Interactions with Projected Augmented Relief Models (PARM)

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Abstract—**Techniques for enhancing physical landscape models with dynamic maps and imagery, termed Projected Augmented Relief Models (PARM), are part of a revival of interest in the power of relief models as tools for geographic visualization. This method enables the creation of dynamic and engaging public displays, which appear attractive but also promote discussion and interaction as revealed through direct observation and video. This paper explores the capabilities of physical relief models as tangible displays for geographic information, and considers the role of interaction using the Kinect sensor for finger detection. The focus of interaction is on making solid landscape models of real geographic areas reactive to touch.**

Keywords: Physical 3D model; augmented reality; landscape visualisation.

I. INTRODUCTION

From ancient times, geographic visualization has played a significant role in human life and it has become even more popular during the digital age. The evidence of ancient people using geographic visualization includes cave paintings and carvings that look like maps. The techniques of map creation have continually developed to make human life easier by supporting many daily activities, as well as being of fundamental importance to diplomacy and defence from the early modern period.

In the past, people drew maps using cartographic methods in 2-dimensional (2D) form to represent the terrain of the earth. They developed these methods further and visualized the landscape in 3-dimensional (3D) models, some of the earliest examples being for military purposes [1]. This kind of model was considered the most representative ‘map’ before the digital era.

The starting point of digital technology was between the late 1950s and the early 1970s, during which time technology developed rapidly in every field, including geography. The development of mapping technology started with field data acquisition, data processing and data representation. Drawing maps using digital technology helps users produce maps faster and more precisely, and the development of geographical information systems combined spatial analysis with map making. However, such complex maps remained the preserve of specialists until the late 1990s, when the increasing popularity and use of the internet popularized digital maps and made them increasingly desirable and useful. In contrast, developments in geographic physical models were not as rapid as with digital maps, being considered less practical for many applications despite their inherent value as representations of terrain.

Since the turn of the 21st Century, the nature of 3D physical geographic models has become more dynamic and there has been a revival in their use, in part due to technologies to increase their interactivity. The Illuminating Clay project [2] illustrated how landscape models made from clay could be manipulated by hand and the resulting changes in the surface model detected, triggering new contour and water flow maps that could be projected back on to the model. TanGeoMS [3] used a malleable surface model connected to the GRASS Geographical Information System (GIS). The Illuminating Clay approach was further extended to use sand as a more modifiable surface in the Augmented Realty Sandbox (Fig. 1) which has been used in an educational context to engage students with topographic mapping and earth science [4].

Figure 1: The Augmented Reality Sandbox. Sandbox unit when not in operation (left). In operation with projected contours and water flow (right) [4].

Whilst the ability to manipulate surface models offers a powerful environment for education and outreach in relation to generic landform and process relationships [5] there are contexts where more geographically specific models are required. Solid relief models are able to replicate details of real geographic environments, with digital elevation data being used to manufacture faithful representations of the terrain. It is easier than ever before to produce physical models either through subtractive techniques like milling or additive techniques like 3D printing, where layers of material build up a surface. Today accurate physical relief models are produced commercially, including examples by manufacturers such as Solid Terrain Modelling [6] and Howard Models [7]. At certain scales it is possible to represent surface features like buildings to allow urban environments to be visualised. Conventional relief models are static in terms of surface texture, typically painted to reflect the land cover. When augmented with projection, solid models can allow alternative forms of information to be displayed, but are generally limited in terms of interaction except where buttons around the model illuminate certain points of interest within the model.

In terms of interactivity the sandbox approach used the Kinect sensor, initially introduced by Microsoft to support the Xbox games console, to detect deformations of the surface, as well as to detect certain gestures for example to instigate rainfall over the model. For solid models the interaction could involve making the static surface responsive to touch. This could trigger certain algorithmic responses for example to route water from that point or to display a visibility map (or view-shed) but could also simply act as a query operation to display information about that place on the model.

This paper describes work in progress towards exploring the potential of making solid relief models more dynamic in terms of surface representation and interactivity. It describes an experimental approach building upon previous work to develop the Projection Augmented Relief Model (PARM) technique for public display, as described by Priestnall et al [8]. The investigation aims to examine whether they offer measurable benefits for the presentation of geographic information to people, and whether people's expectations of interactivity can be addressed, so that interaction delivers geographic information that is best suited to the needs of the viewer. In particular the potential for adding a degree of interaction so the solid model responds to touch, exploiting the ability of the Kinect sensor to detect the position of the finger [9] is being explored.

II. PROJECTION ONTO SOLID RELIEF MODELS

Projection onto solid objects [10] effectively allows dynamic texture maps to be applied to physical models in the real world as might be applied to virtual models. These textures could be a series of static images of video. An example of a landscape model being textured by video is the Dresden Elbe Valley model exhibited in Dresden Museum [11]. A solid terrain model measuring 2m x 1.5m was augmented by a film showing the development of the area since the year 8000 BC.

The development of design and evaluation protocols for projecting detailed spatially referenced information onto equally detailed static physical landscape models has been the focus of the PARM project (Fig. 2). The typical PARM configuration comprises a physical landscape model, a projector, a monitor to display related information and a computer to synchronise digital map and image content across model and monitor. The combination of model and projected content creates a holographic effect that has been seen to be both engaging and informative for viewers, enabling them to explore the model by inspecting it closely from different angles or taking in the broader overview.

Figure 2: Projection Augmented Relief Model (PARM): Tangible Displays for Geographic Information. A selection of data layers used for projection (upper left); demonstrating at a community event at the University of Nottingham, 2011 (upper right and bottom) [8].

An opportunity to study PARM in a public context over a long period of time came with the *Spots of Time* display at the Wordsworth Trust gallery in Grasmere, Cumbria, UK. The model was used to represent key events in the childhood of the poet William Wordsworth (1770 – 1850), connecting them with particular parts of the landscape. Furthermore, those key events also related to poetry that Wordsworth created in adulthood, notably *The Prelude*. The purpose of the model was not only to raise the awareness of the importance of place and memory in Wordsworth's work, but also to encourage the visitor to study the original manuscripts on display elsewhere in the gallery. The PARM configuration used for this display also features a touch screen to trigger three separate projected sequences and an audio shower above the display to allow passages from the poems to be played aloud.

The *Spots of Time* display was in the gallery for over nine months and for around four weeks video observation was undertaken at the display, in addition to direct observation in the gallery. The observation data showed the display was effective in holding visitor attention but also for promoting discussion, often accompanied by pointing or tracing gestures. Even though the model surface itself was not interactive there seemed to be an expectation from some visitors of some kind of touch sensitivity, especially when certain landscape features were highlighted through projection (Fig. 3).

Figure 3: Finger-based interactions observed from video analysis of the Spots of Time display

The *Spots of Time* display went some way towards demonstrating that physical relief models offer viewers a rapid overview of a landscape with the added attraction of physical touch. There is clearly potential for some form of touch-based interaction to extend the capabilities of techniques such as PARM. To underpin this it would be valuable to understand more about the particular aspects of physical models that proved effective, for example in increasing people’s ability to orient themselves, to measure distances or relative elevations, and to achieve a quick understanding of a location or recognizing landmarks. A set of experiments is being undertaken to establish whether such subtle measurable differences can be observed.

III. EXPLORING THE CAPABILITIES OF PARM

A first experiment was designed to explore PARM’s capabilities in the portrayal of relief features using the model of the Lake District used in the *Spots of Time* display. The experiment posed questions of participants about topographic characteristics on both the relief model and a flat surface. A number of different measures were designed to gauge people’s understanding of the landscape form in an attempt to unpick the elements that could be seen as contributing to the viewer’s spatial frame of reference, these were:

- Deciding which of two points was the highest
- Deciding which of two lines was the steepest
- Deciding which of two target points would receive water flow from a single origin point
- Deciding which of two target points was visible from one observer point
- Deciding which cone of vision symbol corresponded to a first person perspective image shown on screen

These measures therefore ranged from a simple comparison of two local topographic characteristics to more complex measures which required a degree of landscape interpretation, and in the case of the cone of vision the ability to take the perspective of viewers ‘on the landscape’. As well as the projected shapes to implement the above tests the backdrop images on the model were also a variable. Earlier observation had indicated a number of projected backdrop textures were effective but it was of interest here to establish if they helped viewers make judgements about various characteristics of the landscape. These backdrop images were a satellite image, a hillshade effect image, a map including contours and a subdued version of the hillshade image.

In order to assess whether there were benefits to adding a third dimension a core manipulation was to present half of the questions about landscape characteristics over the relief model, then the other half over a flat surface. The order of presentation was counterbalanced across all participants and questions were fully randomized. From observation of a pilot study the viewing position of each participant was not the same, so it was decided that the participants’ head and body movement should be restricted to control against some participants gaining additional information from changing their perspective (Fig. 4) even though in practice this would be common, and is one of the virtues of having free movement around a relief model.

Figure 4: The environment for PARM experimentation.

Outcomes from ongoing analysis suggest that for all measures the relief model generated more accurate performance across participants particularly when the satellite image was the backdrop. The model proved particularly effective in terms of accuracy of response when asking participants to interpret the landscape scene, particularly the judgement of water-flow, the cone of vision test and intervisibility. Overall response times were slower for these tests than simple height comparisons, though were quicker for the model than the map. This may suggest that the extra information provided by the physicality of the model allows viewers to construct more complex cognitive models more effectively to support their decisions.

Figure 5. The Nottingham University Park Campus Model.

Since the model in this first experiment was an unfamiliar environment to most participants, an ongoing follow-up study uses a model that represents a familiar area, so that we can observe whether existing knowledge affects the utility of PARM. Here we modelled the University Park Campus at the University of Nottingham (Fig. 5). As well as being a familiar environment for participants, the scale and the nature of the data (airborne laser-scanning) also meant that the model was able to represent major buildings and landmarks. Questions were based on the measures from the first experiment but adapted for the current environment. Early results suggest that the model is most effective in supporting cone of vision judgements along with assessments of intervisibility. We are also interested in the ability of participants to judge the location of newer buildings that are not represented on the model, and there is evidence to suggest that PARM facilitates accuracy for this task, compared to the flat equivalent.

IV. INTERACTING WITH PARM

A third experiment is focussing on direct interaction with the model surface, in particular to establish whether finger point detection algorithms can be used to identify the coordinate where a finger touches the model. This kind of interaction had been observed at the *Spots of Time* display when there was no prompt to interact and no mechanism to offer a response. The aim is to explore whether the Kinect sensor could be exploited to identify the last position of the finger when it touches the model and whether this offers an accuracy which is fit-for-purpose for general geographical query or even analytical activities.

The PARM rig for this experiment has the addition of the Kinect sensor mounted 47cm above the relief model. From experimentation (Fig. 6) this proved to be the most effective distance to discriminate the finger location. The projector is an Optoma HD131Xe mounted 2m above the model which measured 60cm x 60cm. The specification of the computer is an AMD FX-6100 of processor, 16 Gb of memory DDR3 and 4 Gb NVidia GeForce GTX 970 graphic card.

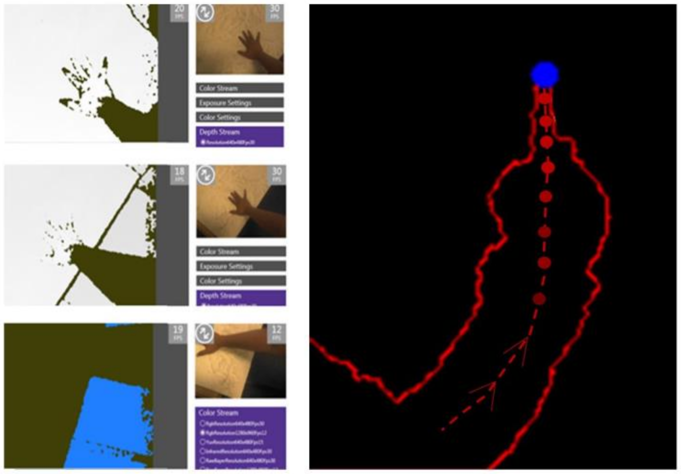
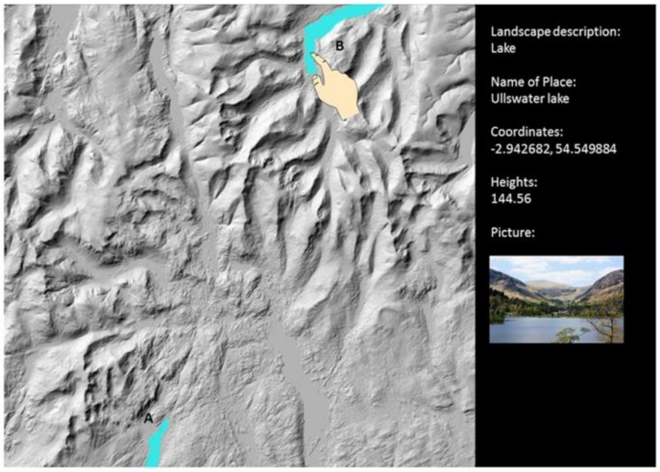


Figure 6: Distance between Kinect sensor and PARM, from top to bottom, 47 cm, 51 cm, 37 cm, shown variations in ability to detect fingertips. The coordinates of the finger as it approaches the model can be tracked and the last coordinate recorded before the finger merges with the model object is indicated in blue (right).

Sequences of finger point coordinates are detected as the finger approaches the model and the last coordinate in theory represents the position of the model just before it merges with the model. Early experimentation suggests the accuracy of this finger point touch detection is in the range of 1.5 – 2.5cm. A full and rigorous test will be conducted to explore the repeatability and robustness of this process by projecting randomized points of interest over the models and recording finger touch coordinates against the known target coordinates. These points should include a wide range of conditions over the model that represent typical points of interest which for rural models may include mountain peaks and valleys and for urban models may include buildings and flat areas between buildings. The aim is to assess how the accuracy of touch relates to the scale of geographical features represented on the model. This would inform both the design of future interactive PARM models and also the nature of any interaction design built in to the system. The proposed query interface (Fig. 7) includes a projected information panel beside the model so touch actions can trigger responses in terms of information about the object queried so as to confirm this response matched the user's expectations.

V. FURTHER POSSIBILITIES

The discussion of previous research presented above indicates a niche between geospatial visualization, spatial cognition and tangible interface that requires further research to improve human perception about topographical surfaces in relation to certain potential application domains. Interactions could relate to simple query operations but could also be task-driven. There are many possible application to explore including: Storytelling in a cultural heritage setting; Military training; Disaster management simulation and awareness (for example flooding); Route planning and tourist orientation, showing visitors the shape of the landscape and relative positions of features of interest around them.



Landscape description:
Lake

Name of Place:
Ullswater lake

Coordinates:
-2.942682, 54.549884

Heights:
144.56

Picture:

Figure 7. Proposed query interface

Tablet-based Augmented Reality (for example AR Toolkit) could also be explored in order to add dynamic 3D content to augment the projected surface. This could be used to explore elements with a vertical dimension that cannot easily be portrayed using projected images over the model, for example volcanic eruptions, tornadoes, or glaciation. One could also simulate past structures on the surface, such as reconstructing building structures over their landscape footprint.

VI. CONCLUSION

This work has begun to demonstrate that solid relief models of real geographic environments can be usefully augmented with projection, and that there is some potential for detecting finger point touch on the model surface. Experiments that attempt to isolate the most useful aspects of physical relief models in judging landscape characteristics have suggested that models may support more complex understandings of topographic form. Observations of displays have also indicated some expectation of touch-based interaction and early experiments with the Kinect sensor show some promise. The accuracy of such touch interactions need to be fully investigated and assessed against the scale of object in the model that would be the focus of such actions.

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