An Affordable Surround-Screen Virtual Reality Display

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Building a projection-based virtual reality display is a time, cost, and resource intensive enterprise and many details contribute to the final display quality. This is especially true for surround-screen displays where most of them are one-of-a-kind systems or custom-made installations with specialized projectors, framing, and projection screens. In general, the costs of acquiring these types of systems have been in the hundreds and even millions of dollars, specifically for those supporting synchronized stereoscopic projection across multiple screens. Furthermore, the maintenance of such systems adds an additional recurrent cost, which makes them hard to afford for a general introduction in a wider range of industry, academic, and research communities.

We present a low-cost, easy to maintain surround-screen design based on off-the-shelf affordable components for the projection screens, framing, and display system. The resulting system quality is comparable to significantly more expensive commercially available solutions. Additionally, users with average knowledge can implement our design and it has the added advantage that single components can be individually upgraded based on necessity as well as available funds.

Keywords: Projection-Based Display Systems, Surround-Screen Displays, MEMS Technology

I. INTRODUCTION

Several members of our research group have been working on surround-screen projection-based Virtual Reality (VR) displays since the early days of the field, when they developed the CAVE™ system [Cruz-Neira et al. 1992], the first of such systems. In the past fifteen years, these systems have been deployed as one-of-a-kind systems in a range of academic, government, and research institutions, as well as in some industry areas such as Oil & Gas and Automotive. However, their widespread use has been limited, primarily due to the high cost to acquire them and the recurrent maintenance costs to keep them operational. The acquisition cost is typically a combination of a customized design for each installation and the use of specialized projectors that support an actively synchronized stereoscopic display. A typical system consisting of three vertical rear-projected screens and a floor can cost well over three-quarters of a million dollars. A significant part of this cost is the customized design of the structure to support the screens that minimizes the seams at the corners providing an almost perfectly flat screen surface, plus the need for building a special room for the system due to the higher ceiling requirements to install the floor projector and mirrors. Furthermore, due to the high-end projection system, most of these customized installations also require additional resources such as power and cooling in order to be correctly and safely operated.

For years we have been interested in investigating the possibility of building a modular surround-screen system that could eliminate the need for a custom design each time a new installation was planned. We were interested in the possibility of "packaging" a standard surround-screen design that could be easily reproduced and installed in a variety of locations without additional redesign or special room conditions.

Recent developments in MEMS technology are allowing the development of significantly lower cost projectors than can support active stereoscopic display and therefore open new possibilities on how we approach the design of surround-screen virtual reality systems.

Figure 1: An immersive simulator running in our surround-screen display system with the omni-directional treadmill.

We present here our first results on designing and building an affordable modular surround-screen virtual reality display based on commercial off-the-shelf (COTS) components. The project was motivated through a collaboration with the Army Research Laboratory's (ARL) Human Research & Engineering Directorate (HRED). As part of this collaboration, we were required to build a surround-screen system, which integrates an omni-directional treadmill, to evaluate dismounted soldier performance [Courter et al. 2010]. Figure 1 shows the resulting system. The surround-screen display encloses the omni-directional treadmill, i. e. the surface the active user is walking on in Figure 1. This enables the active user to intuitively explore the virtual space with natural locomotion, i. e. walking or even running in any direction. We had a limited budget for the construction of the surround-screen system, which did not allow us to work with any commercially available solution. Additionally, we had strict constraints on the space we had to use to place the system in terms of available power, cooling, and lighting conditions. These lead us to work on a lightweight modular low-cost approach for the projection system and framing.

This paper discusses our design approach and our preliminary experiences on using the system for the work with ARL/HRED as well as several other projects.

II. RELATED WORK

Surround-screen displays have been developed for almost two decades starting with the original CAVE™ design [Cruz-Neira et al. 1992, 1993]. The CAVE™ already defined the basic design parameters: three vertical orthogonal rear-projected screens and a front-projected floor displaying stereoscopic real-time images that provide the correct perspective viewing for the active user based on his head position and view direction.

After the CAVE™ was developed, several alternatives for immersive display systems based on screen projection were created. One of those alternatives is a single or two-surface table projection system, such as the Responsive Workbench [Krueger and Froehlich 1994] and the ImmersaDesk [Czernuszenko et al. 1997], where images are rear-projected on a tabletop and an orthogonal vertical screen in front of the user. Support for several users has been shown by [Agrawala et al. 1997].

Advances in projector technology, especially for projecting on non-planar surfaces, led to the development of curved-screen displays such as the i-Cone™ [Simon and Göbel 2002]. Xphere [Jo et al. 2006] uses many projectors to create continuous images on a small half sphere. More recently, the Allosphere project [Höllerer et al. 2007] introduced the concept of users walking into a large sphere for group collaboration.

Also driven by advances in projection technology are developments for high-resolution CAVE™ systems such as La Cueva Grande [Canada et al. 2006] or the StarCAVE [DeFanti et al. 2009].

While these developments have dominated the research efforts since the first CAVE™, there have also been some efforts in bringing this technology to more affordable systems which are to easier to install. One of the first modular surround screen projection systems [Cruz-Neira 2002] was built using passive stereoscopic projection in a set of four self-standing modular screens. The resulting system was of acceptable display quality, but the use of passive rear-projection had a strong impact on the overall brightness of the entire displays. It also introduced noticeable ghosting. But in general, it was a good proof-of-concept to verify that it was possible to design and build a modular surround-screen system that was affordable and easy to reproduce.

III. OMNI-DIRECTIONAL TREADMILL

The omni-directional treadmill is a physical device that allows users to walk and run in any direction. It is a 12×12 feet platform with a walkable area of 8×8 feet. Users stand in the center of the walkable area and perform the same physical actions of walking and running as they would in a regular flat terrain (cf. Figure 2). A set of belts within belts, perpendicularly arranged and each driven by an electro motor, enable the full 360 degree motion of the floor plane. Users are instrumented with a set of body trackers for measuring position and orientation of their center of mass. As the treadmill is operated, it actively counteracts user motion, measured by the tracking system and feedback into the omni-directional treadmill's control software, to ensure the user is always in or near the center of the walkable area. This is necessary for both correct operation of the omni-directional treadmill as well as for user safety, so the user does not trip and fall over the edges of the walkable area. Our omni-directional treadmill is able to support running speeds up to six miles per hour. Because the omni-directional treadmill actively counteracts user motion the user is secured by a harness connected to an emergency shutdown system to prevent harming users. In more than one year of operation many people have used our treadmill and none of them had any problems; most people are comfortable using the device after a training period of five to ten minutes.

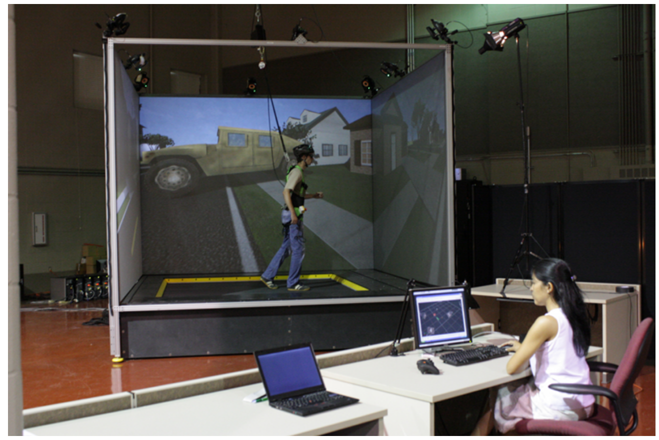

Figure 2: Omni-directional treadmill system in operation. The walkable area of the omni-directional treadmill can be seen surrounded by yellow markings.

IV. SYSTEM DESCRIPTION

This section covers our approach to design and build an affordable modular surround-screen virtual reality display based on commercial-off-the-shelf components. Our goal is to create a usable virtual reality display that is of comparable quality to those commercially available but at more affordable costs as well as to be easier to maintain and upgrade. We capitalized on our twenty years of experience of building these systems to create compelling virtual reality applications and on our experience in transferring these systems to collaborators in academia, industry, and government. From these experiences we have identified a set of requirements and needs as well as challenges we were faced when using these systems that have driven the design presented in this section.

A. Requirements and Constraints

The base design of our system had to provide three rear-projected vertical screens surrounding an omni-directional treadmill with the possibility of adding a fourth vertical screen and a floor projection in the future. All the screens are required to support active stereoscopic projection at acceptable display quality in terms of resolution, brightness, and contrast. Our approach to design this surround-screen system was driven by three main constraints specific to our project: budget, available space, and tightly fitting around the omni-directional treadmill. Furthermore, we wanted to incorporate the more general requirements and constraints we have identified over the years by collaborating with many groups trying to use virtual reality technology. And finally, we also wanted to address the challenges those groups do face when trying to operate such systems and their applications.

Our total budget for the projection system including the computer system was constrained to be under $70K. This made it impossible for us to work with any of the commercially available solutions as even the lowest-cost commercial systems were at least double or triple our budget. We therefore designed and build our system.

Our floor space was limited to a maximum of 48×48 feet to build the complete system. We were unable to hang anything from the ceiling or walls, nor attach anything to the floor, which forced us to design a self-supporting structure. We did not have any ceiling height constraints; our space is located in a converted warehouse with ceiling heights of about 30 feet. We self-imposed a height limitation of 13 feet looking towards future installations that may need to be set in more restricted spaces with regular ceiling heights between 13 and 15 feet.

The omni-directional treadmill, as already mentioned in Section III, has a floor shape of 12×12 feet with a height of two feet and a usable area for locomotion of 8×8 feet. This constrained the width of the screens to a minimum of 12×12 feet, which is slightly larger than typical surround-screen systems. Potentially, this impacts the display quality as we need to cope with a larger projection surface that may create the perception of degraded brightness, contrast, and decreased resolution of the projection system.

In addition to these project-specific constraints, we considered general requirements for surround-screen virtual reality displays. Over the years we have noticed that, although there is a perceived high demand for higher and ultra-high resolution in the projectors for these systems, in reality, two-thirds or more of the VR applications being developed and in use do not take advantage of this increased resolution. This lead us towards a practical approach on selecting projectors that can provide an acceptable resolution (in the order of XGA or a little higher such as SXGA or WXGA resolutions) for general-purpose VR applications. Another aspect we have noticed is that most systems have complex structures and framing to support the screens. This makes it difficult as well as labor intensive to replace an old or damaged screen because most likely the entire structure needs to be disassembled. Even more, some of these framing constructions put so much force on the structure to minimize the seams at the corners that in many cases the screen material tends to fuse together making it impossible to replace a single screen. We incorporated as a design requirement the development of a simpler structure with less pressure applied to the corners, so it would be possible to disassemble each screen individually if the need arises. Most current VR systems require special cooling due to the heat dissipated by the high-end projectors, which generally means that the room in which the system will be installed needs to have a custom HVAC system. This is another requirement we would like to avoid so our system can be installed in a room cooled by standard HVAC. In most cases, electrical power is also an issue as additional or dedicated power circuits need to be available for high-end projectors, which tend to consume in the order of 1,000 watts per unit. We are interested in identifying projectors that can use existing power distribution setups and do not require any more power than other regular electronics equipment found in offices. Finally, projector brightness, although a concern for any VR system, does not have to be extremely high as there is the potential for cross talk among the screens. Brightness levels between 2,000 and 4,000 lumens provide a good display in a controlled light space.

B. Projection-System Design

Our projection system had to meet the constraints and requirements described in section IV A. Reviewing the current available projection technology options, we selected the DepthQ®-WXGA HD 3D video projector [DepthQ Website]. These projectors are based on DLP technology and allow for presenting field-sequential images per video frame. The native resolution of the projectors is 1280×720 pixels at 120 Hz. Our total floor footprint for the system was limited to 48×48 feet, which left us with approximately 16 feet throw distance from the projectors to the screens. To avoid long throw paths or the use of folding mirrors we added NAVITAR® ScreenStar® conversion lenses [Navitar ScreenStar Website] in front of the projectors' output. These lenses allow for a magnification of the image by approximately 1.5 while still keeping our desired projection distance, i. e. 16 feet. We designed a custom mount for attaching the lenses to the projectors because we needed complete control over potential light leaks and the distance between a lens and a projector's optics.

The only challenge we faced was that the DepthQ®-WXGA HD 3D video projectors have a particular light-output path. They are designed to be placed on a flat surface, such as a table, and project images without the need for further adjustments. This is achieved by always projecting approximately 15 degrees above the optical center of the lens. For our purpose that meant that the projectors could not provide a straight projection path and, therefore, we could not place them at the center of each screen; they needed to be placed either on the floor or high up to achieve the correct projection. We decided to use the projectors in a ceiling mount to allow for the best possible pixel alignment at the bottom of the screen and also to protect them from accidental tampering or bumping. Because of our restrictions that we could not attach anything to the ceiling and walls of the installation space, we designed a projector stand

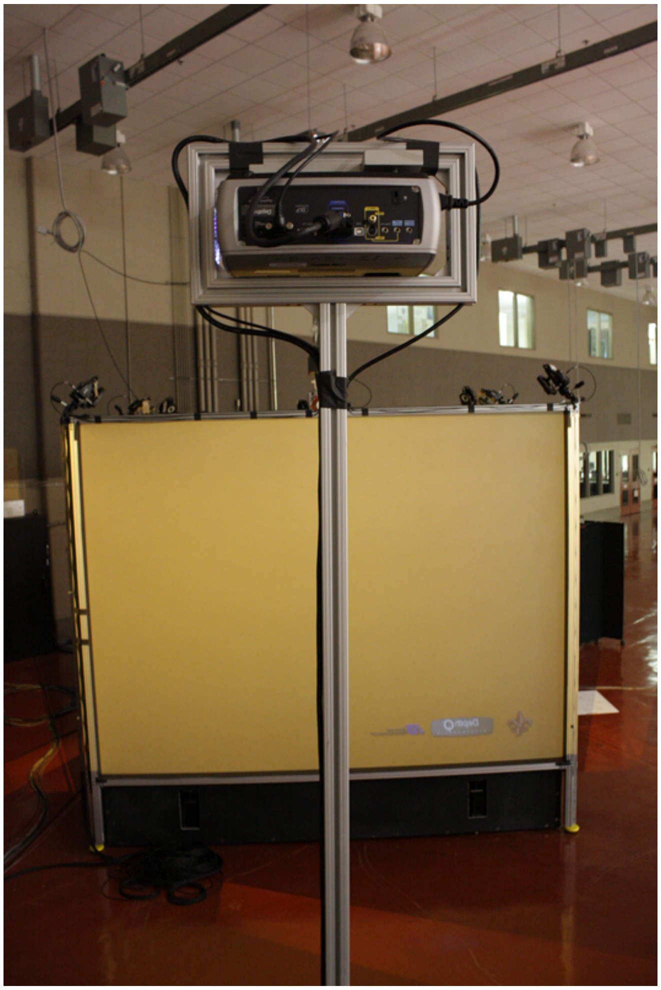

Figure 3: View from the left-side projector onto the back of the left projection screen.

that allows for variable height adjustment. The variable height adjustment was necessary because our installation location featured a slightly unlevel floor, presumably to allow water to flow to sinks. The adjustment of the projector stands also allows for compensation of slight inaccuracies of the projector optics with respect to the projector's mounting base. A beneficial side effect is that the projector base gives us one more calibration parameter that facilitates the alignment of the images. Figure 3 presents a view from behind one of the screens showing the projector base and mount.

C. Screen and Frame Design

The width of the screens was determined by the size of the base of the omni-directional treadmill, which is 12×12 feet. The height was determined by the projection ratio that the DepthQ® projectors could provide. We settled for a value of nine feet as this gave us a 4:3 projection ratio that is well within the capabilities of the projector. Furthermore, this height was a comfortable height to cover the user s complete field of view (FoV) even for those taller than six feet. This way, our system's projection screens are slightly larger than those of a typical CAVE™, but still within a manageable size to use a single projector per screen.

The initial design consists of three vertical screens covering the front, right, and left sides of the omni-directional treadmill. The screens are raised two feet from the ground to align with the surface of the omni-directional treadmill's frame. Again, since we were unable to attach anything to the ceiling or walls or drilling support anchors into the floor of the room, we designed a self-supporting modular structure for the screens. Each screen frame is a rectangular frame with two legs extending down to the floor and standing on large pads. The screens are connected at the top and the bottom corners, with a top and bottom beam between the right and left frames, thus the whole structure appears to form a cube. We used T-slotted aluminum framing material [80/20 Inc. Website] to create a strong but light frame. We needed the strength of the material to create tension on the screens so they will be flat surfaces without any sagging or bowing and have a well-aligned rectangular projection area. We selected a flexible screen material, Stewart FilmScreen 100 [Stewart Filmscreen Website], that could be wrapped around the frame and fastened on the frame s backside to minimize the seams at the corners. The screen material was ordered with snap fasteners evenly spaced on the outer seam. Additionally, the frame corners rest on each other without extra pressure, providing very tight corner seams, but avoiding potential material fusing. The projectors are not attached to the screen frame, but use the mounting base designdescribed in the previous section.

Once completed, the screen structure proved to be very sturdy with the right tension for the screens, while at the same time being light enough for future maintenance and repairs. For example, after the structure was built, we had to make a minor adjustment on the positioning of the treadmill and it was possible for a team of eight people to lift the entire structure and move it a few inches to be better aligned with the omni-directional treadmill without the need for disassembling.

D. Assembly, Setup, and Calibration

After the design was completed, we ended up having a very tight schedule to construct our system due to the manufacturing lead times on the different components (some of them took as much as six weeks to deliver) and the fact that we wanted to showcase our system during the IEEE VR 2009 conference, which we were hosting in our city. Most parts and components arrived a week prior to the conference s opening. Because of all this, assembly, setup, and initial calibration of the surround-screen system were done in approximately three days. The self-standing modular design allowed us to create an "assembly line" to attach all the components and therefore meet our tight schedule.

Screen assembly was broken down into two steps: assembly of the parts for the frame of each screen and the actual attachment of the screen material to the appropriate frames. We were lucky to have enough space available to spread out

(a)

(b)

Figure 4: Assembly process of the screen frames. (a) The assembled frames without the screen material attached. (b) Preparation of the fastening snaps on the frames right before attaching the screen material.

and build the frames near to the omni-directional treadmill (cf. Figure 4a) and also to have enough hands available to help with the screen attachment. Three people assembled the frames beforehand in a matter of hours. Before attaching the screen material to a frame the snap fastener counterparts needed to be placed into the correct grooves of the frame. With enough hands this was another three hours but necessitated meticulous oversight to ensure that the correct spacing of the fasteners with respect to the appropriate spacing on the screen material was achieved. We also used textile tape to further soften the edges of the beams where the screen material was to be wrapped around. Finally, the frames were laid out and, with the help of our students, the screen material was placed on the frames (cf. Figure 4b). While the material was held in place the snap fastener on the screen material and the frames were assembled. This stage required also a certain diligence because the screen material can potentially tear from too much tension when wrapped around the frame. All in all this stage took approximately eight to ten hours.

The display system setup involved the movement of the assembled frames to their final location. While several people were required to actually move one frame two people were enough to hold the frame in place and wait for another frame to arrive. We first moved the front screen into its final position and then the left screen. Both screens were then loosely connected. Afterwards, we added the right screen and then connected the left and right screens with two horizontal beams, essentially creating an empty projection screen for the back side of the omni-directional treadmill (cf. Figure 5). Finally, all remaining connections were tightened to complete the structure. We used multi-hole aluminum plates to connect the frames. This requires very exact placement of the frames with respect to each other because the fastening mechanism does not allow for much leeway.

After the screen assembly and setup, the projection devices mounted on the projector stands were placed in their proper position and connected to the image-generation PCs. The projectors also feature a control mechanism via serial line, so each projector was connected to an USB-serial hub connected to one of the PCs. A simple control software was developed before-hand that could signal the projectors to power-on or power-off. By using a simple terminal program the projectors can be controlled the same as with a remote control. The calibration of the entire system did take approximately four hours. The reason for this is that first the projectors needed to be aligned physically with respect to their appropriate screen. For this a calibration image showing a full circle for the lesser extend of the height and the width of the projected image is very helpful. Then each projector needed to be calibrated for keystone, brightness, contrast, and color to provide a uniform projection across all the screens.

The projectors each receive input from a different PC of a five-node graphics cluster (cf. Figure 6). Three nodes of the cluster are assigned to the three projectors each and one node acts as the master node for receiving external input, computing application-state logic, and distributing the results to the three render nodes. A fifth node is used as a file server for the cluster to minimize maintenance and avoid software inconsistencies on the client nodes.

Figure 5: Our surround-screen system right after assembly as seen from the right-side projection direction.

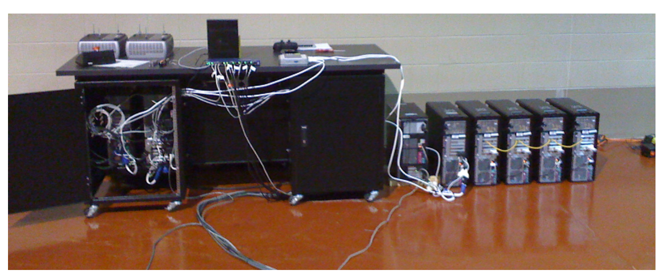

Figure 6: PC cluster driving the projection system (plus additional hardware for operating and controlling the omni-directional treadmill).

V. DISCUSSION

The surround-screen virtual reality display we built is certainly not the first and will also not be the last. Nevertheless, our design decisions, their implementation, as well as its use make the described display system unique.

First of all, our modular design is simple, easy to reproduce, and straightforward to build without much specialized skills. In a sense, it leads to the concept of a surround-screen system in-a-box which could potentially be productized at significantly more affordable costs than most existing systems. Minor adjustments, such as bringing the screens to floor level or smaller screens, translate in just shorter supporting beams for the frame. The modular design also simplified the assembly, as discussed in section IV D, making the total installation time for the entire system approximately three days by putting some five to six hours each day with a crew of eight people. In our case, the installation crew were actually students that had never built these kinds of systems, but their lack of experience did not impact the assembly. This was possible in part because our design was driven by the requirement of having a simple and well-documented process for assembly. The lightweight parts of the industrial construction set we were using helped much in this process as well as the COTS character of any other component (except for the projection-screen material). This clearly shows that it is possible to reduce the time and effort in building a surround-screen system.

It is also enlightening to have a look at the components' costs (cf. Table I). There are two issues of note here. First, the overall parts and components cost of our design is an order or two lower than most current systems. This is mainly due to the reduced cost of the projectors as well as the reduced costs for the framing and projector stands. We do not feel that a straight projector throw would contribute to the cost reduction because the savings we may have had on not using mirrors are counter balanced with the expense we had on acquiring the short-throw lenses. The costs we present in Table I are all-inclusive, i. e. the frame material, the projector stands, and the miscellaneous material, also include custom cutting, mitering, screws and fasteners, as well as shipping costs. An additional cost for this project which is not listed is the design cost and the assembly cost but since we designed this part of the process to be easy and simple enough that it can be done by anyone with some experience of getting parts from a hardware store and putting them together we feel most sites that may want to have such as system probably have in-house personnel that can lend a hand for the installation.

Our modular design also applied to the supporting technology chosen for the display. We selected DELL Precision Workstations T5400 with NVIDIA Quadro FX 5600 graphics cards for the cluster nodes. This allows for easy and affordable upgrading of the graphics sub-system as well as memory throughout the life span of the system. Our experience tells us that this is harder to achieve with non-workstation PC products. The DepthQ®-WXGA HD 3D video projectors where chosen mainly for their ability to output field-sequential video frames required for supporting active stereoscopic imagery. Staying with our design approach of simplicity, we did not want to use the alternative solution, which would be to use, at least, twice as much projectors and present passive stereoscopic images. This would escalate the complexity and calibration efforts because for each screen two projectors need to be setup and calibrated for pixel-level convergence. But we feel that the cost of the DepthQ® projectors (and similar technologies that we know are coming in the next 6–12 months) do allow for affordable upgrades or replacements within the life span of the system.

Part	Cost (US $)
PC Cluster	20,000
Projectors	18,000
Screen Material	10,000
Frame Material	7,000
Projector Stands	1,500
Miscellaneous Material	3,500
Total	60,000

Table I: Parts and cost for constructing the our surround-screen system.

VI. CONCLUSIONS

We have now had our surround-screen system in operation for a little over a year and we have been fairly active in using it. Figure 7 shows the final system in operation. Typically, the system is operating for a minimum of two to three hours for three or four days a week. We have had peak usage at eight to ten hours of continuous operation during special events and visitor groups. All the components have proven to be very robust and reliable, not having any failure during this operation schedule. Maintenance has also been very light. We realign and calibrate the projectors approximately every quarter or in case some other maintenance task requires repositioning of the projector stands. The projector stands provide enough weight to withstand micro vibrations (e. g., by the omni-directional treadmill or by traffic from adjacent streets). Complete calibration of one projector, i. e. physical alignment as well as keystone, brightness, contrasts, and color calibration, takes about an hour. Because the projectors need to be calibrated with respect to their images on the screens the whole projection system can be recalibrated in three to four hours.

The frame design, in particular the design for attaching the screen material to the frame has proved itself to be very successful in that no sagging has occurred in the full year of operation since the initial assembly and setup (cf. Figure 8). Furthermore, the screen tension is still high enough that the screen does not bow from air movement (such as opening and closing doors or the activation of the air-condition system).

The overall visual quality of the display is very good for the cost-quality compromise. As mentioned earlier in this paper, our system is targeted to general-purpose virtual reality applications, which are not extremely demanding on high resolution. Applications such as flight simulators, highly pixel-dense images, such as those found for military command and control,

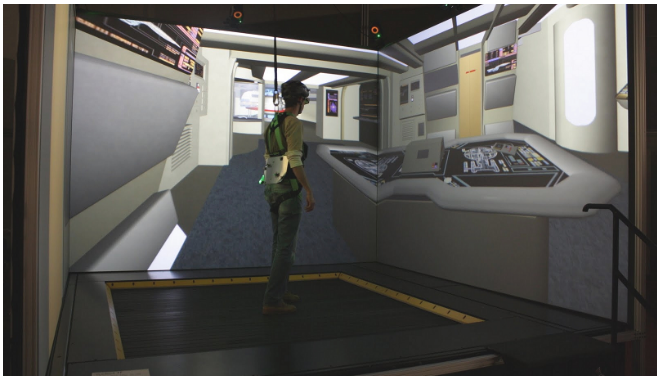

Figure 7: A walk-through application running in our surround-screen display system around an omni-directional treadmill. (Model part of the Star Trek Mesh Collection at http://www.trekmeshes.ch/.)

are outside the scope of our systems. However, there is a large range of applications, such as architectural walk-through, engineering, science visualization, and educational applications that can benefit from our system. Technically, we are aware that the use of magnifying lenses for the projectors to reduce throw distance is visible to the trained eye in two ways. First, the size of a pixel on the screen is approximately 3.8 mm. Second, the small aberrations that occur near the rim axis of the projectors' optics are magnified by the extra lenses. These aberrations cause a degradation of the image quality, but realistically, only the trained eye can detect this with static images. For general-purpose applications with dynamic images it is not noticeable.

Additionally, the screen, when projected with monochrome colors, exhibits a slightly speckled pattern. We surmise this to be a property of the screen material or maybe also generated by the projector's DMD (or maybe a combination of both).

But, as we have said, we are very satisfied with our results. Anecdotically, many of our visitors think they are looking at a commercially available high-end system due to the quality of the display and they are positively surprised when we disclose the fact that we are using relatively low-end COTS equipment. We have had several requests to help other groups to build a system like ours.

A. Future Work

Our surround-screen display is certainly not finished. Experiences from using the system as well as watching others using it, let us to the conclusion that a fourth screen is required. This comes mainly from the fact that with the use of the omni-directional treadmill as the main navigation device users can and will explore the virtual space in a more intuitive way. This includes walking in circles, going back and forth, or turning 180° to understand spatial relationships in the scene. There are several ways of how to add a fourth screen but they need to be evaluated with respect to the overall requirements and our described design philosophy.

We deliberately left out the topic and cost of a spatial tracking system, which is necessary to acquire (at least) the user's head position and view direction to compute images with the correct perspective for that user. In our particular setup that was not a problem because the omni-directional treadmill came with an already installed optical tracking system. However, for a fully closed surround-screen display supporting a tracking system but also keeping the costs at the same level as for the display system may require a different approach. Our group is investigating the use of a hybrid inside-out tracking system, JanusVF [Hutson et al. 2009], which would allow operation in a fully-closed environment.

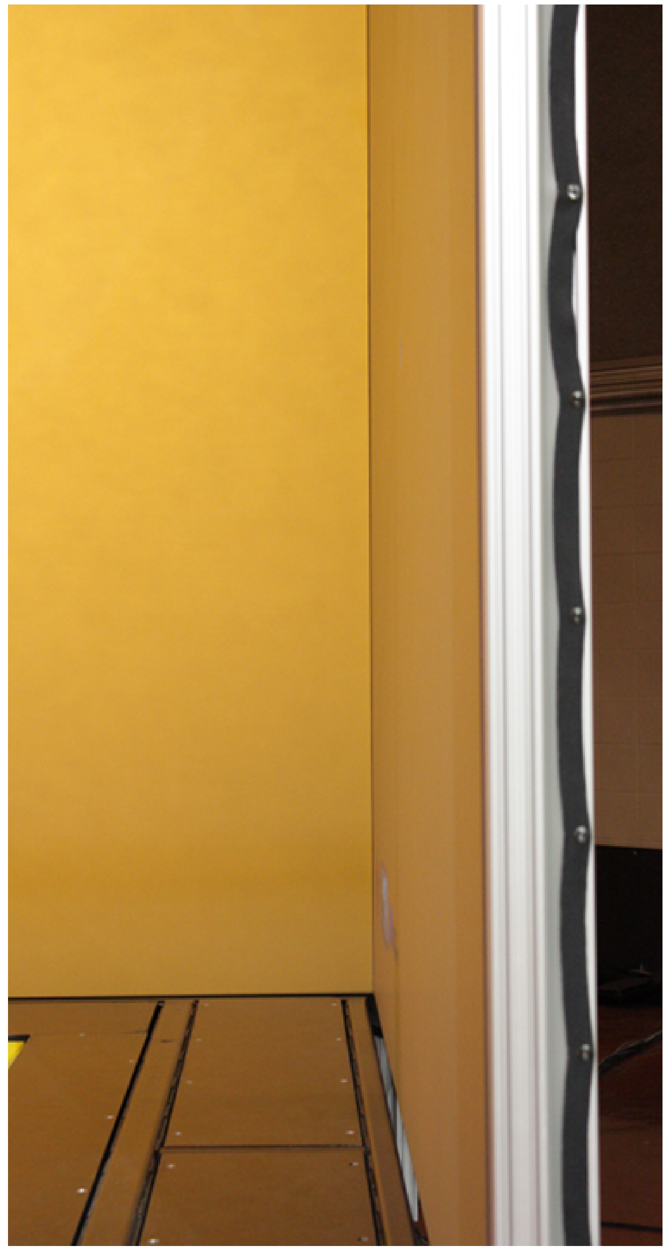

Figure 8: Screen flatness after one year of operation. Figure shows the right screen after a little more than one year of operating the system. The screens do not show any signs of bulging or sagging and appear as if they were made from rigid material.

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Biographies

Carolina Cruz-Neira is the W. Hansen Hall Endowed Super Chair in the College of Engineering at the University of Louisiana at Lafayette and the Chief Scientist of the Louisiana Immersive Technologies Enterprise (LITE). Until 2005 she was the Stanley Chair in Interdisciplinary Engineering as well as the Associate Director and co-founder of the Virtual Reality Applications Center at Iowa State University (ISU). In 2002, she co-founded and co-directed the Human-Computer Interaction graduate program at ISU. Dr. Cruz-Neira's work in VR started with her PhD dissertation: the design of the CAVE™ Virtual Reality Environment, the CAVE™ Library software specifications and implementation, and preliminary research on CAVE™-Supercomputing integration. Since then, her research has been driven by providing applicability and simplicity to VR technology focusing on software engineering for VR, applications of VR technology, and usability studies of virtual environments. She spearheaded the open-source VR API movement with the development of VRJuggler and has been an advocate of best practices on how to build and run VR facilities and applications. Dr. Cruz received a PhD in Electrical Engineering and Computer Science (EECS) from the University of Illinois at Chicago (UIC) in 1995 and a Master's degree in EECS at UIC in 1991. She graduated Cum Laude in Systems Engineering at the Universidad Metropolitana at Caracas, Venezuela in 1987.

Dirk Reiners is an Assistant Professor for Computer Graphics at the Center for Advanced Computing Studies (CACS) at the University of Louisiana at Lafayette. His research focuses on fundamental methods and applications for interactive 3D graphics and Virtual Reality-based on commodity infrastructure. He did his undergraduate work at the Friedrich-Alexander University Erlangen-Nürnberg and performed his graduate work at the Technical University Darmstadt. His work has focused on software systems for Virtual Reality applications, primarily rendering systems. Dr. Reiners holds a PhD in Computer Science from the Technical University Darmstadt for the development of the OpenSG open-source scene-graph system.

Jan P. Springer is a Research Scientist at the University of Louisiana at Lafayette in the Virtual Reality Group headed by Dr. Cruz-Neira. Until 2008 he has been a Research Assistant with the Virtual Reality Systems Group at the Media Faculty of Bauhaus University Weimar in Weimar, Germany. There he worked on a variety of virtual-reality topics such as graphics-cluster-based displays and applications, multi-viewer stereo, the integration of multi-viewer stereo and wave field synthesis audio, and interactive high-quality rendering mechanisms for VR applications. From 1999 to 2001 he was part of one of the premier VR research groups in Germany at the National Research Institute for Information Technology (now part of the Fraunhofer Society) near Bonn. While in this position he maintained and further developed the VR system Avango as well as participated in project work related to the Oil & Gas industry. Dr. Springer received a PhD in Computer Science from the Bauhaus University Weimar (2008) and a Diploma (Master's) degree in Computer Science from the Bauhaus University Weimar (1999).