Room Racers: Design and Evaluation of a Mixed Reality Game Prototype

Lieven van Velthoven
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Media Technology MSc. program, Leiden University
Supervised by Maarten H. Lamers
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***Abstract*— This project investigates the feasibility and 'fun potential' of interactive top-down projection systems for gaming purposes, through the design and evaluation of a racing game prototype. Room Racers allows household items to be used as obstacles for virtual, player-controlled cars. We explain the design rationale behind both the technical and gameplay aspects of the system.**

The difficulties of evaluating HCI entertainment systems are investigated and acknowledged. Our results were evaluated through informal observations and interviews in numerous real-life settings. In addition, we present a summary of expert opinions, honors, awards, and online feedback.

The combined results provide indications of substantial support for the system. We claim to have shown that, even with basic technical means, projection-based augmented reality can be a powerful and (commercially) viable gaming platform.

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***Index Terms*— evaluation methodologies for entertainment systems, game design, human-computer interaction, mixed reality, tangible interaction**

I. Introduction

The video game industry has experienced revolutions on the field of user interaction in the last decade. Currently, the three popular home game consoles all feature technology that aims to bring aspects of the real world (specifically the player's body and movements) into the virtual world, an approach that proved quite successful [1],[2].

This trend of joining the two worlds can also be seen on the mobile computing side, where many commercial examples of Mixed Reality in the form of both Augmented Reality (AR) and Augmented Virtuality (AV) [3], have been created since the first generation of camera phones was released [4].

Although these approaches are interesting on their own, most of them still require us to look at screens. A promising next step for the industry could be to do the reverse: to *actually* bring the virtual world into the real world. We believe that Spatial Augmented Reality (SAR) [5] games could persuade (young) audiences to 'come off the couch' and play more physically, without having to sacrifice the high-tech console entertainment that they love. [6]

We set out to build and explore a consumer hardware based prototype SAR gaming platform, with both home and public use in mind. As its first application, we chose to develop a top-down racing game that uses standard game controllers [7]. This was motivated by the opportunity to bridge gaps between console gaming, tangible interaction, and traditional ground play, considering the familiarity of vehicle-centered play in all these scenarios.

Depending on this experiment's success, other games could later be developed for this SAR platform.

II. Related Work

Numerous projects that explore AR entertainment have been documented in HCI research [8]. These include tabletop racing games on various AR platforms [9],[10],[11],[12].[13].

In the *AR Racing Game* described in [9], fiducial markers represent both the playfield surface and interactively placeable game objects. The game is viewed through head-worn displays and the vehicles are controlled using a handheld marker array that acts as a combined steering wheel and throttle.

Neon Racer is a tabletop racing game on a multi-touch display surface [10],[11]. Everyday physical objects can be placed dynamically by the players and form obstacles for the virtual vehicles, which are controlled by traditional gamepads. Although the obstacles can be freely positioned, players do not define the racing circuit as a whole.

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Lieven van Velthoven is an MSc.student at the Leiden Institute For Advanced Computer Science, Leiden University, the Netherlands (e-mail: lievenvv@gmail.com).

Two projects that are even more closely related to our own are *Micromotorcross* [12] and *MR Auto Racing* [13]: both exploit interactive tabletop projection systems and allow virtual cars to drive around in a physical environment.

Whereas Micromotorcross relies on a depth-sensing camera to continuously generate a three-dimensional map of a tabletop environment, MR Auto Racing employs a more standard RGB camera and does not continuously detect changes to the racetrack. The latter explores both tabletop and vertical (e.g. whiteboard) setups of the system. Sadly, not much documentation exists on the user experiences of either of these games.

III. Project Description

A. Technical design

1) The display

Although impressive applications have been produced for many different kinds of AR technology, we are especially interested in exploring projector-based SAR, due to

1. its ability to *actually augment reality* (i.e. directly augment real environments)
2. its ability to scale easily and facilitate social interaction
3. the possibility for truly direct manipulation
4. relatively low, and rapidly decreasing, hardware cost.

A top-down projection setup was chosen with the most common indoor scenarios in mind: tabletop gaming and classical ground play. Nevertheless, as Cernak demonstrates [13], the same technology works in other scenarios (e.g. whiteboards) as well.

2) Environment reconstruction

There are various technologies available for real-time environment scanning and reconstruction in (spatial) AR [5]. Choosing accuracy, practicality and cost as the main constraints, we decided to use a simple active infrared (i.e. *night vision*) camera setup, due to its high scores on all three aspects. See [fig.2-4].

i) Notes on 3D vision

A tempting alternative was the approach taken by both [12] and [14]: using a depth-sensing camera like Microsoft's Kinect for three-dimensional reconstructions in real-time. This would clearly offer possibilities that our traditional camera cannot.

Unfortunately, experiments using a Kinect sensor indicated that its accuracy is too low for our purposes. Mounted at a normal ceiling height of 2-3 meters, the sensitivity at floor level will be in the range of centimeters [15]. In our case, that means that obstacles about half as high as the cars are wide might not be detected: an error too large for a consistent game experience.

Better depth-sensing cameras are available, but are expensive, impractical or slow [16]. Exploiting the RGB camera of Kinect (for higher-res 2D object detection) would re-introduce interference from the projections. Combining a Kinect with a night vision camera also causes interference, due to Kinect's field of projected infrared dots [15].

Fig. 1. Room Racers; detail of a living room race track. 'Red player' defines the route, getting ready to place the second checkpoint. When a player moves an object, any checkpoints that touch it will resize accordingly.

We believe that stereo night vision cameras might offer the best union between the benefits of 2D and 3D vision in this type of setup.

ii) Image processing

On the software side, we needed an algorithm to reliably detect physical obstacles in a live camera stream. We wanted to allow the players to directly introduce and manipulate *any* physical objects in the game, at any time: fiducial markers (such as in [17]) were therefore avoided. Also, computational cost should be kept to a minimum as to preserve processing power for the game.

Experiments showed that real-time Canny edge detection [18] satisfied our conditions, due to its relative robustness and low computational demands. Finding only the boundaries of physical obstacles was considered to provide a sufficient basis for interaction in this exploratory game [fig. 2].

Temporal image blur was introduced as an optional means of improving sensitivity, at the cost of increased latency in the vision system. Motion detection was added later for dynamic control over this trade-off [19].

iii) Calibration

Calibration of the camera-projector rig was achieved through manual adjustment of sensitivity values, and the alignment of a calibration grid with the camera's view of the projection area. Although the whole process would only take minutes using a proprietary installation GUI, we later developed routines to completely calibrate the system using only its native interface: i.e. no mouse, keyboard, second screen or special GUI's.

Fig. 2. Outlines showing the system's obstacle detection. In the upper right corner: 'Green player' is stuck and can only be freed by moving the object.

Two instructions to the users were enough to accomplish this: one to clear the entire playfield, and one to place small items on designated positions in the projection area.

Much more work could be done to enhance this simple computer vision system. Nevertheless, we will see that it provides a fruitful basis for tangible interaction and (social) gameplay.

B. Game design

Room Racers was intended as a casual, creative, and social game [20],[21],[22], therefore accessibility and intuitiveness were key in its design. Like with traditional ground play, the depth of the experience should come from the players' creativity and social interaction [23],[24]. The feature set of the game was therefore kept to a minimum.

The game's visual design was also kept deliberately simple: besides the scoring and the four little cars, almost nothing is projected. By essentially mimicking (remote controlled) toy cars on self-made toy circuits, we aimed to make the concept of the game instantly clear.

Two game modes were implemented: *'racing'* and *'combat'*. In *racing mode*, players arrange physical obstacles to create circuits for their virtual cars. The route is defined by driving around the track, and pressing a button to place the start/finish line and checkpoints [fig. 1]. The system can then track whoever is winning.

In *combat mode*, players can fire away their headlights (which will regenerate) at opponents. Gaining a point for each 'hit', the round finishes when someone reaches the score limit.

Partly designed for use in public spaces, the game allows players to drop in or out of the game at any time. After each round, the next one starts automatically. To further increase accessibility, the cars' functions were redundantly mapped to multiple controller buttons and axes, thereby catering to different control preferences. In later versions, optional AI opponents (i.e. *bots*) were made available to control any unused cars.

Fig. 3. Infrared camera image of a crowd in action STRP Festival 2011, showing involvement of 'bystanders'. The system automatically saves the camera view at the start of each round.

IV. Notes on Evaluation Methodology

We realize that evaluation methodology is still a hot topic of discussion in the HCI community [25],[26],[27]. Sadly, for entertainment interfaces this problem appears to be even more apparent. Objective measures have traditionally focused on properties like functionality and efficiency, but not so much on measuring subjective experience, or 'fun' [27],[28],[29],[30],[31].

Most well-respected HCI evaluation methods that can gauge user experience each have considerable disadvantages [25],[27],[32]. Isbister, for example, summarizes that post-interaction questionnaires do not capture the richness of the interaction, video analysis is time-consuming and difficult, and think aloud methods may run into other problems [32].

Other research efforts on objectively measuring user experience have generated interesting results using so-called multi-layered or polyphonic approaches, such as [27],[32].

Another promising approach is described in [33],[34],[35], where researchers performed continuous measurements of certain physiological features. Their results showed a strong correlation to verbally reported subjective user experience.

Although the authors claim that their methods provide objective means of measuring user experience, like 'boredom' and 'fun', the results can also be interpreted differently. If objective, physiological markers are shown to correlate with subjective user reports, the paradoxical reverse is that *subjective user reports can be considered objective*.

On this topic of verbal user reports, we also argue that in our case, any affective bias introduced by self-selection does not necessarily undermine the information. Tastes differ, so even if any negative feedback remains unspoken (due to self-selection among commentators), we should judge by the amount of positive response if there is sufficient support for this (type of) game. This view is supported in [32].

In the words of [25], "*there is no 'ISO standard human'*". But, as [26] argues, we cannot simply rely on designers' subjective opinions either.

V. Results and Evaluation

The evaluation of this project was performed informally, but extensively. Within the scope of this project, many of the abovementioned methods were either unavailable (e.g. physiological measures), unpractical (e.g. video analysis) or undesirable for other reasons. Instead, we will summarize observations of gameplay behavior, user feedback, expert opinions, honors and awards, YouTube statistics and our analysis of the system's strengths and limitations. We claim that these provide valuable indications of the project's popularity and success.

Reports in other (online) media have been generally positive as well, but are omitted here for brevity's sake.

A. Observations in real-life gameplay settings

In addition to performing early gameplay tests in a home setting, we installed Room Racers at more than a dozen public exhibitions at various festivals and museums. We did not actively propose to exhibit our project, except to the very first event. These events ranged from one-day showcases to semi-permanent exhibits and catered to various distinct audiences; several attracted visitor numbers ranging in the tens of thousands of people [38],[39],[40].

Many event organizers reported great popularity of our game with the crowds:

" *(…) I am so happy that you were able to come to Toronto with Room Racers. It was a HUGE hit with our audiences.*"
Elizabeth Muskala, Director, TIFF Kids.

"*The exhibition was a great success – especially your work – it was really a magnet for old and young!*"
Magnus Hofmüller, Programme and Production Development, Curator of Interdisciplinary Projects, LENTOS Kunstmuseum Linz.

" *(…) it is very popular!*"
Frank van der Horst, Production and Design 'Neude', Tweetakt 2012.

Peter Weibel, Director of ZKM | Center for Media and Art, referred to our game as both a personal and crowd favorite. After co-selecting Room Racers for the "Car Culture" exhibition in Karlsruhe (87.000 visitors [38]) and again for Lentos Kunstmuseum in Linz (~30.000 visitors [39]), he expressed the desire of acquiring Room Racers for ZKM | Medienmuseum's permanent collection.

1) Gameplay behavior

Besides generating feedback on the overall reception of the game, the exhibitions also provided opportunities to informally observe players' reactions and behavior under real-life circumstances.

In general the crowds were relatively diverse, and people of different sexes and generations often played together. We witnessed some groups of people playing for several hours straight.

The perceived crowd response was overwhelmingly good; typical reactions include: *"wow, this is awesome"*, *"I need this at home / where can I buy this*", *"it works really well"*, and *"OK, one more round"*.

Negative reactions were much more rare and mostly limited to "*too bad you can't drive through tunnels / jump over ramps*", or "*I am not very good with a controller*". We saw many people's controller skills improve, though.

Repeatedly, more people were found around the game than there were cars to control; showing that bystanders also enjoyed to watch, or interact with, the game [fig. 3]. Especially in *combat mode*, players and bystanders could freely rearrange the obstacles during matches, without severely interrupting them. In *racing mode*, everybody could help build the tracks. We observed someone playing for hours, without ever touching a controller.

Of the two game types, *combat* is the more casual and proved ideal for drop-in, drop-out type of crowds. At busy, crowded sessions *combat mode* was favorite.

We envisioned players designing battle arenas and mazes, but found that people often used the tangible interaction in *combat mode* either for the sake of change, or to interfere with the vehicles. People seemed to enjoy 'capturing' and blocking the virtual cars using their hands, feet, or obstacles. More intentional and complex 'arena design' was also witnessed, but generally not to the extent of the circuits being designed in *racing mode*.

Racing mode is somewhat less 'casual', in the sense that it requires some investment and cooperation from its players. Players need to organize themselves in order to create a coherent racing circuit together, and we witnessed this happening at many different events. Particularly at somewhat less crowded locations, we saw that the *racing mode* could provoke a deep, collaborative involvement with the game.

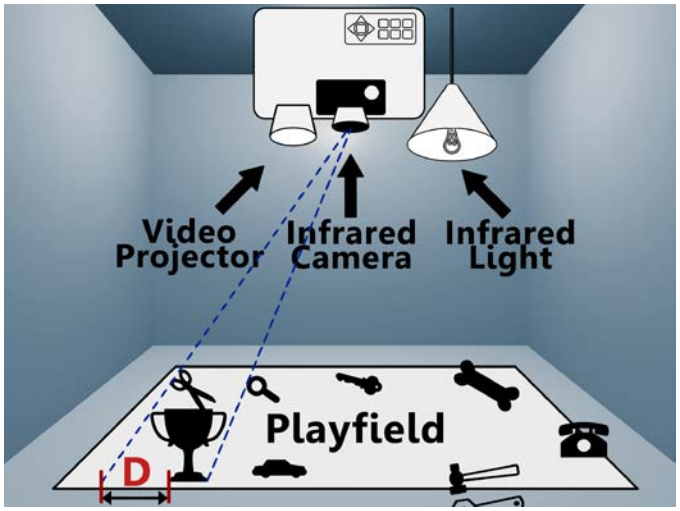

Fig. 4. Schematic illustration of the hardware's setup. The red 'D' indicates the discrepancy between an object's actual and perceived profile: players can minimize this by choosing 'flatter' objects as obstacles.

Fig. 5. A night-time race just started. The virtual headlights illuminate the physical environment.

2) *An anecdote*

One group of (unrelated) people played together for several hours straight at an indie game showcase [41]. They showed very creative use of the system by building a series of challenging racetracks, e.g. ripping up cardboard to create a 'minefield' section, through which many different routes could be taken.

Soon after, someone noticed that printer paper would not get detected by the system; it had the exact same infrared reflectivity as the playfield surface. They started to build paper bridges over physical obstacles, which actually worked because the IR camera could not discriminate them from the playfield. Another person realized he could capture cars by letting them drive onto a sheet of such paper and then quickly lifting it in the air. The system would then detect the sheet, the car would be stuck, and it could be carried around and released elsewhere.

Although we consider this failure to detect an item a flaw in the system, the above examples illustrate that in the hands of creative players, it can actually become a feature (Bartle calls these players *explorers* [36]). Among other things, it is this kind of playful interaction that we wanted to encourage with our game.

The observations showed us what we hoped for: creativity and 'old-fashioned' ground play, while also providing plenty opportunity for Bartle's *achievers*, *socializers* and *killers* [36].

B. *Designer's notes on system strengths and limitations*

1) *Computer vision*

The simple computer vision system performs remarkably well. Using a PlayStation 3 Eye and low-range gaming PC, it can detect objects of only millimeters in size from ceiling height, at 60 frames per second. We found the collisions of the virtual cars sufficiently accurate and convincing for the game.

While performing solidly in many scenarios, our system has some (inherent) limitations:

1. Due to the lack of 3D vision and the single camera perspective, obstacles with relatively large height can be registered as larger than they are, and (partly) obscure the playfield and other obstacles [fig. 4].
2. The limited IR spectrum of the camera causes specific materials to blend in with specific backgrounds, although this is unavoidable with almost any vision method.
3. Using a USB camera is cheap and effective, but does introduce (minor) latency.
4. Our current software demands a smooth and even playfield surface, and cannot discriminate between different (categories of) objects.

2) *Gameplay*

High frame rates, on both the computer vision and computer graphics side, seemed important: 'choppy' graphics or interaction can impair the AR illusion, while smooth, 60 FPS graphics and interaction can seem 'almost physical'. Controller force feedback and the cars' headlights added to this illusion, and due to the 'magic' of projectors, the latter would *actually* illuminate the physical racetrack [fig. 5]. Also, keeping the action strictly on a two-dimensional plane was probably a good choice as it matches the natural capabilities of our simple 2D projection and vision system.

The two input interfaces of Room Racers, i.e. wireless game controllers and everyday objects, each afford 'native' interactions in their own domain. Unlike some AR projects, e.g. [37], both domains serve a clearly distinct purpose and naturally afford interaction.

Some items are really not ideal for use with the system, but this is quickly learned during play. In initial living room gameplay tests, we found ourselves searching the entire house for appropriate objects (i.e. *"I need a long straight"*, or *"I need a wide bend"*), which added to the overall fun. Like some of the later public sessions, these 'tests' could last for hours on end, even though the game itself provides very little depth.

C. YouTube viewer feedback

A low-budget demonstration video of Room Racers was quietly released on YouTube in late 2010 [47]; the game has been slightly updated since. Although the accumulated number of views is relatively modest at over 68.000, the reactions of the viewers were almost unanimously positive: 538 people indicated to *like* the video, versus only 1 *dislike*, and none of the 57 viewer comments (excluding author's comments and spam), were negative[1].

D. Honors and awards

Other testimonies to the project's success came in the form of honors and awards. Room Racers was considered for a 2010 *Wozzie Award* [42], and semi-finaled in the 2011 *Indiepub Independent Propeller Awards* [43]. Neither of these juries played the game.

In 2011, Room Racers was nominated for two *Dutch Game Awards*, the sector awards for the Dutch game industry: winning 'Best Student Game' [44]. It received the *Cinekid International Children's Film, Television and New Media Festival's* Jury Award for 'Best New Media Production' that same year; beating nominated products from Microsoft, Nintendo, Disney and other companies [45]. Cinekid Festival is the largest of its sort, worldwide. *Het Virtueel Platform*, a Dutch government funded sector institution, honored the project as "*an exemplary contribution to Dutch E-Culture*" [46].

A more complete list of honors, awards, media coverage and event invitations is available upon request.

VI. Conclusion

We have explained the main design choices and rationale behind a SAR racing game prototype, and briefly assessed the problems of user experience evaluation in the HCI community. We presented an evaluation of our own project based on extensive subjective reports from various sources.

Room Racers proved to be a remarkably popular concept. In addition to certain choices in gameplay design, this was likely due to the intuitive, direct and social interaction it facilitates. Acknowledging the known difficulties of evaluating entertainment systems and user experience, we cannot draw any hard conclusions from our research. Nonetheless, judging from the immense support that Room Racers has received, we believe that further research on the topic of SAR gaming is justified.

Many other games could be designed for this (type of) technology, and still more if the computer vision system were to feature functionality like object categorization or depth sensing. Still, we claim to have demonstrated that even a simple SAR system can function as a viable platform for gaming purposes. Considering the steady decline of hardware prices, we envision the development of projector-based (home) game consoles in the future.

[1] 47 YouTube comments contained explicitly positive remarks, 5 conveyed tips/ideas/questions regarding the game, and another 5 did not directly concern our project (www.youtube.com/watch?v=oxjGRL7ZiLE, August 9th, 2012).

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