Immersive Analytics for Geology: Field Sketch-Like Visualization to assist geological structure analysis during fieldwork

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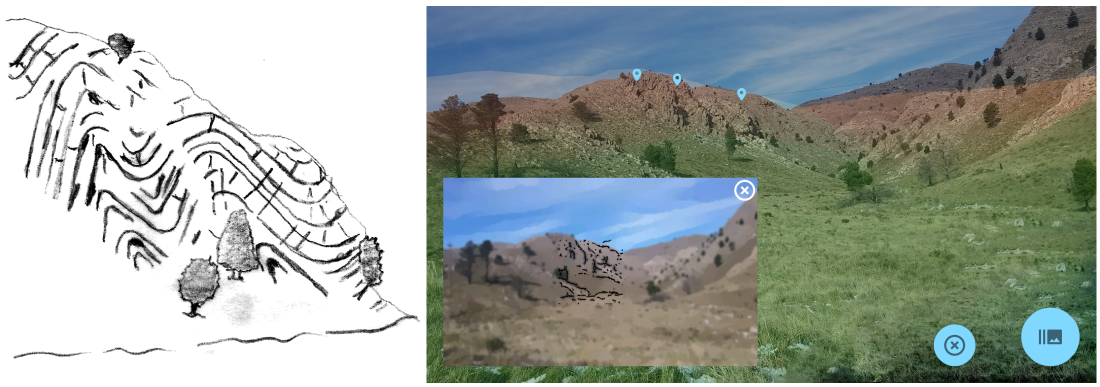

Figure 1: (Left) Common field sketch drawn by geologists during their usual workflow for analysis and interpretation of folded rocks. (Right) The proposed Augmented Reality (AR) system to assist geologists during the fieldwork. It allows the incorporation of geo-tagged information and it incorporates a sketch-like visualization (at the bottom left) that helps to analyze the complex geological structures.

Abstract

We explore if and how immersive analytics, in particular AR and Sketch-Like Visualization, can be used to support the geologists' field workflow. Fieldwork involves careful observations and measurements in the field, the collection of rock and fossil samples and the recording of complementary information for further analysis. In the field, the workflow comprises in-situ hand drawing of sketches through careful observation of the area to be explored and the incorporation of all the data that the geologist collects in the field to these drawings. This implies that a constant association of 2D (sketch)-3D (real environment) information is being carried out at all times, taking into account a previously defined scale of work. Our main goal is to support the field workflow integrating the real environment with an automatically generated sketch to facilitate the geologists' fieldwork. Our system is based on an interactive AR approach on mobile devices. We evaluated the introduced approach using a real-life case study. User feedback and observations from our interdisciplinary team indicate the utility of the approach for the current case study as well as some shortcomings and areas for future research.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities;

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1 Introduction

Advances in mobile devices have benefited the analysis of on-site visualizations for interactive exploration of data. These tools can play a crucial role for professionals of earth sciences, such as geologists, since they usually spend much of their time performing fieldwork, collecting samples and making measurements and observations. This workflow is performed by geologists to understand earth processes at any given location, and it opens up a lot of possibilities to explore AR based systems that could help them in carrying out their field activities. Based on an interdisciplinary work between professionals of Computer Science and Geological Science, we explored how immersive analytic tools can be seamlessly integrated to a case study of geologists' workflow.

First, they usually make a careful inspection of the region they are going to work on, to identify the location of the features they are going to analyze. This actual process is complemented by drawing paper sketches (see Fig. 1 (Left)) in the field to record key geological information (i.e. folded structures) or important visual references that must be taken into account later on. Afterwards, they move to the selected locations to perform the sample extraction and data measurement, also dumping this data on the respective sketch. In this stage, it is crucial to keep track of the initial overview of the location, which can be interpreted from the field sketch drawn previously.

A big challenge and useful approach is to assist the geologist fieldwork supporting the described workflow. The goal of this work is to enable the geologist to explore the environment using a fully interactive augmented view by means of a virtual terrain. Furthermore, we integrated the concept of field sketches to fill the gap of the constant association between 2D (sketch on paper) and 3D (real environment) information, and to provide an interactive visualization of recorded viewpoints. Our proposed immersive tool assists the geologist in analyzing geological features of the geological information, easing the spatial interpretation of the environment. It smoothly runs on current smartphone and tablet Android devices.

We can summarize our main contributions as follows: (1) The integration of immersive analytics techniques to a case study which combines AR with an interactive visualization which resembles the field sketches performed by geologists. (2) The results of a user study of the geologists' interaction with the proposed immersive tool. (3) Interesting insights of the remaining challenges for the geological context as an area for further exploration of immersive analytics.

2 Immersive Analytics in Geosciences

Fieldwork involves making careful observations and measurements in the field, which can be really challenging even for experienced professionals [2]. This strong visual approach for the measurement and analysis of geological data becomes an excellent area to explore the application of immersive visualization and analytics [8].

Geovisualization in immersive environments was explored by means of Virtual Reality. Westerteiger [14] described how useful immersive technologies can be used for the fieldwork planning and for the analysis of the data samples. In fact, complex 3D volume data can be intuitively explored using immersive environments [1].

Thanks to the massive adoption of mobile devices, immersive technologies can be used in a broader sense, including the application of visualization methods for data gathering and analysis during the fieldwork. AR simplifies the comprehension process of understanding geological data by showing relationships among data to the surface. AR devices have been proved to offer significant improvements when performing complex tasks and in the interpretation of complex systems in the real world [5, 6, 10]. In-situ visualization by means of AR was explored to present on-site visualization and interactive exploration beyond tabular data and basic 2D plots [12]. Extended overview techniques were also evaluated using AR in outdoor environments, in order to overcome the problem of data visualization over large areas [13].

AR has proven its potential in this area, as its main feature is to assist the user during the interpretation of 2D data and the corresponding 3D features in the real environment. Moreover, taking care of the visual coherence of the output image (i.e. spatial registration and visual cues) and the application of situated visualization techniques [7, 11] (i.e. visualization techniques used to present AR information) grants a more effective integration of augmentations within the real scene. However, outdoor AR still has some well known drawbacks mainly due to limited device capabilities [11]. For instance, the display technology and the built in inertial and orientation sensors tend to be inaccurate. In addition, the necessity of all these sensors in conjunction becomes a problem in terms of energy consumption. Another challenging problem is to incorporate the proper interactions to explore data, since the augmentations must complement and not obscure the conducted work by the user.

Nevertheless, there is still an open opportunity to further incorporate these technologies to different activities conducted by professionals of geosciences. Our case study analyzed and evaluated the workflow performed by geologists to study and understand geological data. In particular we explored the potential of combining AR and sketch-like interactive visualizations to assist the analysis of geological structures. Based on the conducted evaluation we show how these technologies help to bridge the gap between the current data exploitation they are used to, and the one offered by the immersive analysis. Based on our experience in interdisciplinary research work, we envision an increasing interest of professionals of other areas to incorporate immersive and interactive exploration to their respective fieldwork.

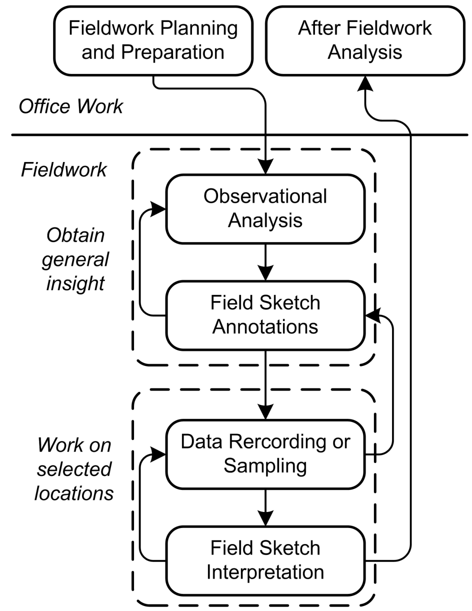

Figure 2: Typical workflow performed by geologists to analyze and interpret folded structures.

3 Immersive Interactive Sketch-Like Visualization

3.1 Typical workflow: Geological Mapping

Geologists fieldwork oriented to folded structures interpretation involves a careful iterative observation process (see Fig. 2). Even though the prior fieldwork planning and preparation is an important task that can be done in the office, the actual fieldwork becomes a really daunting activity because of its both observational and interpreting nature. Geological folds can be clearly observed from distant points of view (see Fig. 1 (Right)). The geologist can observe the field attitude of folds, vital information to interpret the complex geological processes responsible of their formation. During this stage the geologist obtains a general insight and takes notes of the relevant features to be measured, which means bearing and inclination angles.

However, in areas subjected to several episodes of folding it is really challenging to identify the measurement location, which has been previously defined from a distant viewpoint. Working on each selected location involves a complex constant association between 2D information depicted in the sketch, and the 3D information present in the real environment. In fact, the geologist must be cautious enough to not bias their attention to the folds that can be easily recorded because of the references present in the environment (i.e. trees in the field or distinctive rock structures).

Finally, after the fieldwork the geologist analyze the collected data in the laboratory. Nevertheless, the drawn sketches over the fieldwork are still useful to link the gathered data to the outdoor environment.

3.2 Proposed Immersive Tool

We focused on the described workflow and explored an immersive analytic tool to assist the geologist on two main steps:

- to get a general insight of the area of work.
- to work on the selected locations.

The developed immersive tool provides a 3D terrain overlay that can be used to incorporate geo-tagged information (see Fig. 1 (Right)). Moreover, the geologist can take a snapshot of the location he/she is observing and will explore later. This snapshot is useful

Figure 3: (Top) Example of geological folds. (Bottom) The same image but with the sketch-like visualization used to enhance the features of the folds.

for the next step, because it allows to relate points of interest identified in the overview with the actual location of the geologist in the field. It also comprehends an interactive sketch-like visualization associated to the area where the measures are going to be taken. Furthermore, the geologist can use finger gestures on the snapshot to move a virtual window that encloses a visualization enhancing the edge features of the folded structures (see Fig. 3). Regarding to the second main step of the traditional workflow, the system allows to add environment information, and the geologist can still interact with the sketch-like visualization to further interpret its features using the collected data.

In addition to these features, the immersive tool has a great advantage because it can be seamlessly incorporated to the traditional workflow. This is due to the integration of elements to the immersive system that are present in the typical workflow (e.g. sketch, maps, compass, GPS devices, etc.). It does not replace the traditional tools, but offers an integrated view of the environment allowing to get insight of relationships among geological data that otherwise would be difficult to discover. For instance, it grants an augmented view of the environment, easing the link of 2D information to the 3D nature of the geological structures. Moreover, the interactive sketch-like visualization is relevant when the geologist is collecting data, because it allows to keep track of the points of interest identified from a distant point of view and those on-site location where the geologist is actually making the observations and measurements (i.e. distant view in contrast to on-site view).

3.3 Sketch-like visualization based on a edge detector

In this prior stage, the sketch-like visualization that resembles the field sketch drawn by geologists was designed mainly as an edge detector over a non-photorealistic rendering. It consists of two main steps: (i) apply the edge detector to the moving window and (ii) overlay the result of the first step over a non-photorealistic version of the image.

The step (i) consists on downsampling the input image applying n-steps of a median blur (the number of steps depends on the image resolution). The edge features are obtained using an adaptive threshold. The output from this step is an image with edge features.

The step (ii) involves obtaining a reduced color palette of the initial image. We used a bilateral filter to reduce the color palette of the image (method generally used to produce cartoon effect images). Then the result from the previous step is combined with this color reduced image.

Finally a couple of post-processing methods are applied to the result of this second step. It consists of a skeletonize method followed by an open-close morphological operations to obtain sharpening edges. As a result, the final image to be displayed is obtained.

3.4 Methods and Implementation

Since we wanted to focus on common mobile devices due to its massive use, we developed the immersive AR tool using the Android platform. We used OpenCV to detect features in the images and OpenGL ES 3.0 to render the results of the feature detection. The render engine and critic time tasks were fully implemented using the Native Development Kit (NDK) and Java Native Interface (JNI) allowing a fluid real-time performance experience.

We have a fully-functional immersive system in which the user is provided with an interactive augmented view using a virtual terrain superimposed over the real one. We use Digital Elevation Models (DEM) provided by the Shuttle Radar Topography Mission (SRTM), as height maps for the terrain synthesis [4]. Due the limitations of the hardware available in commercial mobile devices we used the lower resolution 3 arc-second per tile SRTM instead of the 1 arc-second SRTM. Since large terrain height maps contains billions of samples, still far too many for render interactively by brute force [9] we choose Geometry Clipmaps as the Level of Detail (LOD) technique to allow real-time rendering. The render engine design was based on the 3D virtual globe engine presented by Cozzi et al. [3].

The user can add billboards, virtual 3D models and pick positions over the terrain. Also the user can store all the data gathered in the field in an internal database, this includes storing the position of multiple points of interest and sketches from different viewpoints.

4 User Evaluation

We designed a user evaluation to measure the potential of the proposed tool. After a short introduction to the system, we proposed to conduct their usual workflow assisted by the system. Five geologists of ages from 30 to 57 with mean of 44.0 were the participants of the formal evaluation (three males and two females). There was no restriction to the time spent in each session and we observed taking notes of how they performed the evaluation. We conducted the evaluation in Sierra de La Ventana, Buenos Aires, Argentina because it is interesting from the geological point of view and also because the geological structures can be measured in a relative accessible mountains zone (1200 m.a.s.l.). The devices used were two smartphones, a LG Nexus 4 with a 4.7" display and a LG G3 D855 TITANIUM with a 5.5" display. A Samsung Galaxy Tab S with a 8.4" display was also provided.

Observations and Feedback

Several observations were generated during our interdisciplinary work, and we also obtained a rich feedback from the geologists that performed the fieldwork evaluation. We consider relevant, as the system is in an early stage, to expose feedback details collected during this initial evaluation. We observed and perceived that participants really engaged interacting with the system. From a questionnaire interview (5 best positive score, and 1 worst negative score) the overall result was positive towards the system ($mean = 4.2$, $sd = 0.84$). Participants considered that the system complements their fieldwork (*mean* $= 4.2$, *sd* $= 0.84$) and that it is easy to use (*mean* $= 4.0$, *sd* $= 0.7$). They acknowledged that the visualization was of significance to their geological structure analysis (*mean* $= 4.2$, *sd* $= 0.45$). However, from the questionnaire it was not clear if the system was cumbersome or if it caused fatigue (*mean* $= 3.8$, *sd* $= 0.45$).

The geologist appointed that the generated sketch-like visualization helps to perceive information that is difficult to see or is hidden at first sight. Folded structures that are hard to notice on-site are more easily recognized with the proposed sketch-like visualization. Besides on this initial stage the visualization is based on a edge detector, the geologists liked the results it provides because it highlights features that they could not pay attention at first sight. They are used to interpret the fault in terms of its curvature. This observation deserves to be further analyzed conducting more tests with a fully interactive sketch visualization. The domain experts are enthusiastic about this future improvement.

Geologists also noted that the system can integrate in a single view many of the workflow's common used tools, like geological maps, compasses and sketches. They adopted this integration very soon and gave us a very positive feedback which confirms the usefulness of our proposal. We observed that even though the system provides a useful tool that integrates different elements of the fieldwork, it does not replace them. The geologists continued to use their traditional tools for some tasks such as log annotations, GPS device and compass to obtain the samples positions and orientations. In some degree, we consider this as a positive feature, because it reflects how the proposed system can seamlessly be integrated into the traditional workflow. However more tests around this hypothesis are planned to be taken into account.

5 Future Work

The proposed sketch-like visualization allows to interactively move the virtual window that encloses the edge features enhancement but it does not provide interactions to further edit the generated visualization. We plan to incorporate more interactions to allow the sketch edition by the user.

The feedback obtained from this early stage points out that the sketch-like visualization based on a edge detector was surprisingly useful for these professionals. However we plan to extend the edge detector to highlight more precisely the geological folds in a similar fashion as the sketches drawn by the geologists. This is a really challenging goal, and to cope with it we plan to explore more sophisticated methods such as deep learning techniques.

6 Conclusion

In this paper, we explore the potential of immersive analysis and real-time on-site visualization applied to geologists fieldwork. We show how these technologies can be incorporated as a complement to the typical workflow carried out by these professionals. We consider that the most successful features of this case study are: (1) the possibility to link the measured 3D structures with the features marked in the sketch-like 2D visualization in an immersive fashion, and (2) the integration of several elements present in the case study workflow which granted a higher degree of immersion with the proposed tool.

We look forward to continue working in this direction, adapting and enhancing the immersive tool using the feedback obtained in the evaluation test. The obtained positive outcome indicates how immersive analytic tools seamlessly integrate to this context. We consider that the main remaining challenge is to continue analyzing to what extent both worlds can complement each other. For instance, measuring to what extent immersive tools extend the traditional workflow or even replace some portions of it. In fact, we believe our results can be extended to other contexts involving outdoor activities.

References

[1] M. I. Billen, O. Kreylos, B. Hamann, M. A. Jadamec, L. H. Kellogg, O. Staadt, and D. Y. Sumner. A geoscience perspective on immersive 3D gridded data visualization. *Computers and Geosciences*, 2008. doi: 10.1016/j.cageo.2007.11.009

[2] A. L. Coe. *Geological field techniques*. Wiley-Blackwell, 2010.

[3] P. Cozzi and K. Ring. *3D engine design for virtual globes*.

[4] T. G. Farr, P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, M. Kobrick, M. Paller, E. Rodriguez, L. Roth, D. Seal, S. Shaffer, J. Shimada, J. Umland, M. Werner, M. Oskin, D. Burbank, and D. Alsdorf. The Shuttle Radar Topography Mission.

[5] S. Feiner, B. MacIntyre, T. Höllerer, and A. Webster. A touring machine: Prototyping 3D mobile augmented reality systems for exploring the urban environment. *Personal Technologies*, 1(4):208–217, 12 1997. doi: 10.1007/BF01682023

[6] A. Fond, M.-O. Berger, and G. Simon. Facade proposals for urban augmented reality. In *16th IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, 2017.

[7] O. Hugues, J. Cieutat, and P. Guitton. GIS and augmented reality: State of the art and issues. In *Handbook of Augmented Reality*, pp. 721–740. 2011. doi: 10.1007/978-1-4614-0064-6_33

[8] O. Kreylos, G. W. Bawden, T. Bernardin, M. I. Billen, E. S. Cowgill, R. D. Gold, B. Hamann, M. A. Jadamec, L. H. Kellogg, O. G. Staadt, and D. Y. Sumner. Enabling Scientific Workflows in Virtual Reality. In *Proceedings of the 2006 ACM International Conference on Virtual Reality Continuum and Its Applications*, 2006. doi: 10.1145/1128923.1128948

[9] F. Losasso and H. Hoppe. Geometry Clipmaps: Terrain Rendering Using Nested Regular Grids. 2004.

[10] G. Schall, E. Mendez, E. Kruijff, E. Veas, S. Junghanns, B. Reitinger, and D. Schmalstieg. Handheld Augmented Reality for underground infrastructure visualization. *Personal and Ubiquitous Computing*, 13(4):281–291, 5 2009. doi: 10.1007/s00779-008-0204-5

[11] D. D. Schmalstieg and T. Hollerer. *Augmented reality : principles and practice*. Addison-Wesley Professional, 2016.

[12] E. Veas, R. Grasset, I. Ferencik, T. Grünewald, and D. Schmalstieg. Mobile augmented reality for environmental monitoring. *Personal and Ubiquitous Computing*, 17(7):1515–1531, 10 2013. doi: 10.1007/s00779-012-0597-z

[13] E. Veas, R. Grasset, E. Kruijff, and D. Schmalstieg. Extended Overview Techniques for Outdoor Augmented Reality. *IEEE Transactions on Visualization and Computer Graphics*, 18(4):565–572, 4 2012. doi: 10.1109/TVCG.2012.44

[14] R. Westerteiger. Virtual Reality Methods for Research in the Geosciences. 2014.