Late breaking results: ARPipes: Aligning Virtual models to their Physical Counterparts with Spatial Augmented Reality

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ABSTRACT

This paper reports on the use of Spatial Augmented Reality to align virtual models to their physical representation. ARPipes provides both a visual overlay of physical plant equipment and simple interactions allowing a user to quickly and easily align objects in the virtual model. The paper describes the process of employing original CAD data of plant equipment and transforming the data into a usable SAR system, which is the first step of a larger augmented reality maintenance task.

KEYWORDS: Spatial Augmented Reality, Visualization, Industrial Application.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation]: Graphical User Interfaces—Input Devices and Strategies; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction Techniques

1 INTRODUCTION

One of the common questions with Augmented Reality (AR) is how to apply visualizations to real world situations. The Intel Corporation and the University of South Australia have a collaborative investigation into the use of AR to assist with maintenance tasks in fabrication plants. This paper presents the first step in the AR process, the visual updating and validating of CAD models against their physical counter-parts. We describe ARPipes, an application of Spatial Augmented Reality (SAR) that assists aligning Computer Aided Drawings (CAD) to real world equipment. ARPipes provides a visual overlay to physical objects allowing virtual objects to be manipulated by users. Figure 1 depicts the user's view of the system in operation.

ARPipes is designed to address a real world problem at Intel Corporation. The first step in that problem is aligning existing CAD Models to their real world physical counterparts. Chip manufacturing requires a large number of highly complex tools from many different vendors. Any large scale deployment of AR in such an environment requires an AR system capable of coping with a large quantity of diversity and complexity. For each piece of equipment detailed physical information is needed to support AR maintenance activities. Since the tools are complex, often the supplied drawings and CAD models do not reflect the final tool that was installed. For instance, physical pipes may be in a different location, or additional pipes may have been added to the equipment. Multiply these ground truth differences by the large number of tools and the complexity of a large scale AR deployment in manufacturing becomes daunting. ARPipes provides a way to quickly align all components of existing CAD models to match the actual physical location of the tools. It also allows quick identification of various objects regardless of their physical occlusion.

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2 BACKGROUND

Spatial Augmented Reality [1] is the projection of virtual information directly onto and registered to physical objects, and is a branch of Augmented Reality research [2]. SAR has been applied to surgery [3], and in an industry setting it has been employed for visualizing designs [4]. Laser projection augmented reality is employed in industry to show locations for welding, gluing, and assembly [5]. SAR is a key technology for ARPipes.

SAR makes use of digital projectors to display graphical information onto physical objects and scales naturally up to groups of users, allowing for collocated collaboration between users. Hence ARPipes is not limited to use by one user but can be used by a group. A key difference of SAR from other forms of AR is the decoupling of the display from the user, and SAR has several other advantages over traditional head mounted displays and handheld devices. The user is not required to carry equipment or wear the display over their eyes whilst working on equipment, making SAR a good candidate for collaborative work. SAR does not suffer from the limited display resolution of current head mounted displays and portable devices. Being a projector-based display system it can simply incorporate more projectors to expand the display area. Where portable devices have a small window into the world for drawing, a SAR system can display on any number of surfaces of an indoor setting at once. The tangible nature of SAR makes this an ideal technology for maintenance work, as SAR supports both a graphical visualization and passive haptic sensation for the end users. ARPipes applies SAR in an industry setting to aid in correction of projected CAD information via means of object manipulation. SAR allows all objects in the model to be visually verified at once. Any misaligned or missing objects can then be quickly corrected.

3 ARPIPES

ARPipes is designed to aid in aligning objects from CAD models with the actual physical equipment. These objects can be edited live, allowing the user to have instant feedback as to the accuracy of their updates. Because the purpose of the new CAD models are for AR highlighting only, the accuracy of free-hand editing is deemed sufficient. ARPipes employs the following process to enable live editing in a SAR environment:

1) A CAD model of a piece of plant equipment (in this case a cabinet full of chemical pipes) is supplied by an external party.

2) The CAD model is carved up into objects suitable for translation to the SAR system (i.e. individual pipes) using an off the shelf 3D program (Autodesk Maya). Each object's position and orientation is replicated from the original CAD model.

3) The objects are then translated into a format appropriate for a SAR system (OBJ format).

4) A projector and computer are physically set up so the entire view volume of the projector covers the physical piece of plant equipment.

5) Manual calibration is performed to obtain the projector intrinsic and extrinsic parameters.

6) The ARPipes system is employed to edit the SAR 3D model via object manipulation.
7) The resultant SAR 3D model is saved and can be reloaded.
Once each step has been performed the resultant 3D model can then be reused, requiring only steps 4, 5, 6 and if desired 7 to be performed for updating or for viewing of the stored model.

Calibration is performed using an eight point calibration process. When carving up the CAD model is done, coordinates for a quad on the front plane and rear plane of the outer shell of the plant equipment are recorded. A calibration program which projects a cross hair in screen coordinates onto the physical plant equipment is then run. The user then aligns the cross hair in the corresponding locations on the plant equipment. Once all eight points have been located, a configuration file is update with the projector intrinsic and extrinsic parameters

At this point the ARPipes system can be started. ARPipes allows a number of different user interactions. At present all interactions are performed using a wireless keyboard. When the system starts all objects (ie pipes) and the outer shell of the plant equipment (used for calibration alignment) are projected onto the physical plant equipment. The view of the outer shell allows for last minute manual tuning to correct potential calibration alignment problems. Pressing 'c' turns off the projected outer shell showing only the internal objects (ie pipes). A user is able to toggle between objects using the tab key on the keyboard. Each object is highlighted in a specific color as it is selected. A user is also able to switch all objects, except the selected object, to wireframe. This allows occluded objects to be clearly seen behind objects in front of the occluded object. For example a pipe can be seen through a container in front of it. The wireframe mode also proves quite useful to reduce the visual clutter of the projection as most objects appear less intrusive. A user is also able to shift the location of an object. At present objects can be manipulated using the up/down/left/right keys on the keyboard. Currently only translation in two axes are possible, though 3 axes, rotation and other manipulations are planned. We also plan a number of editing operations to change the shape of the pipe, such as adding a bend. The new locations of the manipulated objects can be saved at any point, allowing quick reloading to a calibrated system.

4 Implementation

ARPipes is implemented in C++ as a software module in the SAR framework created by the Wearable Computer Lab at the University of South Australia. The SAR framework provides fundamental support for loading OBJ graphics models, support for custom modules and basic features needed by SAR including calibration of projector intrinsic/extrinsic parameters, OpenGL output capabilities, keyboard and mouse input capabilities.

When implementing the ARPipes module, a number of issues were encountered. The surface properties of the equipment being projected onto caused problems due to its mirror finish. Whist the objects being projected onto were illuminated correctly, the requirement for very accurate calibration became an issue. Any misalignment shows up as a reflection back to the user. Associated with this, the mirror finish caused problems with displaying information to the user, such as textual overlay. These cannot be show next to the pipes as they simply reflect. The colors used to illuminate objects were also investigated. Originally white, the overlays were hard to see when overlaying the fine pipes of the physical equipment. More distinct colors (red, cyan, yellow) were selected and are now options in a configuration file.

Initially pipe selection was completed using vision tracking via the ARToolkitPlus toolkit. Fiducial markers were placed upon a wand and this wand could be used for both manipulation of pipes and pipe selection. The mirror finish of the machine caused lighting problems. In the end the decision was made not to use vision-based tracking in the first instance, as an overall reliable system was a higher priority than one incorporating potentially unreliable tracking.

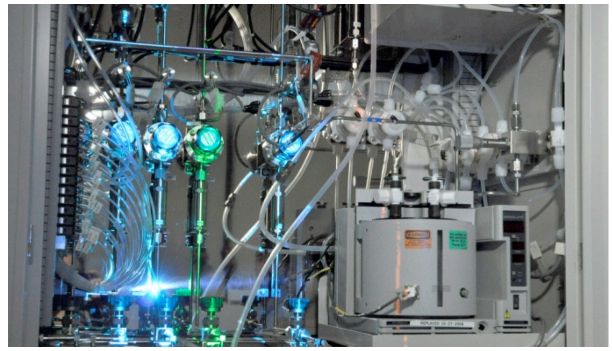

Figure 1. ARPipes in operation

5 Conclusion

The ARPipes prototype highlights an actual use of SAR in the real world. The system presents an initial object selection and manipulation interface. Whilst this is a straight-forward example, it highlights a number of challenges when taking SAR out of the laboratory and into the real world.

ARPipes has been demonstrated to a number of experts and stakeholders at Intel Corporation, and there was broad agreement that augmented reality is a game changing capability for manufacturing on the scale of adding robots to the factory. Our efforts have shown Intel experts and stakeholders that AR is not just for the lab but a real possibility for use in the factories.

Future work is underway to extend the ARPipes system to be more self contained (combining the calibration/editing into one application, removing the object carving) and to help provide real world training of technicians via overlaid instructions direct on the physical tools. Investigation into using alternative projection and calibration techniques is also being considered.

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7 References

[1] R. Raskar, G. Welch, K.-l. Low, and D. Bandyopadhyay, "Shader Lamps: Animating Real Objects with Image-Based Illumination," in *12th Eurographics Workshop on Rendering (EGWR)* London, 2001.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, "Recent Advances in Augmented Reality," *IEEE Computer Graphics and Applications,* vol. 21, pp. 34-47, Nov 2001.

[3] L. A. Kahrs, H. Hoppe, G. Eggers, J. Raczkowsky, R. Marmulla, and H. Worn, "Visualization of surgical 3D information with projector-based augmented reality," *Studies in Health Technology and Informatics,* vol. 111, pp. 243-246, 2005.

[4] J. Verlinden, A. Kooijman, E. Edelenbos, and C. Go, "Investigation on the use of illuminated clay in automotive styling," in *Proc. of CAID/CD conference*, 2005, pp. 533-538.

[5] B. Schwerdtfeger, D. Pustka, A. Hofhauser, and G. Klinker, "Using laser projectors for augmented reality," in *Proceedings of the 2008 ACM symposium on Virtual reality software and technology* Bordeaux, France: ACM, 2008