Techniques for localized data representation in Augmented Reality

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Abstract

In this paper we discuss techniques for localized data representation in Augmented Reality (AR) by showing the existing visualization techniques. A visualization allows to transform raw data into a simple visual representation and several techniques can be used depending on the data. To display localized data, it is necessary to use these visualization techniques in a context. Context-driven visualization allows the display of information that is related to the real-world environment. The visual representation is strongly tied to a physical referent in a geographical location or to an object, a sensor or the scene itself. When visualizing data in AR, it is important to take into account the depth cues but also the overload of data displayed, the scale of the virtual element and the uncertainty or else it will produce inconsistencies and misunderstandings of the data.

Keywords— augmented reality; situated visualization; embedded visualization

1 Introduction

Data visualization in Augmented Reality (AR) is a rapidly growing field that combines data visualization techniques with AR technology for a better understanding of the data set. The use of AR allows a user to overlay data over the real world environment thanks to different tools such as Head Mounted Display (HMD), mobile devices or projectors.

In this paper, we focus on localized data which refers to information that is specific to a location or a geographic area. These data can be of numerous types including 1D/2D/3D and can be discrete or continuous. There are several ways to display them, more or less suitable depending on the environment or the data itself. Some visualization techniques may cause some issues due to AR's limitations and must be taken into account to avoid misunderstandings.

To write this paper, I started by reading the articles provided by my lecturer. To find others, I used a keyword based search using "augmented reality", "situated visualization" and "data visualization" and I selected in priority the reviews and survey in Google Scholar or ResearchGate. For the articles that describe a precise visualization technique, I chose those that were referenced in these reviews.

The remainder of the paper is organized as follows. Firstly, I will give a background about what a visualization technique is and describe the main visualization techniques. Secondly, I will explain how context-driven visualization can be useful to visualize data in its context. Finally, I will identify the main challenges linked to AR and these visualization techniques.

2 Background

To begin with, it is important to differentiate data representation and data visualization. Data representations refers to the way data is structured, organized and stored in a format that can be easily understood by a computer. Whereas, according to Zollmann et al. (2020), data visualization "can be described as the process of converting abstract data into a visual representation that is comprehensible by a human observer". It can be done thanks to different visualization techniques such as charts, graphs or diagrams.

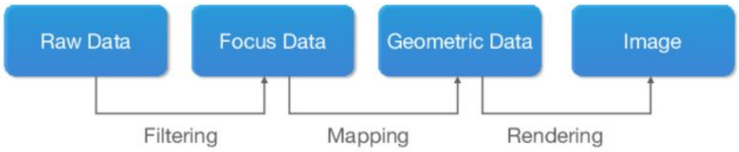

Figure 1: Scientific visualization pipeline with its three main steps: filtering, mapping, and rendering. From Zollmann et al. (2020).

To switch from a representation to a visualization, the data goes through a visualization process. The visualization pipeline (Zollmann et al., 2020) transforms raw data into a visual representation via three main steps: filtering, mapping and rendering (see Fig. 1). Filtering allows to reduce the data set, the mapping step generates the geometric information and the rendering produces the image that will be displayed for the user.

3 Visualization techniques

In this section, we will review visualizations techniques that can be useful to display data in AR. Depending on the type, dimension and size of the data, visualization techniques can be more or less suitable to understand it.

3.1 Single-dimensional data

Single-dimensional data, or univariate data (Olshannikova et al., 2014), refers to data that only have one variable or one dimension. This data can either be quantitative or qualitative (Miranda et al., 2022). Quantitative means that the data can be measured and analyzed using statistical methods whereas qualitative data can be categorized and analyzed according to their characteristics. These visualization techniques may not be useful for complicated data structures (Olshannikova et al., 2015). Here are some suitable visualization techniques for these types of data:

- Bar chart: Graphical representation of frequency of qualitative data. Padwal et al. (2021) shows an example of a bar chart visualization in AR that visualizes crop production.
- Pie chart: Graphical representation of a proportion of each qualitative data. The whole representation shows the number of observations.
- Line graph: Graphical representation of quantitative data. This visualization technique is useful when the single-dimensional data changes over time, i.e. if it is a continuous data.
- Labels: Labels allow to display annotation on real-world elements to indicate what that element is. Grasset et al. (2012) work on a view management technique to display labels over landscape pictures in AR (see Fig. 2).

Figure 2: Example of how to display labels in an environment. From Grasset et al. (2012).

3.2 Two-dimensional data

Two-dimensional data refers to data that contains two variables that represent a different aspect of the same observation or entity. These variables can also be quantitative or qualitative. Here are two suitable visualization techniques for these types of data:

- Heatmaps: Graphical representation that uses colors to show the value of the variables. Willett et al. (2017) shows how to use a heatmap in addition to embedded visualization. The authors explain that a user can overlay a heatmap over shelves of products to show off the sales.
- Scatter plots: Graphical representation of the relationship between two quantitative variables. A dot represents an observation of the two variables. In the work of Padwal et al. (2021), the authors say that “the AR environment and the additional dimension makes it simpler and faster to identify hidden patterns in the data” when using scatter plots visualization technique.

3.3 Three-dimensional data

Same as two-dimensional data but with a third variable. Here are some suitable visualization techniques for these types of data:

- Surface plots: Graphical representation useful for complex mathematical functions (Padwal et al., 2021). The surface is represented by a mesh or grid of points where each point is an observation of the three variables.
- 3D models: 3D models allow to represent data in different ways. White and Feiner (2009) use 3D models such as spheres, cylinders or fog to represent the carbon monoxide level in a street. Charts and graphs can also be rendered in 3D (Lobo and Christophe, 2020). Moreover, it can be the representation of an object.
- Point clouds: Graphical representation which can be used to display data from sensors (Lobo and Christophe, 2020). This visualization can also be useful to visualize a large amount of data and each point can be color coded to represent an additional attribute.

4 Context-driven visualization

Visualizing data can be done in many different ways, using computers or paper, the visualization of the data stays the same regardless of the environment (e.g. a graph about sales of a product will be the same if a user looks at it in their office or in a warehouse). With AR, new visualization techniques have emerged to allow a user to display information related to the real world surrounding them (Kalkofen et al., 2011). As mentioned by Kalkofen et al. (2011), there are different context-driven visualizations which are situated visualization, object as context, sensors as context and scene as context. In addition to these, embedded visualization (Willett et al., 2017) is another way to display data and is strongly related to situated visualization.

4.1 Situated visualization

Situated visualization allows to display data in context, namely according to the environment in which it is in. In order to do so, the visualization technique must rely on the physical world (see Fig. 3).

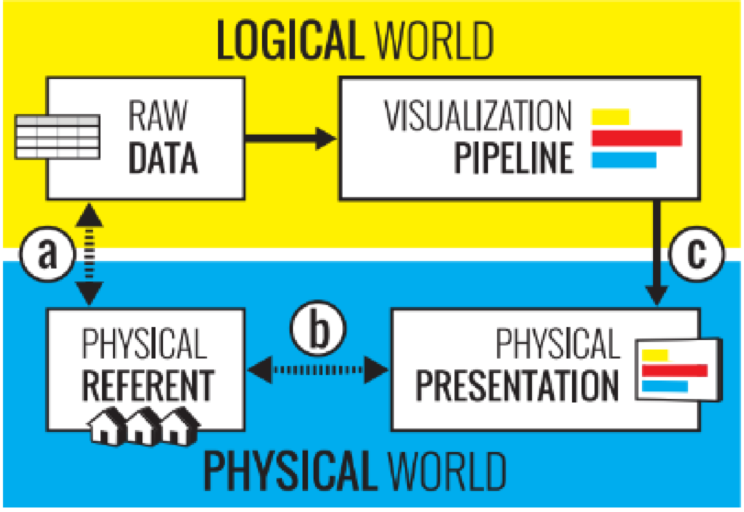

Figure 3: A traditional visualization pipeline extended to the physical world. Raw data and data presentations are both linked to a physical referent. From Willett et al. (2017).

Based on Willett et al. (2017), the logical world is composed of the raw data and the visualization pipeline. The visualization pipeline produces a physical presentation of the raw data. The physical presentation and the data are linked to a physical referent in the physical world. To simplify, “the physical referent is the physical object or physical space to which the data refers” and “the physical presentation is the physical instantiation of the visualization produced by the visualization pipeline” (Willett et al., 2017).

Several criteria must be taken into account for a visualization to be situated. According to Martins et al. (2022), the type of the represented data is not taken into account, it can be abstract or physical. Also, the use of AR is not enough for a visualization to be situated. In fact, the main condition is that the physical presentation of the data have to be “located close to the data’s physical referent” (Willett et al., 2017). “Close” has diverse meaning, the physical presentation can be spatially, temporally or geographically close to the physical referent.

Willett et al. (2017) introduced the terms “spatial indirection” and “temporal indirection”. The spatial indirection is the spatial distance between the physical referent and the physical presentation, whereas the temporal indirection is the temporal distance between taking the data's physical referent and displaying its physical presentation.

Lobo and Christophe (2020) introduced an additional term, "geographical indirection". The geographical indirection refers to the distance between the geographical referent and the physical referent (see Fig. 4). The geographical referent is the geographical position of the data. If a visualization is geographically situated, that means that the physical presentation has the same position as the geographical referent.

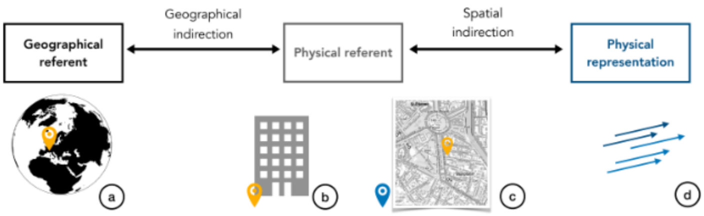

Figure 4: Presentation of the different indirections and referents. From Lobo and Christophe (2020).

4.2 Embedded visualization

Embedded visualization is a sub-category of situated visualization. While situated visualization is based on one physical presentation, embedded situation instead allows to display several physical presentations of several physical referents, i.e. several virtual elements can be displayed alone and each of them is tied to a real-world element with a low spatial indirection. (see Fig. 5).

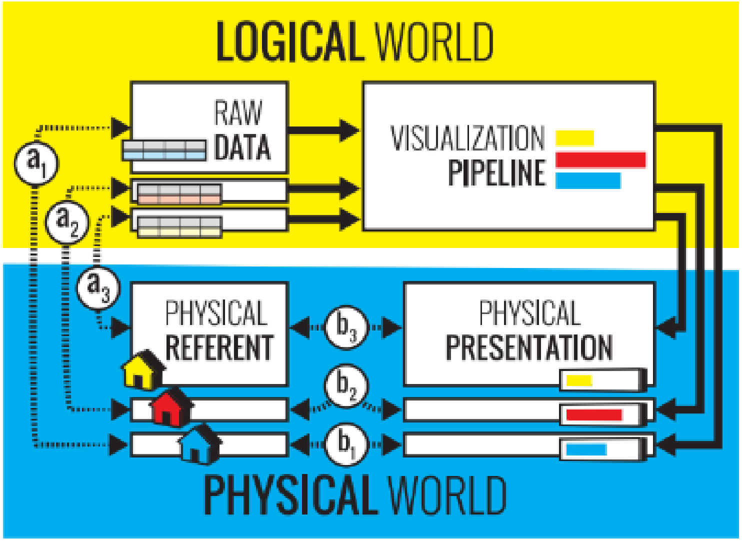

Figure 5: A visualization with multiple physical referents and physical pre- sentations that can be composed and interpreted together. From Willett et al. (2017).

As described by Willett et al. (2017), embedded visualization is "deeply integrated with the physical spaces, objects and entities to which the data refers" and the main reason that each physical referent has its own physical presentation is to allow each presentation to be closer to its referent.

In fact, the main differences between situated and embedded visualization are the indirections. Embedded visualizations will have a very low spatial indirection and no geographical indirection unlike situated visualizations, which can have a high spatial indirection as soon as the physical presentation is in a relevant location.

4.3 Object, Sensor data or Scene as context

These three visualization techniques, described by Kalkofen et al. (2011), use a specific focus to display related data. First of all, object as context. As the name suggests, the main focus is an object in the scene. To visualize data related to the object, static visualizations is useful to display the name of the object or any of its characteristic. Then, sensor data as context. It is a more complex visualization technique because it allows to display data that come from sensors, i.e. data that varies over time. Moreover, it can be used to display invisible aspects of a scene, such as the level of carbon monoxide in a street (White and Feiner, 2009). Last but not least, scene as context. The scene serves as a support for the visualization, it "provides semantic and optical context" (Kalkofen et al., 2011). That means that some part of the scene can be emphasized to give the correct information. The visualization must therefore not obstruct the view and must take into account the background.

These visualizations can be used independently or in addition to situated and embedded visualizations. In the case of object and sensor data as context, the geographical position of the focus does not matter. Kalkofen et al. (2011) show an example of object as context visualization. A tree leaf is placed on a cardboard and the visualization displays the species of the leaf. This is not a situated / embedded visualization because the data displayed does not change depending on whether the leaf is viewed in one location or another. However, if this technique is used directly on a tree in a park, this visualization becomes situated as it concerns a leaf in a specific tree.

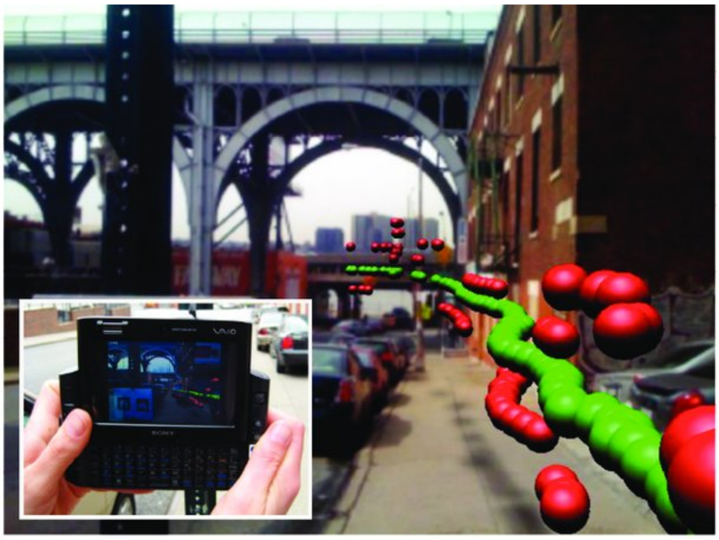

Figure 6: Example of context-driven visualization. From White and Feiner (2009).

A great example to show these context-driven visualizations is the work of White and Feiner (2009). The authors used a hand-held visualization tool to allow a user to see the level of carbon monoxide in a street (see Fig. 6). The data used come from sensors and can be visualized in three ways: with sphere, cylinder or fog. Their visualization is considered as situated but also as sensor data as context and scene as context.

5 Challenges

The visualization technique, the data or even the augmented reality itself brings some challenges and difficulties that must be considered while visualizing data in AR. One of them is missing visual coherence, which often occurs when one or more depth cues are missing. Uncertainty, overload and scale are also recurring challenges.

5.1 Depth cues

Depth cues are visual cues that help the brain perceive the depth and distance of objects in the real world, or in AR it can be difficult to provide accurate depth cues of a virtual object in a real-life environment. If a visualization does not take into account these depth cues, it will result in a wronged perception of it. As said by Zollmann et al. (2020), additional cues are essential. The authors called them virtual cues as they are not present in the physical world.

These depth cues can be monocular or binocular and the monocular ones can also be divided into dynamic depth cues, oculomotor cues and pictorial cues (Kalkofen et al., 2011). Dynamic depth cues refer to the phenomena that occurs when looking at a fixation point. The farthest objects will move slower than the nearest objects when a person moves their viewpoint. Oculomotor cues refer to the action that the eye makes to clearly see a close object. Pictorial depth cues refer to the depth cues that can be found in a single image (Kalkofen et al., 2011). Kalkofen et al. (2011) indicate these cues: occlusion, relative size, relative height, detail, shadow, atmospheric and linear perspective.

- Relative size: An object farther away looks smaller than a closer object.
- Relative height: An object which is higher on a picture seems to be further away.
- Linear perspective: Parallel lines converge to a vanishing point.

These three cues can give a spatial relationship between a virtual object and a real one (see Fig. 7).

- Detail: A distant object will have less detail than a closer one.
- Atmospheric perspective: A distant object will be perceived more blurred than a closer one.
- Shadow and lighting: Objects of the same scene will have similar shadows and lights but an object can cast shadow on another object.
- Occlusion: Occlusion, or overlapping, is an essential criteria to be taken into account. Occlusion allows to place the object in relation to the others. If all the depth cues are respected except for the occlusion, it will give the impression that the visual element is floating (Kalkofen et al., 2011) and it will result in a wronged depth perception (Lobo and Christophe, 2020) (see Fig. 8). Some techniques exist to counteract occlusion, such as the phantom model and x-ray visualization (Kalkofen et al., 2011). X-ray visualization allows to emphasize what is hidden by a virtual element, by showing off the contours of the hidden element. The phantom model compares the depth values of the elements, real and virtual. The virtual elements that represent a part of the real ones are rendered invisible which allows to render only the virtual elements that are not hidden by the real ones (Kalkofen et al., 2011).

To help a user to better perceive the depth, additional cues have to be used. Wither and Höllerer (2005) show several examples of virtual cues that help a user to place a label

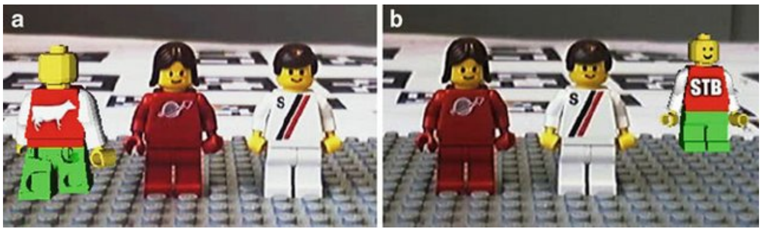

Figure 7: Example of a 3D Lego model with good perspective compared to real Lego minifigure. From Kalkofen et al. (2011).

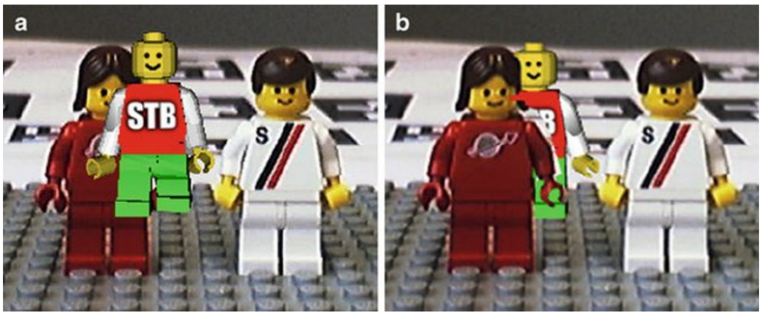

Figure 8: Example of a 3D Lego model visualization when occlusion is ignored. From Kalkofen et al. (2011).

on markers, which are at different distances from the user. The first technique described is to use shadow planes, two semi-transparent planes that cast the shadows of the markers onto it. Another technique is a top-down view where the location of the markers are shown relative to the user.

5.2 Uncertainty

Uncertainty is the degree of error when positioning a virtual element over the real-world environment (Lobo and Christophe, 2020). This problem often arises when mapping virtual objects onto the real world (Zollmann et al., 2020) or when there are errors in tracking the user's position. To minimize the effect of uncertainty, adding another representation can provide a better understanding of the data (Lobo and Christophe, 2020). This representation can indicate the degree of uncertainty by adapting the color of the virtual element or by indicating the degree of confidence in percentage. This is even more important in the context of a context-driven visualization and especially for situated and embedded visualizations as a visual representation is related to its physical referent thanks to the spatial indirection.

5.3 Scale

Scale is the difficulty of accurately representing the size and scale of virtual objects in the real-world environment. With context-driven visualizations, virtual objects are usually of the same size and scale of their physical referent but in the case of huge objects, such as buildings, it can be difficult to represent them (Lobo and Christophe, 2020). A solution for manipulable objects would be to track the physical referent before displaying the virtual object and a solution for unmanageable objects would be to have several views of them (Lobo and Christophe, 2020), as in, a view from the top and the bottom.

5.4 Overload

Overload occurs when too much data or visual elements are overlaid over the real-world environment. The user has too much information to look at and this can lead to cognitive overload and difficulties understanding and processing the information. Visualizations have to provide the user with the relevant information in order to avoid confusion (Olshannikova et al., 2015). To prevent cognitive overload, a visualization technique must be able to simplify the data in such a way that it can be understood by a user (Martins et al., 2022). Some solutions could be to allow a user to choose between different visualizations of the same data or to highlight the most important data among those displayed.

6 Conclusion

In conclusion, we first gave an introduction about techniques for localized data representation in augmented reality. We then looked at the visualization techniques that exist and that can be useful in AR according to the type, dimension and size of data. After that we looked at how to use these techniques to display information using localized data, that is specific to a location or a geographic area. To do this, the main visualization techniques are the situated and embedded visualizations, which allow to display data that makes sense in its environment and also visualizations that use a focus in a scene as context to display the data such as objects, sensors or even the scene itself. These techniques and the AR technology bring a lot of challenges. We focused on depth cues, and especially on occlusion. We observed that it is not the visualization technique itself that allows us to display localized data but the way we use it.

The interest of AR, more than just visualizing data, is to be able to interact with it, in an immersive way. A future work could be to identify the interaction techniques as interactivity can provide a new way to visualize data, such as changes in scale or visual mapping (Miranda et al., 2022). Interactivity can also take place in situated visualization, Martins et al. (2022) proposed a theoretical model that allows a user to interact with both the physical referent and the physical representation.

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