SAR² - An Augmented-Reality App for Exploration of Principles of Synthetic Aperture Radar

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Abstract

SAR² is a prototype educational simulation software for the Microsoft Hololens, developed by students as part of a geoinformatics course. The aim of this software is to provide a tool to introduce and explain the concept of synthetic aperture radar (SAR) to students, as well as the general public, by visualizing and interactively exploring the process of a SAR acquisition in a 3D virtual environment.

A distinctive feature of SAR² is that the SAR acquisition procedure is simulated in real time within a Unity Engine environment, using a set of algorithms which replicate the real-life SAR processing algorithms. While this provides a challenge due to the limited computational power available on the Microsoft HoloLens 1 device, it allows maximal freedom to the user in setting whatever configuration they would like to see. This would not have been possible if an approach using a pre-selected set of scenarios was chosen.

The augmented-reality (AR) app works in 3 phases:

- In the first step, the user is shown a terrain model, and a satellite model inspired by the TerraSAR-X. The user can adjust selected parameters of the acquisition by manipulating the satellite and model using intuitive AR controls (e.g. by physically grabbing and rotating the objects with their hands).
- After configuring the parameters, the user launches the acquisition and observes it in real time. The satellite model flies over the terrain, and the "flow" of the data into the storage is immediately visualized.
- After the acquisition is finished, the user can explore the focusing procedures that need to be applied to the data - namely the range and azimuth compression. Different geometrical effects (shadowing, layover) can also be explored at this stage.

The SAR² app used in concert with conventional educational approaches can reinforce the learned material, clarify misconceptions, and provide intuition for the complicated concepts of synthetic aperture radar.

Keywords
augmented reality, public outreach, synthetic aperture radar, visualization

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Acronyms/Abbreviations

AR	*Augmented Reality*
SAR	*Synthetic Aperture Radar*
SAR²	*Simulated Augmented-Reality Synthetic Aperture Radar*
VR	*Virtual Reality*

1. Introduction

Synthetic aperture radar (SAR) is a powerful method for monitoring of the Earth's surface using ground-, air- and space-borne sensors [1]. It can operate at any time of day, and in all weather conditions. Because of this, it has become one of the main sources of global-scale environmental data, with widespread socioeconomic impacts in areas of agriculture, disaster prevention/response, climate change monitoring and many others [2,3]. Due to these impacts, the method and its capabilities are often the subject of discussions between not only subject matter experts, but also policymakers, researchers from other fields, as well as students and members of the public. The method and its principles are however quite complex, making use of advanced signal processing algorithms. There thus exists a natural gap between the educational resources currently available (mainly university courses, demonstration videos, and webpages [1,4,5]), and the need for a relatively simple way to explain the principles of the method to non-experts. There is a temptation to use simplified explanations, which can however lead to misinterpretation of the method's capabilities and its limitations.

Education of SAR principles is challenging also due to absence of practical, small-scale educational models. Most SAR sensors are deployed on spaceborne or airborne platforms, and ground-based sensors remain costly and impractical for classroom or indoor demonstrations. There exist educational resources for building one's own low-cost SAR instruments [5], which is undoubtedly a very engaging pathway towards complete understanding of the SAR principles. However, the technical expertise and time investment necessary for such a project are too high for most members of the public. An alternative, less costly approach towards this challenge is use of virtual-reality (VR) or augmented-reality (AR) environments. Such an approach has been already used in other educational efforts [6-9]. This approach allows seamlessly downscaling SAR observations from hundreds of kilometers down to several meters. Furthermore, it imposes no additional hardware requirements besides the availability of a VR/AR device, and offers great flexibility in terms of preparation of specific demonstration scenarios, as well as repeating experiments.

SAR² (pronounced as "*SAR squared*," formerly HoloSAR) is an application for the AR device Microsoft HoloLens, which demonstrates SAR acquisitions on the human scale within a virtual environment. In order to maximize user freedom and verisimilitude of the simulation, it implements real-life SAR processing algorithms.

2. Development

SAR² was developed in 2020 as part of the ETH Zurich course GIS and Geoinformatics Lab. A key developmental decision was a complete implementation of a SAR acquisition simulation within the virtual environment of the Unity Engine, which computes the acquisition outcomes in real time while the application is being used. This allows for complete freedom in exploration of various acquisition configurations, and exploration of different phenomena which affect SAR acquisitions.

This developmental decision however imposed a performance bottleneck, since the simulation needs to be performed in real time on the Hololens device, which offers limited computational resources. Through use of graphics processing shaders, background processing, and parallelization [8], reasonable real-time performance was achieved. Processing of the data was implemented in a matter replicating the real-life SAR processing pipelines. Notably, azimuth compression – a key processing step for SAR data – is implemented using the real-life range migration algorithm [9].

3. Usage

The interaction of the user with the augmented-reality app can be roughly separated into three phases:

3.1. Setup

The user is shown a 3D environment with a SAR satellite model, a model of the Earth's terrain, and several basic shapes, which can serve as test targets. The user can manipulate (reposition, rotate, and scale) the models using the AR touch controls. Furthermore, the user can manipulate several settings of the SAR sensor, namely the start and end position of the acquisition, the look angle, and the antenna parameters (width, height, maximal range).

An interesting phenomenon to explore is the effect of the antenna dimension on the angular coverage of the resulting beam of radar waves. A demonstration of this phenomenon within SAR² is shown in Figure 1.

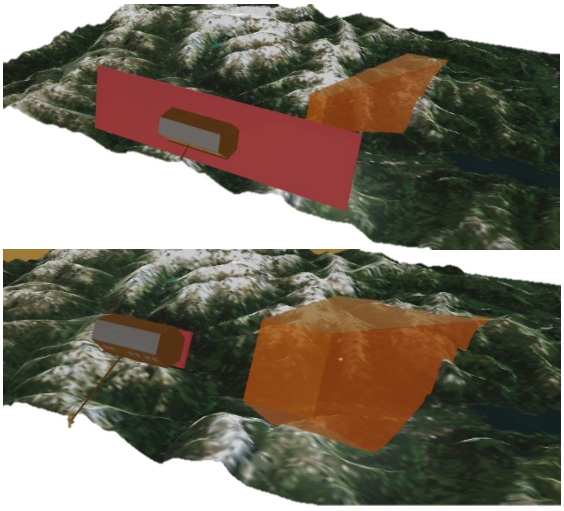

Figure 1: Demonstration of the effect of antenna size (visualized in red) on the resulting radar beam (visualized in orange). For narrower beam widths, which are desirable to achieve high resolution, an antenna with unpractically-large physical size is required (top image). Such antenna is not possible to operate on a spacecraft. This makes the synthetic-aperture approach attractive, since high resolution can be achieved also with smaller antennas (bottom image).

3.2. Acquisition

Once the user has configured the desired acquisition geometry, the acquisition is triggered with the push of a button. The satellite flies over the model of the terrain, and the line-by-line "flow" of the data is immediately visualized.

3.3. Evaluation

The acquired image is yet not compressed in the azimuth direction. The user can trigger the application of the range migration algorithm to compress the image, and retrieve the final single-look complex (SLC) image. This can be explored for features (such as shadowing, foreshortening, layover...), and also stored for later comparison.

The setup-acquisition-evaluation loop can be repeated several times in order to explore effects of different acquisition parameters on the final result. A demonstration video of the use of an earlier SAR² prototype can be viewed online [10].

4. Discussion

While SAR² was developed with use of the augmented-reality headset Microsoft Hololens in mind, owing to its implementation in Unity Engine, it can be quickly adapted to other platforms, such as Android phones or virtual reality headsets. Currently, only individual use of the application is possible (i.e. multiple users cannot share the same virtual environment). However, the HoloLens offers multi-user capabilities, which can be applied in the future in order to allow multi-user operation and facilitate further interaction between the educator and the audience.

The app, used in concert with conventional educational approaches, can reinforce the learned material, clarify misconceptions, and provide intuition for the complicated concepts of synthetic aperture radar. The availability of augmented-reality devices, and their track record in educational use [6,7,11,12], opens up opportunities of the approach for other topics related to space activities (e.g. orbital mechanics, interplanetary mission planning etc.). Development of such applications can also be an educational activity in itself and can be carried out as part of a university course, or a bachelor/master thesis -- students often already have experience with the needed development environments, and the process of development of the software would reinforce the student's understanding of the given concept.

5. Conclusions

SAR² can offer an alternative, engaging approach towards demonstration of synthetic aperture radar principles. It can be used as a public outreach tool in museums, science fairs, and similar environments. Furthermore, it can serve as a complementary tool to conventional, more rigorous explanatory methods in higher education remote sensing courses.

Acknowledgements

The authors would like to thank the GIS Lab at ETH Zurich for supporting the development of SAR², the ETH LET office for providing the hardware, and Pol Villalvilla and Philipp Bernhard for fruitful discussions regarding naming of the software.

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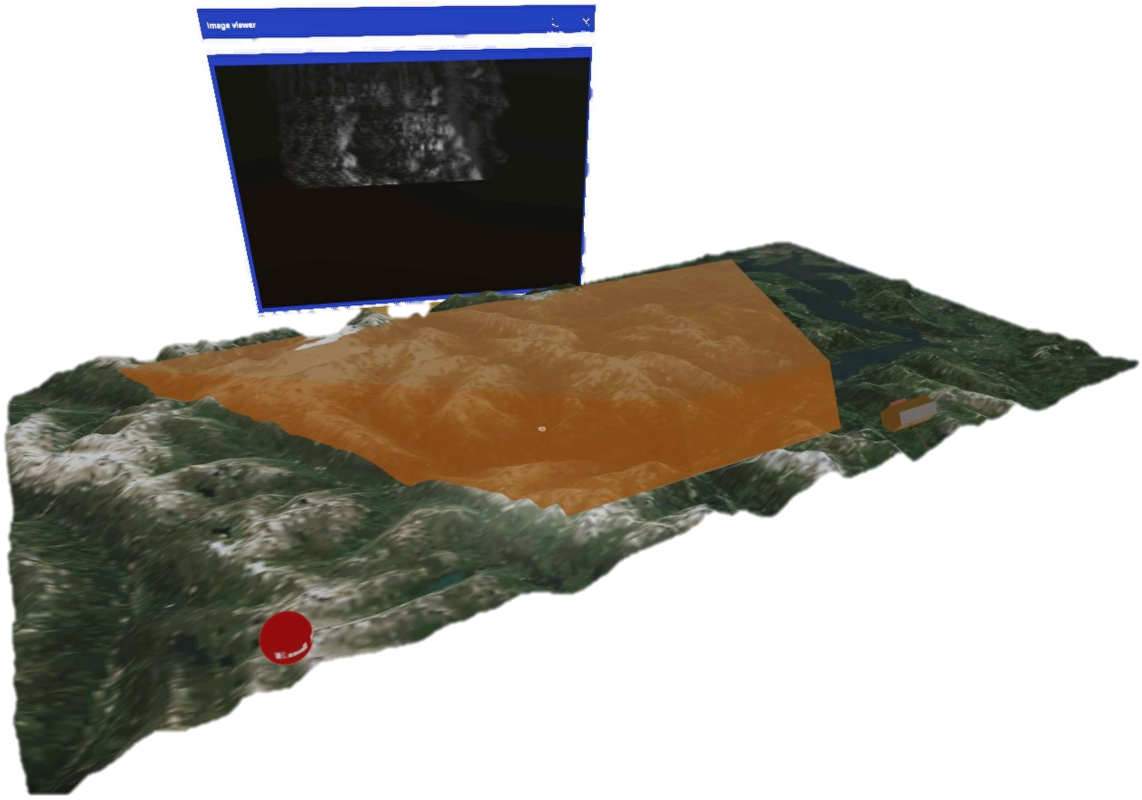

Figure 2: SAR² demonstrating an acquisition over a virtual terrain model of the St Gotthard region of the Swiss Alps. The acquired radar data is immediately visualized on the display panel in the top part of the figure.