

EKGAR: Augmented Reality Support for Learning of Electrocardiography (ECG) Analysis

Henrik Hedegaard, Mads R. Dahl.
Section for Health Informatics
University of Aarhus Aarhus, Denmark
{hhm, md}@hi.au.dk

Kaj Grønbæk
Center for Interactive Spaces
Department of Computer Science,
University of Aarhus, Denmark
kgronbak@interactivespaces.net

Abstract: Electrocardiography analysis is an essential part of the medical education, but also one of the most difficult disciplines to learn and master. We introduce an innovative augmented reality concept that enables medical students to combine medical theory on ECG analysis with interactive 3D representations of the human heart. Based on modern learning theories the EKGAR system aims at creating optimal flow-state scenarios in which medical students are completely immersed in playful learning experiences. Using visual markers and a ceiling mounted camera, we track the user's interaction with a 3D heart. A real-time visualization of this interaction is either projected on a wall or displayed in a HMD. Utilizing visual markers, the students can make selective slicing in the 3D heart in order to examine its insides and its arteries. Design issues, technical implementation and preliminary user evaluations, as well as the prospects of further development of techniques are discussed.

Introduction

With our ever-increasing unhealthy lifestyles such as smoking, lack of exercising and massive consumption of fast foods, "heart attacks", or acute myocardial infarctions (AMI), has become one of the primary causes of death among westerners. The clinical tool for identifying such heart deceases is electrocardiography (ECG/EKG) analysis. Even though this diagnostic tool is presented early in medical education many students find these diagrams difficult to interpret, and even fully educated physicians spend a lot of time on ECG reading in their daily practice.

In the footsteps of recent technological advances new ways of applying technology in educational settings have become possible. Augmented Reality (AR) ((Azuma et al. 2001) and (Billinghurst et al. 2001)) is one such technology and denotes a practice of overlaying the perceived physical world with a digital layer of information. That way, an AR application addresses a scene from the physical world by augmenting this with computer-generated objects that stimulate our senses and perception of the physical space. The digital objects are most often 2D or 3D objects but the range of perceived objects can be expanded to include sounds, smells and alternative methods of visualization. Thus, when interacting with the physical surroundings the virtual objects of the AR application will appear natural to the user; as if the objects were an integrated part of the physical world (Mackay 1998).

The goal of the EKGAR project has been to perform initial qualitative evaluations of the potentials of combining AR technologies with ECG Analysis in medical education, to determine whether AR can extend medical student's spatial awareness in relation to specific myocardial deceases.

Anatomical and Physiological Principals

The heart is one of the most vital organs in the human body and its primary functions are: 1) to supply the entire body with oxidized blood (left ventricle) and 2) to transport blood containing waste substances away from the body (right ventricle), e.g. via the kidney or the lungs. Due to high perfusion-pressure during contraction, the left ventricle

is surrounded by a thicker heart muscular tissue (myocardium) than its right counterpart. Any damage to this tissue may result in severe consequences to the individual's overall physiological condition. The damages often occur due to luminal obstructions in the coronary arteries (cardiac stenosis). These arteries supply the myocardium itself with blood and nutritional substances, which enables the heart to pump sufficiently. Thus, stenosis in the arteries will significantly weaken the heart and if a single stenosis is large enough, ischemia will cause cell necrosis in the myocardium and an AMI occurs, meaning that a small part of the heart dies. If doctors don't identify and remove such stenoses in time the infarct will continue to grow and eventually penetrate the myocardium, which is fatal in most cases.

The concept of ECG was coined by the Dutch physician Williem Einthoven in 1902 when he discovered that multiple leads attached to a patient's body can generate 2D graphs visualizing the heart's physiological condition when it pumps (Bell et al. 2004). Today physicians attach 9 leads on the patient to generate the standard 12 leads ECG consisting of 3 standard leads (I, II and III), 6 precordial leads (V_1 - V_6) and 3 calculated augmented leads (aVR, aVL and aVF). If the physician/medical student is able to combine these leads correctly, they can construct mental 3D images of a potential AMI's whereabouts in the myocardium and quickly initiate the correct treatment plan to cure the patient (fig. 1).

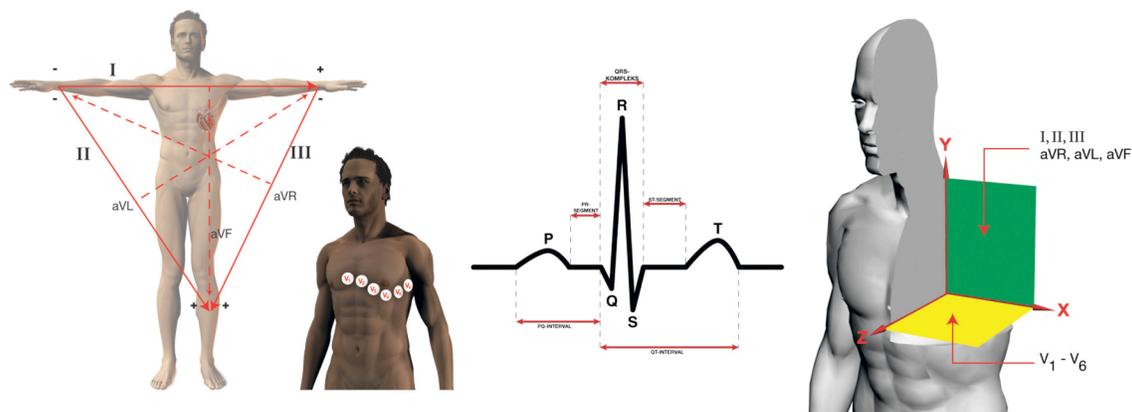


Figure 1: ECG leads location in 2D and 3D as well as sample ECG.

In the EKGAR project we currently focus on inferior AMIs located on the backside of left ventricular heart wall. Our choice is based on statements from several medical students who stated that they in particular find such infarctions difficult to identify when presented with a patient's ECG diagram. A key factor in fully understanding myocardial infarctions is having a spatial awareness of the human heart, thus it calls for Augmented Reality support in the learning process.

Application Design and Concept

The EKGAR-concept is a walk-up-and-use AR-system that allows medical students to intuitively explore patient specific cases of cardiac diseases in 3D using tangible interaction with a virtual heart positioned in the physical space. The concept uses technology to create supplementary learning experiences that are interactive, engaging, and fun. Thus, the concept addresses two main issues in traditional educational ECG teaching: 1) one-way communication in the educational setting and 2) mental overhead in understanding 2D ECG diagram data as imagined 3D images.

In EKGAR, students first select an RFID-enabled box containing specific case material. Then they approach the EKGAR's proximal zone, where the system automatically detects the box' RFID-chip and initializes the corresponding patient data and 3D models. Interactive real-time visualizations of the 3D models take place either next to the patient data and ECGs on a wall-sized display (fig. 2 and 3) or in a head-mounted display (HMD) (Billinghurst et al. 2001).

Whilst the students sit/stand in front of EKGAR, natural interaction is mediated through a joystick-like interaction tool enabling the users to flip and turn the 3D heart (fig. 4). If the current heart visualization supply insufficient information to determine the patient's heart disease the students can freely change the fiducial marker (Billinghurst et al. 2001) located on top the of interaction tool and thereby slice open the heart to get an visual perspective on its inside condition. In doing so the learning situation is no longer characterized as with traditional ECG teaching, but becomes a constructionistic experience (Papert & Harel 1991) where the students can completely immerse themselves in playing with the 3D heart and thereby construct new knowledge, correlating what they see on the inside and outside of the 3D model with the appearance of the ECG plots (Papert & Harel 1991).

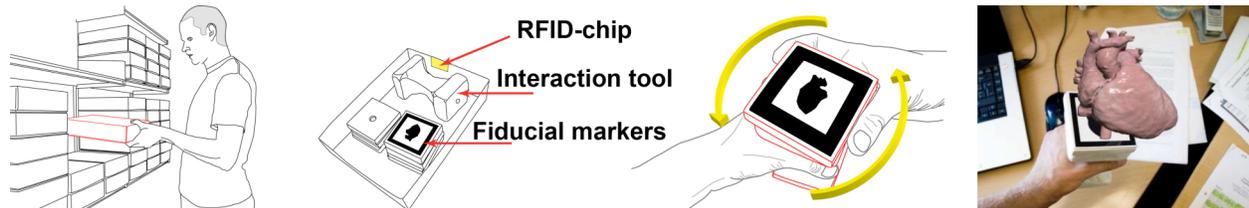


Figure 2: Scenario of EKGAR concept

3.1 Physical Setup of the Prototype

The physical setup of EKGAR is illustrated in figure 3. When the system is activated by an RFID-scanner, the unique ID of the selected case material is sent to the computer that is connected to a central database containing sets of different patient based case materials. The system uses the ID to extract the related data from the database.

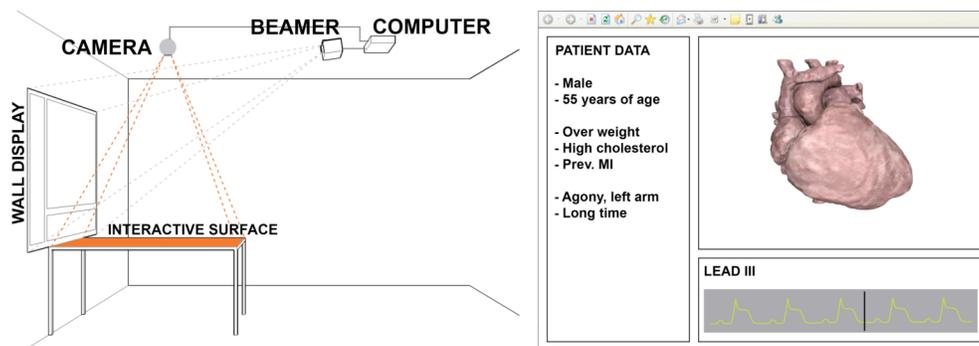


Figure 3: Illustrated hardware setup and interface design in the EKGAR prototype.

With the data initialized, the camera in the ceiling starts capturing live images containing context sensitive data that describes the users' interaction with the physical surroundings. This data is extracted from a set of wooden blocks with attached fiducial ARToolkit markers patterns, inspired by (Billinghurst et al. 2001) and (Andersen et al. 2004). When the images are streamed to the computer, binary image analysis is used to detect the location and rotation of the marker patterns' relative to the camera's position. The outcome of the analysis is used to translate the 3D model of the heart and merge it with the live images in real-time, thus integrating the digital information layer with the real world. The overall output is sent to the beamer, which project the merged image-stream, ECG graphs and patient data onto the wall surface. Hence the medical students can see themselves interact with virtual heart and at the same time observe the patient's ECG status and overall medical profile.

The camera in the ceiling lets the students observe their interaction from above, which may reduce the immersive feeling and sense of natural interaction with the virtual heart. As presented in (Fishkin 2004) one solution would be to use HMD or HHD instead of projection display and thereby increase the sense of presence when examining the virtual heart. But this on the other hand would pose certain technical problems as well as diminish the walk-up-and-use dimension of the application. Therefore we have preferred a setup with a projection display since it supports collaborative use of EKGAR among several students, but we acknowledge a need for exploring alternative displays.

Prototype Implementation

The EKGAR prototype is implemented as a context-aware AR-application (Dey 2001) using vision based 3D tracking (Azuma et al. 2001) and implicit interaction (Schmidt et al. 1999) to create an immersive learning tool (Csikszentmihalyi 1997). With our current implementation we have focused on optimizing visualizations, interface designs and developing a natural interaction metaphor. The prototype functionality thus enables the users to interact with a 3D heart but also to slice through it in certain regions, e.g. the back wall, to look inside the heart. Also, the implementation is able to extract patient data from predefined XML-databases and display the output in the GUI. The RFID-scanning part of the concept is left for future work.

The application is based on Designer's Augmented Reality Toolkit (DART), a free AR framework plug-in for Macromedia Director 2004 allowing for rapid prototyping of AR-applications using drag-and-drop construction and reducing the amount of programming to a minimum (MacIntyre et al. 2003). A main asset of the DART framework is the support for 3D tracking of ARToolkit markers. We utilize this feature in combination with a set of 16x16 sized binary marker patterns that comes with the standard DART installation. Normally you design your own patterns with a semantic appearance relevant to the application domain, but we found that tracking became more reliable when using binary thresholding (fig. 4) compared to grayscale thresholding as is typically used with ARToolkit.

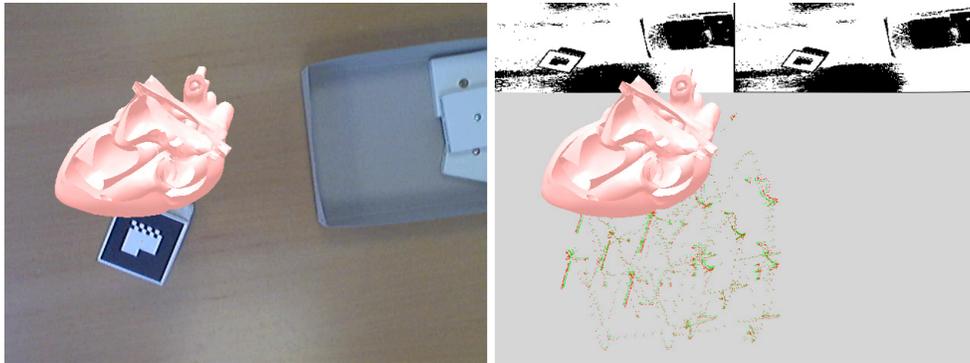


Figure 4: EKGAR screen capture with image analysis in DART

Convincing immersive experiences are important factors when establishing flow-state learning experiences in educational scenarios. As pointed out in (Jones et al. 1998), it is especially the possibility of an extraordinary experience in the learning environment that gives the grounds for students' increasing motivation to learn. With the use of AR technology in EKGAR such extraordinary abilities are offered due to the possibility of interacting with the virtual objects in ways that are without parallel in the physical world. In EKGAR it is not only the combination of 3D elements and visualized ECGs that create immersion and states of flow. Equally it is the way in which EKGAR assists in defining, supporting and giving life to a use scenario that cannot be experienced in the real world. Especially we observed that the students became increasingly motivated to learn when presented with the ability to interact with the 3D heart and getting a feeling of holding it in their own hands while examining and slicing it. Thus the virtual dimension of EKGAR became an actuator for motivation and increased immersion.

A recurrent issue when developing real-time render-based virtual learning tools for medical education is the visual quality of the 3D models. Real-time polygon rendering is to some extent solved in DART and Director since DART theoretically does not have the same upper limit as in VRML. Instead the limit of performance is solely based on hardware limitations. Even so, we experienced massive performance issues when using a detailed 3D model with approximately 180.000 polygons, constructed from an MRI-scan of a human heart. Our solution was to design a much simpler 3D heart (13.000 polygons), using 3D Studio Max, and with an appearance like the ones in the medical books. As a result we could integrate multiple 3D heart models with different slicings and running relatively smoothly at a rate of 14 fps rendering in a 640x480 pixel resolution.

As a GUI tool Director is somehow limited for this domain as it only makes use of raster graphics. In EKGAR we need an interface to dynamically create GUI elements such as ECG graphs. With the recent developments of the Flash 8 Asset Xtra (Bleyle 2005) for Director, we have designed and programmed the GUI solely in Macromedia Flash and integrated the resulting SWF-elements in Director. In that sense we're using Flash as a backend for our

communication with the patient database as well as extracting patient information from XML files and displaying the content on the stage in Director. Accordingly, in EKGAR the main job of Director is solely to use the DART framework in communicating with external units and handle their inputs/outputs.

Use Scenarios and Initial Experiences

To get an idea of whether our design has a potential value in ECG learning we conducted several interviews with medical students as well as a handful of user evaluations during the prototype development. The general response to our investigations was that a tool such as EKGAR is very sought for in medical education. Specifically the medical students pointed to the fact that they typically are either on internship and only have access to the patients' ECGs or have access to contained organs at the university labs. In both cases there aren't much room for error or mishandling of the specimens but in EKGAR they can do whatever they want without hurting any patient.

Further they pointed to the application's ability to help them enhance their spatial awareness of AMIs. It was emphasized that each student create a personal interpretation of the AMIs whereabouts but this application could help in giving them a common visual understanding of the locations.

When presenting the simplified 3D heart to the medical students there was an overall consensus that a simple 3D model would enhance the learning as opposed to the complex MRI-based heart. The students' had a strong case in saying that with the simple 3D heart it is much easier to tell the difference between heart chambers and thus simplifying the navigation inside the heart. Further they were positive towards the simple 3D heart in EKGAR, due to the fact that it resembles the human heart illustrated in their medical books, thus making it easy to draw a parallel between their visual observations in EKGAR and the theory they read.

Even so, the main points of criticism were still in relation to the 3D model. Mostly the medical students stressed that we need to further develop the model's surface texture and coronary arteries but first and foremost to extend the model in such a way that the users can observe cell necrosis in the myocardium. As shown in figure 4 the 3D model is currently a shell model, which only makes it possible to look for MIs on the surface of the myocardium.

Related Work

We have seen many examples on applying VR in medical education, e.g. (Bell et al. 2004), and medical practice in general but the amount of AR-applications for medical education is still very limited and amounts to only a few applications, such as (Schnaider et al. 2003), and to our knowledge none of these directly address ECG training in medical education. Thus there are no systems within the medical domain that compares to EKGAR, however in the AR domain similar systems have been developed e.g. for exploration of volcanoes, archeological findings, and the like in natural science museums (Woods et al. 2004).

Conclusion and future work

In this paper we introduced a new concept of applying AR technologies to enhance the ECG learning experience in medical education. The EKGAR prototype addresses challenges met many medical students when trying to convert 2D ECG graphs to mental 3D images of the locations of myocardial infarctions.

Compared to the above-mentioned state of the art, we have contributed with a novel AR system for teaching ECG reading, which have no direct competitor. We have positive user reactions to the concept and we have identified both potentials and challenges to overcome.

If implemented in full-scale various aspects of the application need to be further developed. This includes better visualization of the virtual heart, but also a better 3D tracking methodology. Finally the implementation of an RFID-scanner should be completed to fulfill the complete concept scenario.

With respect to the systems overall usability, a more extensive investigation needs to be carried out. This would include a larger population of test users including students that are currently enlisted at the faculty of Health Science but also cardiologist who are experts in the field of specific cardiovascular diseases.

References

- Andersen, T.L., Kristensen, S., Nielsen, B.W. and Grønbaek, K. (2004) Designing an Augmented Reality Board Game with Children: The Battleboard 3D Experience. In Druin et al. (eds.) Proceedings of Interaction Design and Children (IDC 2004) June 1-3, 2004, University of Maryland, USA. ACM, New York, 137-139.
- Azuma, R., Baillet, Y., Behringer, R., Feiner, S., Julier, S. & MacIntyre, B. (2001). Recent Advances in Augmented Reality. In IEEE Computer Graphics and Applications, November/December 2001.
- Bell, C., Mooney R., O'Sullivan C., Ryan J. (2004): A Virtual Reality Electrocardiography Teaching Tool. Proceedings of the Second International Conference, Biomedical Engineering, 250-253.
- Billinghurst, M., Kato, H., Poupyrev, I. (2001). The Magic Book: An Interface that Moves Seamlessly between Reality and Virtuality. In IEEE Computer Graphics and Applications, vol. 21, no. 3, May/June 2001, pp. 6-8.
- Bleyle, J. (2005). About Flash Asset Xtra for Flash Player 8, Macromedia Publishing [Online], <http://www.adobe.com/support/director/flash_8_asset_xtra.pdf>
- Csikszentmihalyi M. (1997). Finding Flow: The Psychology of Engagement with Everyday Life, Basic Books, 1997.
- Dey, A. K. (2001). Understanding and Using Context, IN: Personal and Ubiquitous Computing, Special Issue on Situated Interaction and Ubiquitous Computing, 5:4-7, Springer-Verlag, London 2001.
- Fishkin, K. P. (2004). A taxonomy for and analysis of tangible interfaces. Personal Ubiquitous Comput. 8, 5 (Sep. 2004), 347-358.
- Jones M. G. (1998). Creating Engagement in Computer-based Learning Environment. In: ITForum, paper no. 30, e-mail list: invited paper posted 7 December 1998 and WWW document URL: <http://itech1.coe.uga.edu/itforum/paper30/paper30.html>. The University of Georgia, Department of Educational Psychology and Instructional Technology.
- MacIntyre, B., Gandy, M., Bolter, J., Dow, S. and Hannigan, B. (2003). DART: The Designer's Augmented Reality Toolkit. Presented as a demo at The Symposium on User Interface Software and Technology (UIST '04), November 2-5, 2003, Vancouver, BC, Canada.
- Mackay, W. (1998). Augmented Reality: Linking real and virtual worlds. A new paradigm for interacting with computers. In: Proceedings of AVI'98, ACM Conference on Advanced Visual Interfaces, 13-21. ACM Press, New York, 1998.
- Papert, S. & Harel, I. (1991): Situated Constructionism, In: Constructionism. Ablex Publishing Corporation. <http://web.media.mit.edu/~calla/web_comunidad/Reading-En/situating_constructionism.pdf> [Online]
- Schmidt, A., Beigl, M., Gellersen, H.-W. (1999). There is more to context than location". Computers & Graphics Journal, Elsevier, Volume 23, No.6, December 1999, 893-902.
- Schnaider, M., Schwald, B. Seibert, H., Weller, T. (2003): "Medarpa - A Medical Augmented Reality System for Minimal-Invasive Interventions". Medicine Meets Virtual Reality, 2003 pp. 312-314.
- Woods, E., Billinghurst, M., Looser, J., Aldridge, G., Brown, D., Garrie, B., and Nelles, C. (2004). Augmenting the science centre and museum experience. In Proceedings of the 2nd international Conference on Computer Graphics and interactive Techniques in Australasia and South East Asia (Singapore, June 15 - 18, 2004). S. N. Spencer, Ed. GRAPHITE '04. ACM Press, New York, NY, 230-236.