HIGH-PERFORMANCE SAR SIMULATION ON RETAIL VIDEO GAMING CONSOLES FOR EDUCATION AND TRAINING PURPOSES

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ABSTRACT:

For SAR education a combination of theoretical lectures and practical image analysis is advisable. Using podcasts for assisting the dissemination of background knowledge and retail video gaming consoles for the practical lectures in combination is proposed. SAR simulators are widely used for teaching SAR image analysis, because they can deliver pre-defined SAR images. Even more, they can provide thousands of different images of the same object. Learning by using these training databases of simulated images is normally not very effective, due to the monotonous presentation of the data. A real-time simulation can overcome these limitations by interactively presenting the results. The user interface design of the educational simulator system adapts the user interface of modern computer games. The idea is to give the impression of gaming instead of learning. Additionally, beside the visualization of scenes, educational game modes are available.

1. INTRODUCTION

The recently launched commercial and military high- and very high-resolution SAR satellite systems, like for example Terra-SAR-X, COSMO-SkyMed, Radarsat-2 or SAR-Lupe, provide SAR images of the highest quality in remarkable resolutions. These new SAR image sources will broaden the user base of SAR images and various new users will start to work with high-resolution SAR data.

But to broaden the user base not only the availability of data but also new ways of teaching the basic knowledge and the theoretical background of microwave remote sensing will be needed. Today's students and young professionals grew up using digital technology. They spent over 10,000 hours playing videogames, they sent and received over 200,000 emails and instant messages and watched over 20,000 hours TV before they get 21. At the same time they spent at the very most 5,000 hours of book reading (Prensky, 2003). For teaching this new generation, classical teaching methods should be assisted by e-learning and podcasting. To achieve fast and sustainable success in training and education the theoretical courses are supported by practical exercises using a real-time SAR simulation system on a retail video gaming console. This high-performance SAR simulation system is an economical and highly efficient tool for education and training purposes. The fast simulation speed of about 30 frames per second allows the user to interactively change the sensor properties as well as the simulated scene and get immediate feedback from the system. In this way the user can for example change the looking angle or the radar band and directly experience the changes in the simulated image. The fast feedback guarantees a faster and a more sustaining learning success.

A strong theoretical background is the basis for analyzing radar remote sensing data. The Institute for Photogrammetry from the Universitaet Stuttgart has made good experiences podcasting lectures (Fritsch, 2007). The podcasting allows the students to learn anywhere and anytime (24/7/365), providing the flexibility and freedom needed for successful learning. Most interestingly, the attendance of the students in the "live" lectures did not decline but did instead increase, although the students could just download and watch the podcast and did not necessarily need to attend the lectures and exercises, respectively.

In the upcoming section the concept of podcasting photogrammetry and remote sensing is explained. In section 3, the SAR simulation system on retail video gaming consoles is presented and described. Applications in training and education are presented in section 4 and finally conclusions are drawn.

2. PODCASTING PHOTOGRAMMETRY AND REMOTE SENSING

Figure 1. Apple's iPod Nano and iPod Touch family (Copyright: Apple)

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The word "podcasting" is derived from Apple's iPod and broadcasting information content - it describes the option to download digital media files or especially a series of media files over the internet to a portable player or a computer. Using podcasts in the Higher Education (High Ed) environment has driven Apple to offer the iTunes University portal. In spring 2007 already more than 400 US universities and schools collaborated with Apple to podcast teaching units. Podcasts enable students and teachers to share information at anytime. An absent student can download the podcast of the recorded lesson. The main objective is to improve the quality of teaching and to archive the lectures.

Since October 2006 the Institute for Photogrammety of Universitaet Stuttgart, Germany, started the podcast production of photogrammetric modules and related disciplines. Learning from previous e-learning programs, the idea was to keep it simple and to use standards. The basic idea was to record and archive lectures in photogrammetry, signal processing, statistical inference, geoinformatics and remote sensing and providing the recorded lectures/exercises to the students, just after finishing the teaching units. The whole process should not result in a lot of extra work for the staff and should be easily and fast accessible by the students. Furthermore, it should be established in a low-cost environment – a constraint in every university of the world. The key elements can be summarized as follows:

- Improve the quality of the lectures/exercises and the corresponding notes
- Keep the students interested and motivated
- Keep the efforts reasonable and use standards
- Replace blackboard writing by annotating the lecture notes with handwritten explanations (text and formula derivations)
- Offer the annotated lecture notes immediately after finishing the unit (in pdf format)
- Provide downloadable video podcasts of the lecture/exercise at several formats (320*240, 480*320, 640*480)

The pilot project was a great success and was extended in summer 2007 to offer all lectures and exercises of the Institute for Photogrammetry in this manner. Evaluations revealed the positive impressions of the students. Most of them wished all the lectures and exercises in their curricula should be offered in this excellent way of teaching.

To be able to record and display the handwriting, a Tablet PC has to be used. We use Camtasia Studio 4 (TechSmith) as screen video/audio recording and presentation software. The recording hardware and software come off-the-shelve. They are therefore cheap and solve all the tasks necessary. Using the standard equipment the following workflow could be maintained:

1. Convert the lecture notes to a so-called journal file (jnt)
2. Start the video/audio recording software
3. Present the lecture/exercise in front of the students using the Tablet PC, a beamer and a microphone
4. After finishing the lecture/exercise save the handwritten notes into a pdf-file and put it on the web
5. Process the raw video file and put it on the web

The fast availability of the lecture notes and the podcasts increase the acceptance and the usability of the podcasts. The lectures/exercises can be watched several times. This is especially important for foreign students, because they might not understand everything at the first time due to language problems. Being able to hear the difficult parts several times increased their learning success, which was proven by oral examinations later. Although the students did not have to attend the lectures and even could download them easily from the web, the attendance did not decline at all. This interesting fact encouraged us to continue the project and to provide pdf lecture notes and podcasts for all courses.

Giving the students additional teaching material and providing them with the option to learn at a fingertip wherever and whenever they want is a huge step into the future of life-long learning. The possibility to use "cool" gadgets, like Apple's iPod, helps to learn and is improving their motivation. Using the student's inherent interest of game play and fun, more sustainable learning results can be achieved. The Institute for Photogrammetry has a long experience in using computer game engines for applications in 3D visualization, photogrammetry and education (Fritsch, 2003). Based on this experience we developed a learning environment for SAR image interpretation using retail video gaming consoles to assist the practical image analysis training courses.

3. REAL-TIME SAR SIMULATION ON RETAIL VIDEO GAMING CONSOLES

Besides learning the theory of microwave remote sensing, the practical experience of analyzing SAR images is very important. Therefore, it is necessary to analyze various SAR images containing different sensor properties and scenes. Only the experience of examining various SAR images can help the student to develop "SAR eyes" and to be able to immediately recognize the objects of interest contained in a scene, even if they are disturbed by various SAR effects. Because they can deliver defined SAR images of objects, SAR simulators are widely used for this purpose. Even more, simulators can provide thousands of different images of the same object types which would not be possible or affordable otherwise.

Normally a set of training databases containing different SAR simulated objects of interests are created and used for training purposes. Learning by using these training databases of simulated images is normally not very effective. The problem is the monotonous presentation of the data as well as the simplified presentation of single objects without disturbances from surrounding objects. A real-time simulation can overcome these limitations by interactively presenting the results.

3.1 Real-time SAR simulation

The capability to simulate SAR data in real-time by using computer graphics techniques has already been demonstrated (Balz, 2006; 2007). By using the programmable graphics pipeline of modern graphics cards (see Figure 2), the SAR geometry and SAR radiometry can be implemented on the graphics hardware.
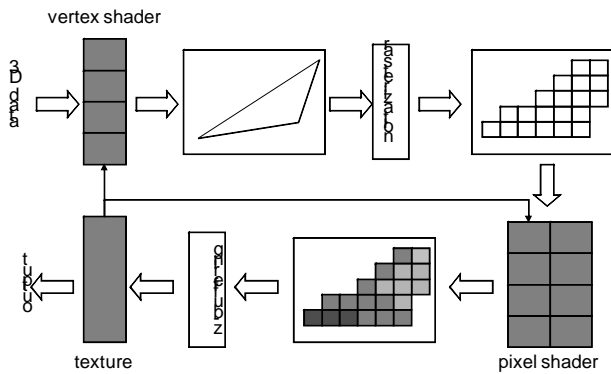
Figure 2. Programmable graphics pipeline

The real-time SAR simulation is capable of high-quality single-bounce simulation, but is lacking double-bounce support. The single-bounce simulation results are comparable to the results of ray-tracing simulators (Hammer el al, 2008).

The 3d data is transformed from the world coordinate system to the screen coordinate system using the vertex shader. By implementing the SAR geometry using the flexible programmable vertex shader, the transformation can be adjusted according to the SAR geometry. By furthermore implementing the SAR radiometry to the pixel shader, a SAR simulator on the Graphics Processing Unit (GPU) can be realized.

The geometry changes due to the implementation of the SAR geometry can be seen in Figure 3. A simple wall is transformed to the SAR geometry. Due to the signal running time geometry, the upper part of the wall is imaged more close to near range.
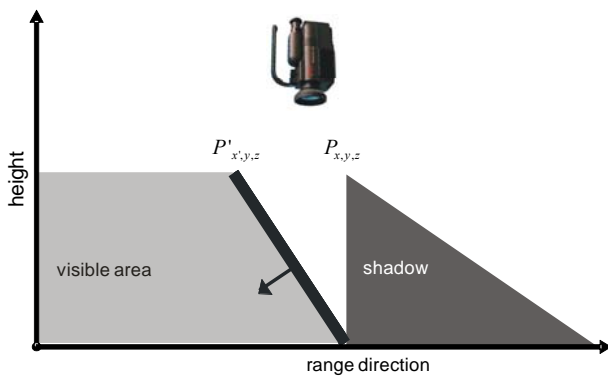

Figure 3. Transformation to the SAR geometry

The virtual camera is placed in nadir position instead of the sensor position to directly visualize ground-range images and to avoid time consuming transformations between slant and ground range. Because of the shift in near-range, several problems occur. First, the backside of the wall is visible instead of the front side. Therefore, no back face culling is possible. Also, when calculating the reflection strength, the sensor position has to be used instead of the virtual camera position. Because of the changes in geometry, z-buffering (Catmull, 1978), cannot be used.

The shadow mapping technique (Williams, 1978) can be used, to calculate shadows and occlusions. This image based algorithm is fast and can not only be used for shadow calculation but also for occlusion detection and is therefore a useable substitute for the missing z-buffer.

Reflections having the same signal running time, but occurring at different positions in the world coordinate system are another problem. These signals have to be summed up. This can be realized easy and fast by using alpha blending. Normally the result of an alpha blending operation σ is calculated from the already available value σ_z, the added value σ_q and the blend values b_q and b_z.

$$\sigma = (\sigma_q \cdot b_q) + (\sigma_z \cdot b_z)$$

b_q and b_z are derived from the alpha value $\alpha_q \mid 0 \leq \alpha_q \leq 1$

$$\sigma = (\alpha_q \cdot \sigma_q) + (1 - \alpha_q) \cdot \sigma_z$$

Using this alpha blending method, the final result depends on the order of rendering. Because the order cannot be guaranteed, the additive alpha blending is better suited for 3d visualizations.

$$\sigma = (\alpha_q \cdot \sigma_q) + \sigma_z$$

With $\alpha_q=1$ the desired effect of additive signals can be achieved.

3.2 Requirements of SAR simulators for training and education purposes

SAR simulators for training and education purposes have to fulfill different requirements as SAR simulators used for mission planning or sensor design. The simulator should be easy and fun to use. The system must simulate in real-time or near real-time to avoid boring and unproductive waiting periods. Furthermore the system should allow the user to play with the scene and the sensor properties and immediately see the results.

The system should support different visualization modes. Simple or complex scenes should be visualized as SAR or optical images. The visualizations should be comparable to aerial or real SAR images of the simulated area, because by comparing the different visualizations, effective learning is possible. Furthermore, by comparing real SAR images and SAR simulated images the student should realize the limitations of the SAR simulations used for basic training.

The user interface design of the educational simulator system should be oriented on computer games. The idea is to give the impression of gaming instead of learning. As input device we suggest a game pad instead of a mouse, although for compatibility reasons a mouse should also be useable on PCs.
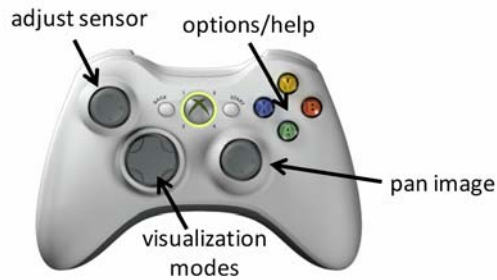
Figure 4. Using Microsoft's game pad as controller for the SAR simulator

The scenes should not be static. The user should be able to move, rotate and accelerate certain objects inside the scene and see the results. The effects of moving objects in SAR are important and the simulator should be able to simulate these effects. The user should have the possibility to interactively change the speed and direction of certain objects and see the results of these changes in real-time on his screen.

We furthermore suggest visualizing single objects of interest in game-like visualization modes. In these modes, objects can be visualized using different sensor properties and the student has to determine the object type and the sensor properties. The more reliable and the faster a user can identify the objects, the higher his score will be. Using these game modes, the student's motivation increases and a faster and more sustainable learning success can be achieved.

Because of their ease of use and administration, video gaming consoles are ideal e-learning devices. They are comparably cheap and they are designed to be usable by everybody. Besides, using retail video gaming consoles as education device has not only the psychological advantage of creating a game-like and fun environment for students to learn, they are also comparably cheap. Because of their standardized hardware, no compatibility issues are to be expected. But the short usage time of the developed software is hindering the development. It is likely that the next generation of gaming consoles won't support the old software. Therefore, we suggest keeping the software code flexible and useable in a PC environment as well as on retail gaming consoles.

3.3 Implementing real-time SAR simulation on a retail video gaming console

From the new generation of retail video gaming consoles, Sony's Playstation 3 as well as Microsoft's Xbox 360 are accessible and programmable by the end user. Sony supports the installation of Linux OS on the Playstation 3 (Bartlett, 2007) and Microsoft's Xbox 360 can be programmed using the XNA Framework (Nitschke, 2007). Sony's Playstation includes the powerful Cell BE architecture, which would be an ideal choice for a real-time or near real-time ray tracing SAR simulator. But the Cell technology is not compatible to standard PCs. Using Microsoft's XNA Framework the developed software can be used on the Xbox 360 and on standard PCs. This offers a high degree of flexibility and guarantees that the software will still be useable on standard PC hardware even if the Xbox 360 is not sold anymore.

Figure 5. Microsoft Xbox 360 (Copyright: Microsoft)

The XNA Framework is based on Microsoft .NET and only supports the C# programming language at the moment. On a PC the whole .NET Framework can be used, whereas on the Xbox 360 the .NET Compact Framework is used. The basic idea of the XNA Framework is to offer hobbyists and enthusiasts the possibility to develop games for the PC and the Xbox 360 as easy and as fast as possible.

The access to file system and network is limited while using the Xbox 360 due to security and stability concerns. XNA offers various useful functions like a game loop or the content pipeline. Using these, the developer can concentrate on the game logic and the content and does not need to bother with basic functionalities. The content used by the application has to be preprocessed by the content pipeline if the Xbox 360 is being used. Therefore, it is not possible to load new content, like a newly acquired scene, during runtime. This is a big drawback for a normal simulation system. For applications in training and education this is no problem, because only predefined scenes are used in these applications anyway. Applications like image analysis depend on the possibility to load new content fast into the system and need the possibility to update scenes or load new scenes and/or background images during runtime. For such applications the Xbox 360 version is not useable, whereas this is no problem for the PC version, because the XNA Framework is not limiting the functionality of the PC version.

To include the material properties into the content pipeline, a new strategy to describe the material properties has been chosen. The backscattering calculation of SARVizEdu is based on the Phong (1975) reflection, modified regarding Ulaby & Dobsons (1989) tables (Balz, 2007). The values to calculate the reflection of a certain material are saved in a 4x32-bit texture with 256x256 pixels. The texture can be interpreted as a database, where each of the 65,536 texture positions represents the reflection parameters of one material. For every combination of radar band and polarization a material database texture has to be generated. Each model which is imported into SARVizEdu is textured according to the material it is consisting of. This texture describes the position of the desired material in the material database. The red value is the x-position and the green value is the y-position. Because the material database consists only of 256x256 values, 8-bit textures are sufficient. Using the material database texture, a lot of GPU memory can be saved because, only the material database texture need to have 32-bit, whereas the models only need 8-bit textures. Furthermore this material description allows for a fast and easy change of the simulated radar band by only exchanging the material database texture. For future generations of SARVizEdu, which may include dif-

ferent backscattering algorithms, the new material properties can be included easily by only exchanging the material database textures. The models and the model textures can be left unchanged.

Deploying the compiled application to the Xbox 360 is easy. Using Microsoft Visual C# 2005, the compiled source is deployed to the Xbox 360 using a LAN connection. The Xbox 360 beforehand has to install the XNA Framework via the internet and the user needs a Creators Club subscription. The Xbox 360 also has to be connected to the internet. After deploying the application, the program can be run on the Xbox 360. Using the PC in combination with the Xbox, the application can even be debugged using Microsoft Visual C# 2005.

Although the applications developed with the XNA Framework should be identically running on the Xbox 360 and the PC, there are some incompatibilities due to hardware differences. In our case the biggest compatibility issue is the alpha blending support. Modern graphics cards support alpha blending textures even for 4x16-bit textures, whereas the Xbox 360 graphics hardware does only support the alpha blending for 4x8-bit textures. Simulating SAR images, 32-bit textures would be desirable, but 16-bit textures are useable. 8-bits are too less to represent the huge dynamic range in microwave backscattering. Encoding the desired 32-bit value into three times 8-bit for the red, green and blue channel (the alpha channel must be used for the alpha blending operations), the most important part of the dynamic range could be kept.

For the GPGPU (General Purpose Computation on Graphics Processing Units) operations implemented, like for example the determination of the side lobe positions in the image, further differences between the Xbox 360 and the PC hardware occur. Obviously the Xbox 360 graphics hardware is saving the texture values internally in a different order as the NVIDIA graphics hardware we used in our PC. The NVIDIA graphics card uses the R-G-B-A order for the red, green, blue and alpha colors, whereas the Xbox seems to use the A-B-G-R order.

Some performance issues have to be regarded while programming on the Xbox 360 and while using managed programming languages for real-time applications. The main processor of the Xbox 360 is slow compared to modern CPUs. The Xbox 360 has six hardware threads and three cores. Using multiple threads can increase the speed drastically. The GPU of the Xbox 360 is fast. Applications which depend mainly on the GPU speed will run fast on the Xbox 360.

Managed programming languages are often criticized to be too slow. Although this is not true for most applications, one reason behind this criticism is the negative effect of the automated garbage collection on real-time applications. Although automatic garbage collection is a big improvement in software design, real-time applications can be disturbed by the automated garbage collection. The garbage collector could use CPU speed at the wrong moment and disturbing the visualization. This can lead to a sudden drop of the applications frame rate. This effect can often be avoided by generating as less trash as possible and by calling the garbage collection manually at suitable times like scene transitions.

4. EXAMPLES OF APPLICATIONS IN EDUCATION

For applications in training and education, usability is of utmost importance. An educational tool which requires a long training period before it can be used is not helpful. Using the application should be fun and easy. The GUI has to be designed to meet these requirements and to give the impression of playing a computer game (see Figure 6
Figure 6).

Figure 6. SARVizEdu user interface

The application is easy to use and the user guidance is almost similar on the PC and the Xbox version. The PC version is supporting mouse and keyboard as well as a game pad as input tools. The Xbox version only supports a game pad. The user interface has to be designed to support all input methods equally comfortable.
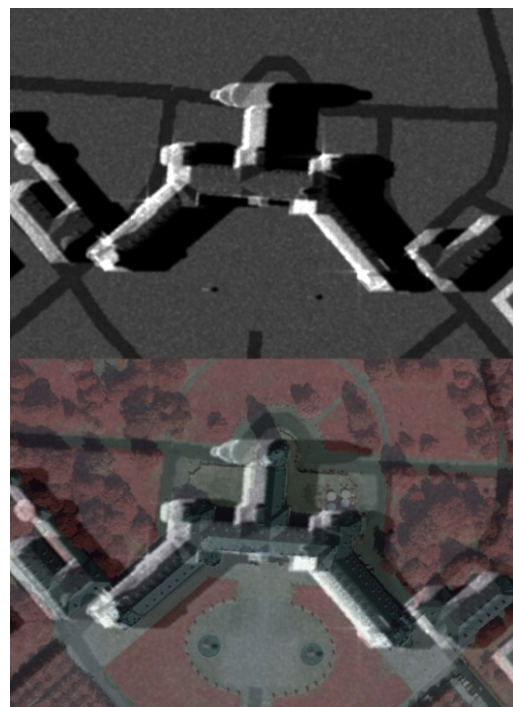

Figure 7. SAR simulation (up) and simulation overlaid with an aerial image (down) of the area around the Palace of Karlsruhe

To support training and education, SARVizEdu offers various visualization modes. The basic mode is the visualization of realistic SAR scenes from real world examples. As depicted in Figure 7
Figure 7, the SAR simulation can be compared to aerial or SAR images if available. The SAR sensor properties can be changed on a fingertip and selected models can be moved, rotated or accelerated. This way, the basic SAR effects can not just be seen, but experienced. In addition more complex SAR effects, like moving objects, can be simulated. The student can test these ef-

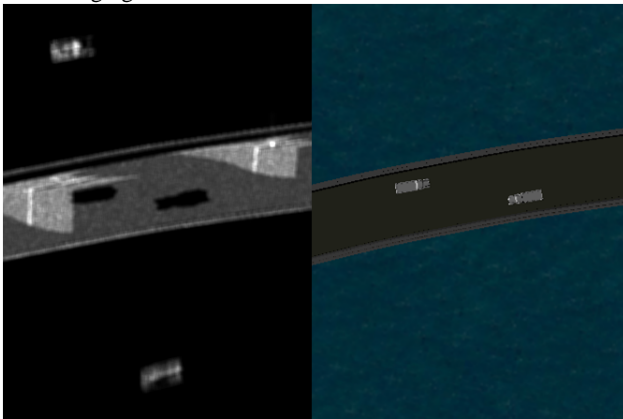fects and can directly experience the effect of movements on SAR imaging.

Figure 8. SARVizEdu simulation and visualization of two trucks moving over a bridge

Additionally some special modes for object recognition training can be used. In these gaming modes, the simulator is simulating a single object using either pre-selected or random SAR sensor properties. One game like mode is a memory game of different simulated objects. Two identical objects have to be identified. These objects consist of either one SAR simulated object and an optical visualization of the same model, or of two SAR simulated objects but with different SAR senor properties. A screenshot of the game is depicted in Figure 9.
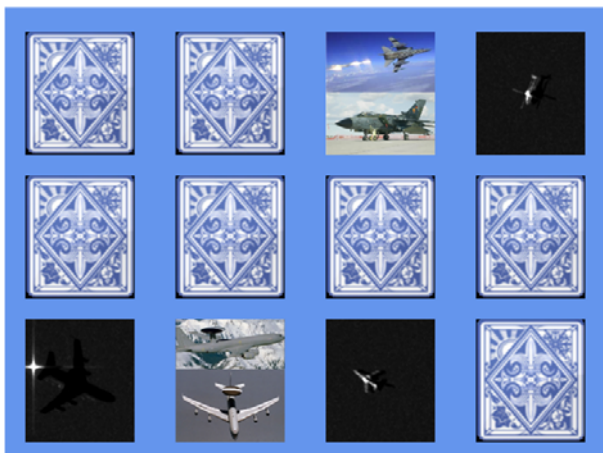

Figure 9. SARVizEdu visualization in the "memory game" mode

The second game mode gives the student a mission which he has to solve in a limited time. In the style of the TV series "24", the student has to help a "special agent" analyzing radar remote sensing data (see Figure 10 Figure 10). In only 48 seconds he has to analyze the simulated image and mark the target in the image. To improve the fun and the learning effect the student can change the sensor properties in real-time, because the object he is searching for might be hidden in a shadow or layover area.

Especially the "48 seconds" mode contains the basic elements a serious game should contain according to Prensky (2001): fun, play, rules, a goal, winning and competition. The students stay motivated and actually keep learning a lot about SAR object recognition without them even knowing. This effect has been

called "stealth learning", a term which originates from Doug Crockford while working on an educational title for LucasArts.
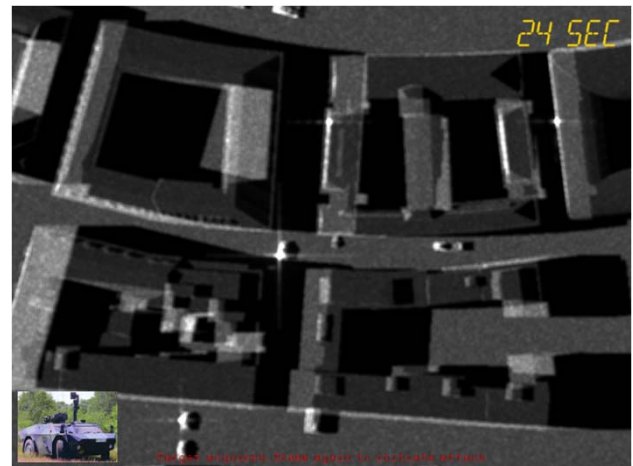

Figure 10. SARVizEdu viusalization in the "48 seconds" game mode

5. CONCLUSION

While teaching complex subjects, like radar remote sensing, it is difficult to keep the students motivated. This is even truer for the training of military personnel, where the trainees are less used to learn from the books. To keep them motivated and interested, the lectures can be assisted by podcasting and automated script generation as described above.

The students' desire to play can be used for a digital game based stealth learning approach. Using podcasts and retail video gaming consoles can drastically increase the students' motivation and improve the learning success. This can even be achieved without high costs or a lot of extra work for the staff. Even more, the podcasts of all the lectures can be archived and the additional pdf-script for each lecture/exercise is available for the students without any extra work for the teaching staff. Even the video generation and uploading of the files is mostly automated. Still learning the theoretical background of radar remote sensing requires effort and concentration. Assuming this could be all fun and easy is wrong and misleading. But offering podcasts and automated scripts of the given lectures offers the students the possibility to learn whenever and wherever they want.

Using a SAR simulator for learning SAR image analysis cannot replace the experience of analyzing real SAR images. But it can reduce the amount of real images needed and it can loosen the lectures and motivate the students. Especially for beginners, the real-time SAR simulation is useful to understand the basic SAR geometry and radiometry principles.

Today's gaming devices provide high-performance computing at low costs. They are fully programmable and the high flexibility of these devices allow even for real-time SAR simulation applications. Using Microsoft's XNA Framework the developed software can not only be used on the Xbox 360, but is also useable on standard PCs. This guarantees a high degree of flexibility. Although managed programming languages are often regarded as slow and the Xbox 360 is not as fast as modern gaming PCs, the real-time SAR simulator SARVizEdu was implemented on the Xbox 360 using the XNA Framework. Real-time simulation of complex scenes is possible on the Xbox 360 and because the application's speed depends mostly on the GPU performance,

no major slowdown due to the comparably slow Xbox 360 main processor or the managed programming language could be detected.

The combination of podcasted theoretical lectures and high-performance real-time SAR simulation on retail video gaming consoles offers a new, fast, efficient and sustainable way of training and educating radar remote sensing.

The implemented serious games used for training and education are using the young people's experience with computer games for a fast and sustainable learning effect.

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