CT and MRI data with the VKHP, we attached Beekly<sup>4</sup> CT markers to the skin of the phantom. The CT markers were coated with an infrared reflective foil in order to make them visible for our infrared camera tracking system described in detail at [3]. Next, point

<sup>1</sup> Materialise Group, Leuven, Belgium

<sup>2</sup> Standard Triangulation Language

<sup>3</sup> FIT Fruth Innovative Technologien GmbH, Parsberg, Germany

<sup>4</sup> Beekly Inc.

correspondences between the CT spots segmented from the CT data volume and the same spots detected by the tracking cameras are determined in order to compute a rigid registration transformation [3].

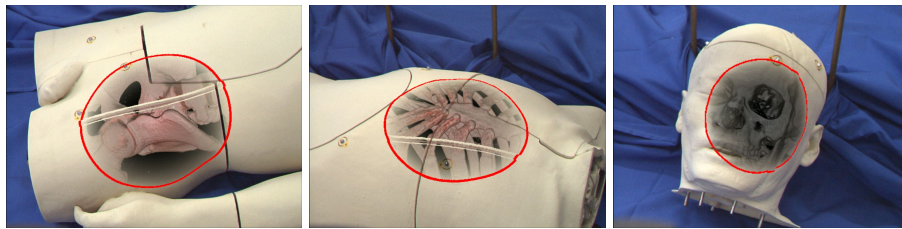
For practical reasons, we decided to divide the VKH data set into two separate tracked anatomic regions, the thorax/hip region and the head region. This allows us to reduce work space in our AR test bed and share the VKHP for parallel work.

The original VKH data set was acquired without the mentioned CT spots or comparable artificial landmarks that can be used for registration. For this reason, we took a high resolution scan from the two separated anatomic regions of the VKHP mentioned above. After the scan, we extracted the centroids of the attached CT markers from the new data set fully automatically, based on intensity thresholding and moments analysis. Finally, the original VKH CT data and the new phantom CT data are registered by non-linear intensity based registration. Mutual information was selected as a similarity measure and a best neighbor optimizer was used [8].

### 3 Results

Recent investigation in applying adaptive focus and context visualization for Medical Augmented Reality have shown promising results [9, 12, 3]. We are working on an approach where the transparency of the skin region in the video image is manipulated by geometric properties of the CT scan in the skin region, the observer's view direction and his/her point of view [3].

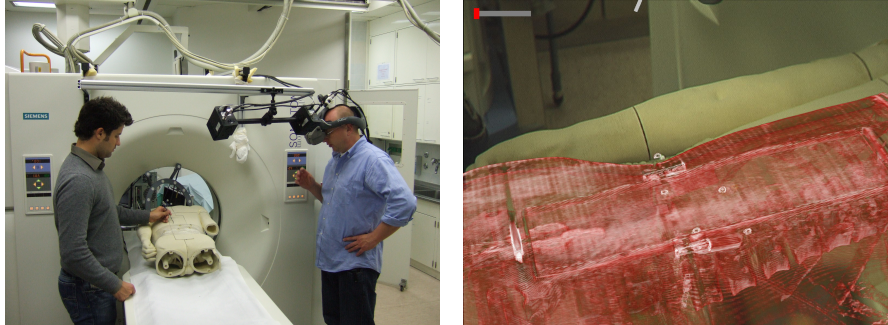
The VKHP has been successfully used for developing an improved and more flexible approach [11] for in-situ visualization of the VKH CT data set. The resulting AR scene corresponds to almost real conditions. Figure 2 shows focus & context visualization of the bone structure in the head and the thorax region on the VKHP. Within the long term project *Augmented Reality Aided Verte-*



**Fig. 2.** First results of a new direct volume rendering approach for AR focus & context visualization augmenting CT data of the VKHP.

*broplasty - ARAV* [2], we use the VKHP for feasibility studies to integrate an AR system based on the stereo video see-through HMD into the trauma room of our clinical partner (see Fig. 3(a)). For the feasibility study (see Fig. 3(b)),

we do not augment the original data set but the CT from a test run. In this case we are interested more in planning the operating scheduling and equipment positioning than in visualization issues. Due to the true scale VKHP we are able to plan different camera setups, scan volumes and marker positioning with a dimensionally realistic experimental setup.



(a) VKHP is positioned on the bedding of the CT scanner. (b) A trauma surgeon is observing the augmented VKHP.

**Fig. 3.** The Visible Korean Human Phantom (VKHP) used for a feasibility study with the Augmented Reality Aided Vertebroplasty - ARAV project.

## 4 Discussion

The interior of the VKHP is equipped with the bone structure printed from the VKH CT data set. This allows for simulating different procedures related to spine, hip and shoulder surgery. However, it does not provide a test bed for soft tissue applications such as tumor resection in different organic regions. There are rapid prototyping 3D printers on the market, which are capable of printing all kinds of materials with varying physical properties. The VKH data includes a set of segmented data volumes showing the main organs such as heart, colon, lung and liver. For a second version of the VKHP, we plan to install different soft tissue organs into the phantom that can also be removed when not needed or replaced when being damaged due to experiments.

Feedback from physicians of different disciplines such as anatomy, anesthesia and trauma surgery recommended using the AR system and the phantom simulation scenarios to train medical students and professionals. Different issues of teaching in anatomy courses can be addressed by the present AR system to study anatomic structures, inter-organic functionality, surgical access routes to operating sites and analysis of different imaging modalities.

## 5 Conclusion

We presented a new type of phantom adapted to the needs of the development and evaluation of visualization techniques and navigation systems in medical augmented reality applications. The Visible Korean Human Phantom - VKHP is printed from real CT data, which allows for accurate registration and realistic visualization of real patients data. This concept helps us to avoid cadaver and animals studies, which are expensive, often difficult to be justified and hard to be accessed. The VKHP has been used for the development of an advanced approach of direct volume rendering of CT data. In addition, we used the VKHP for a feasibility study to investigate the integration of our AR system into the trauma room. Following the statement of Park et al. [13] that "the VKH has exciting potential applications in the fields of virtual surgery, virtual endoscopy, and virtual cardiopulmonary resuscitation", we believe that the research progress in Medical Augmented Reality can be strongly stimulated by using comparable phantoms, since realism of the test and develop environments can be extremely increased. In order to support this evolution, we would like to share upon request the STL data, which is ready to be printed.

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