IncreTable, a mixed reality tabletop game experience

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ABSTRACT

IncreTable is a mixed reality tabletop game inspired by The Incredible Machine. Users can combine real and virtual game pieces in order to solve puzzles in the game. Game actions include placing virtual domino blocks with digital pens, controlling a virtual car by modifying the virtual terrain through a depth camera interface or controlling real robots to topple over real and virtual dominoes.

Categories and Subject Descriptors

H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems— [H.5.3]: Collaborative computing—Computer-supported cooperative work K.8.0 [Personal Computing]: General – games.

Keywords

Mixed Reality, Interaction design, tabletop gaming, tangible user interfaces, pervasive games.

1. INTRODUCTION

IncreTable is a tabletop game inspired by The Incredible Machine[1]. The original game was published by Sierra in 1992, building up on the idea of Rube Goldberg machines. The idea was to arrange a given collection of items in a needlessly complex way in order to solve a simple puzzle, provoking user creativity. Until 2001 several publisher developed different versions (see Figure 1), but the original idea of solving puzzles has never been changed.

Figure 1: The Incredible Machine, version three has been developed by Sierra.

IncreTable (see Figure 2) is designed as a tabletop game and provides multi-modal interaction based on bi-directional projection display, digital pens, a depth-sensing camera, and custom-made physical (tangible) objects and robots. Real world objects provoke the user's active participation in creating content which diffuses the boundary between the real and virtual world.

Figure 2: IncreTable is a collaborative tabletop experience which allows playing with digital and real content simultaneously.

Summarizing, IncreTable has the following novel features:

- Novel combination of multi-modal interaction based on new technologies
- The provision of new experiences dissolving the boundary between virtual and real worlds
- User-generated content through multi-user, interactive interfaces
- Bi-directional projection setup that allows content to be displayed in multiple levels.

The amalgamation of the real and virtual world through our technological developments allow for a new, unparalleled gaming experience.

2. RELATED WORK

Over the past decade, tabletop games are becoming more and more popular [6][7][8][9][11][13][15]. In order to improve the social gaming experience, Magerkurth et al. proposed a tabletop setup which combines the advantages of a digital environment with the social impact of board games. In this setup, users can either use personal mobile devices or interact with the public tabletop display. All users are sitting face-to-face, they share the same experience, and they play in a new digital/real world. The game MonkeyBridge, presented by Barakonyi et al. [2], extends the idea of Magerkurth et al. They implemented a collaborative Augmented Reality game using Head Mounted Displays (HMDs). Users can use physical (tangible) objects, which have to be placed correctly, to guide digital, augmented avatars. Especially the

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[1] http://en.wikipedia.org/wiki/The_Incredible_Machine

rising popularity and availability of prototyping toolkits like Phidgets [5], Arduino [14] and games like Lego Mindstorms and respective DIY (Do It Yourself) communities empower researchers to combine custom interfaces in games [12]. In the following section selected relevant examples are introduced briefly.

KnightMage is based on the STARS-platform [10] and is played collaboratively by multiple users sitting around the STARS-table. The hardware setup of KnightMage consists of a tabletop display and a wall display, on which participants can share relevant information to other players. All the hardware components are part of the STARS platform, which is designed to support classical board games with the use of various multimedia-devices. With the use of several displays which can either be public or private displays the STARS setup allows developers to create very complex game scenarios which can for example both collaborative and competitive elements in one game. An embedded camera allows the system to detect and identify game pawn on the interactive screen. In addition, the table includes RFID readers which in combination with RFID tagged objects can be used to save and load different scenarios and games.

Weathergods is a turn-based game that can be played by up to four players simultaneously on the Entertaible system [1]. Each player has three different pawns that can perform different actions in the game. Wilson demonstrated PlayAnywhere, a flexible and transportable tabletop projection setup [17]. Wilson also presented the pairing of a depth-sensing camera with an interactive tabletop to create a car racing game in which virtual cars raced realistically over physical objects placed on the table's surface [16][17]. IncreTable was influenced by this approach and we wanted a physical correct behavior of the digital domino stones, which can be placed on any adequate surface.

3. INCRETABLE

Inspired by the Incredible Machine, the general objective of IncreTable is to arrange a given collection of items in a complex way in order to solve a puzzle. Each level presents a puzzle requiring multi-modal interaction provoking user creativity.

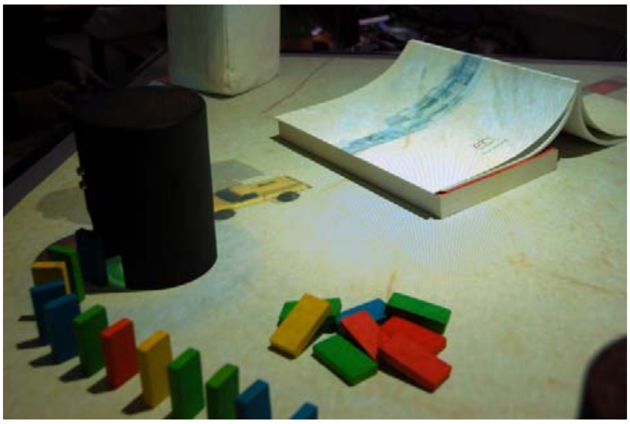
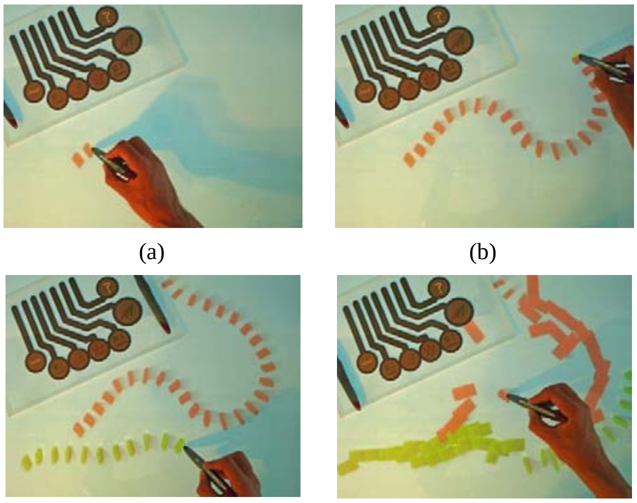


Figure 3: Even folded paper books can be used to modify the terrain.

In each level of the game, users have to play with both digital and real objects. In Figure 3, for example, the goal of the level is to build a ramp with real objects. A virtual car is projected from top onto the objects on the table. The physical objects on the table are tracked using a depth camera. When the level is started, the rolls down the ramp. The car's speed and direction are defined by the placement and height of the real ramp. The car itself has to cross the area under the physical tower (portal) which is then activated and topples over the real domino stones which can be seen in the front. Another physical portal detects if all the dominoes have fallen down and tells the game if the level has successfully been cleared.

Figure 3 also depicts a scenario where the players have used everyday objects as game components. In this scenario, for example, the car jumps over real books which are represented as ramps in the virtual terrain.

Other scenarios include setting up domino blocks in order to achieve certain goals in the level. In IncreTable, users cannot only play with real domino stones, but also with virtual ones. Using a wireless pen-interface, players can draw a path on the table's surface for placing the digital (projected) domino tiles (see Figure 4). Since our system is based on a physics engine, even the digital tiles can topple down by awkward handling.



(a) (b) (c) (d)

Figure 4: The digital domino pieces are placed with a digital pen. The use of a physics engine allows realistic interaction with other game components and the virtual environment.

Players can select between different actions, set up domino pieces, re-position, or delete domino pieces using a tangible toolbar. At the same time, other users can start setting up real domino pieces directly on the projection surface of the back-projection table, creating a very strong mixed reality experience. While playing, users can move freely around the table. IncreTable has no dedicated mode for setting up the domino pieces. Hence it happens quite often that either the real or the virtual domino pieces start toppling over before the chain-reaction is started by the users, forcing the users to concentrate and work together even more.

The use of physical game components also works as catalyst for players to get involved in the game. Since players are familiar with setting up real domino stones even if they have no gaming experience, they can easily join a group of other players and get involved in the game (see also Figure 5).

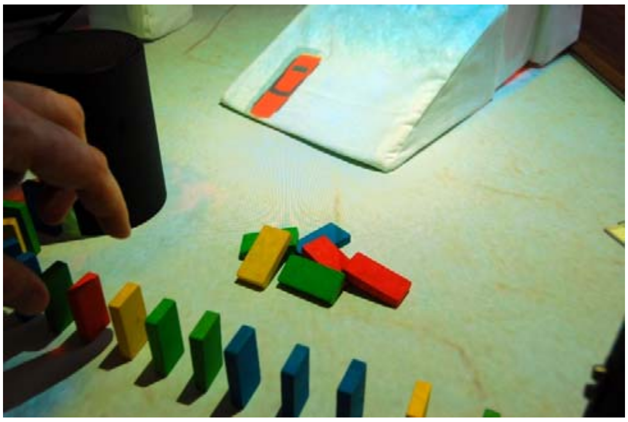


Figure 5: The hands on experience when directly modifying the virtual terrain by moving physical objects or when setting domino stones, allows an easy-to-user interaction.

4. IMPLEMENTATION

4.1 Tabletop setup

Figure 6 shows the hardware setup of IncreTable. The table hardware setup features a rear-projection screen with a Toshiba EX20 short-throw projector. Due to the projectors high lens offset it is easy to use this projector in combination with only one mirror. The mirror and projector can be simply mounted at a 90° angle. The overall table box has a height (depth) of 550mm with an operative screen size of 35.4”×26.75” (900mm × 675mm). On top of the truss, we mounted a second projector for the tabletop projection and a depth-sensing camera for capturing the table’s surface.

Figure 6: Two projectors mounted inside the table and on the ceiling are used in the IncreTable project. Moreover, the depth camera tracks the surface.

The two-projector setup allows for various novel display and augmentation techniques:

Displaying content on the rear projection screen, the players do not drop shadows when interacting on the tabletop with their hands. This way, interactions performed directly on the tabletop surface are best projected from the rear. However rear projection cannot be applied when augmenting real objects which are placed on the table. In this case, projection from the top is used on order to augment real objects with projected textures.

Overlying two images on the table’s surface using both projectors at the same time can create effects which are not possible any other way. Rear projected objects can be hidden under very bright areas from the top projector creating a scenario where users have to shade certain areas in order to see the hidden content. This can also be used the other way round. The location of virtual game pieces which are occluded by physical objects can be indicated by projecting hints from above.

Figure 7 shows a screenshot of one level of our application. Both the bright and the dark area show the same area in the virtual environment. The bright image on the left is projected from the top, augmenting the real objects on the table. The right area is projected from the rear and lights up areas where objects are on the table. This way, also the parts of the table which would usually be in the shade still show the game environment.

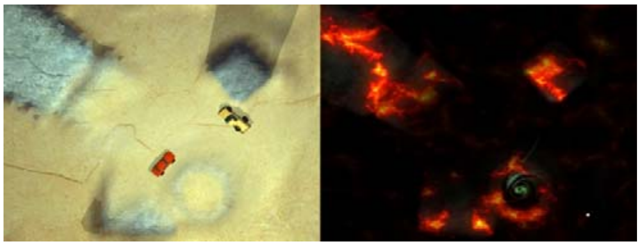


Figure 7: Two different images are projected on the top surface and from the rear projection screen.

The textures of the virtual terrain change dynamically depending on the depth information obtained by the depth camera. Up to four textures are blended one into another depending on height information.

4.2 Digital Pen Interaction

Direct user input in IncreTable is implemented through the use of digital pens.

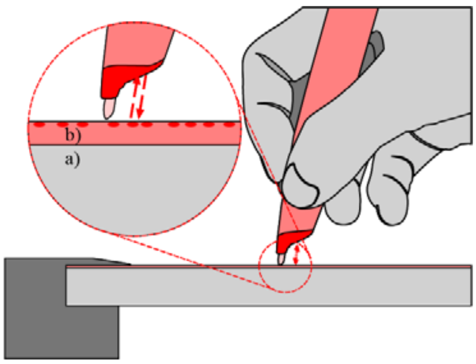


Figure 8: The two layers of the interactive surface: polycarbonate plate (a) and a backlit foil with the Anoto pattern printed on it (b).

Figure 8 shows the different layers used for tracking the pen interaction on the table, which has been presented in [3]. The digital pen (with its embedded camera) tracks the Anoto-pattern printed on a special backlit foil (b). This foil diffused the illumination from the rear LCD projector resulting in an image with no hotspots visible at the front of the screen. The polycarbonate surface served as a rigid base (a) for the backlit foil (b).

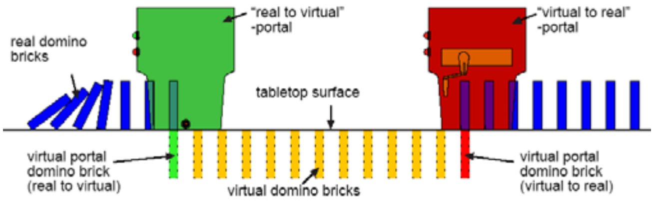
In our setup, we use Maxell DP-201 digital pens from Anoto which are sending stroke data via Bluetooth to a PC. Anoto-based digital pens are ballpoint-pens with an embedded infrared camera that tracks the pen movements. The pen has to be used on paper with a special pattern of printed on top. This pattern is printed with 600dpi and consists of small dots with a nominal spacing of 0.3mm.

The pen uses an embedded image processing chip to calculate its absolute position on the pattern using the captured frames. Once illuminated by the IR-LED, which is also embedded in the pen, the Anoto dot pattern appears dark (carbon-based ink is absorbing the IR light). The optimal base-material (reflecting the IR light) appears bright resulting in a high contrast image. For optimal tracking results, the IR-camera built into the digital pen must capture high contrast images. If the material is too transparent or too glossy, the contrast between background material and dot pattern is not high enough to ensure robust pen tracking.

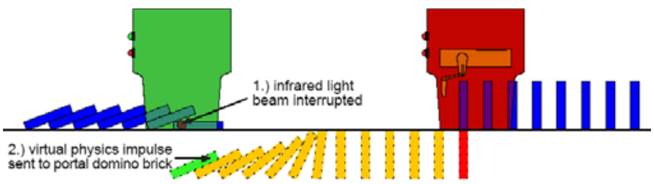
Our setup utilizes a special rear projection foil which is suitable for both top and rear projection as well as digital pen tracking and for the use with the 3D camera while being relatively durable.

4.3 Portals (Gates)

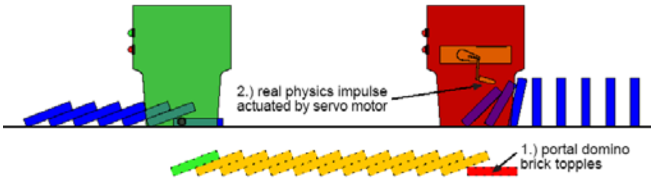
To connect the virtual and real domino blocks, we implemented special physical interfaces, so called gates. These special gates are currently placed on a fixed location in the virtual environment and indicate where the physical interface should be placed by the players for the chain reaction to work as intended. Future implementation could incorporate marker recognition for the tracking of the portals on the table. Figure 9 illustrates the interaction between virtual and real domino bricks in IncreTable.



(a)



(b)



(c)

Figure 9: Special "portal dominoes" act as virtual counterparts to the physical interfaces, allowing the transition from the real to the virtual world and vice versa.

Both functions, the pushing of domino stones and the detection of falling domino stones have been implemented in one single gate. To push domino stones, the gate has a rotation arm which is controlled by a Micro Controller Unit (MCU). The MCU communicates with a PC over a Bluetooth module.

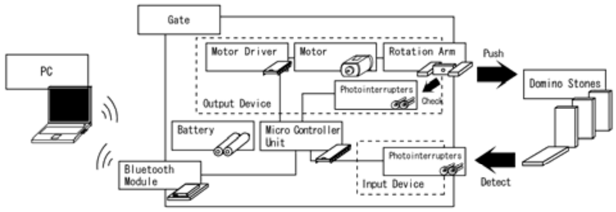
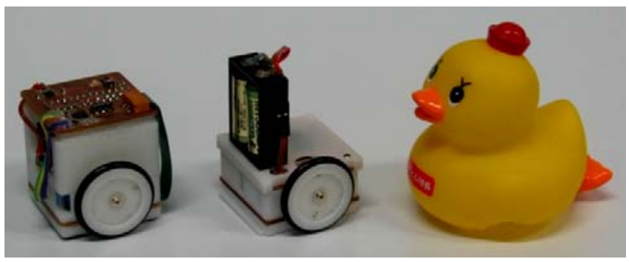


Figure 10: Block diagram of portal domino bricks.

In addition, the MCU can detect reactions of domino stones by an infrared (IR) photo-interrupter. So, the gate can perform as an interface between the real world and the virtual world. Figure 10 shows a block diagram of the gate.

4.4 Robot

In IncreTable, we also use real robots, which can be moved with augmented fiducial markers that are projected on the rear-projection screen (see Figure 11). The robot plays an essential part in the IncreTable game, because it can primarily be used as a bridge between the digital content and the physical world (e.g. they can hit the physical domino tiles). Each robot is equipped with five brightness sensors in order to calculate relative displacement between robot and the marker image, and robot is programmed to follow the marker image by feedback control. Thus, we can move the robot by simply moving the fiducial marker.



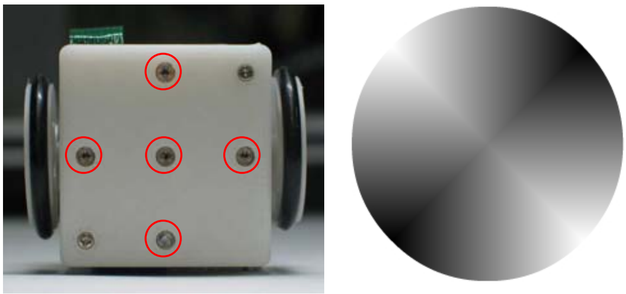


Figure 11: The robot can have different shapes and sizes. The brightness sensors (marked with red circles) are tracking the fiducial marker which is projected on the surface. According to the projected position, the robot can be moved.

In contrast to the robots presented in [6], we improved the size and the weight of the robot (cf. Table 1) as well as the fiducials for achieving a better performance in speed and accuracy.

Table 1: specifications about robot

Dimension	40mm×40mm×40mm
Weight	90g
Driving system	differential wheel drive
MPU	PIC16F876A(16MHz)
Sensor	photo transistor × 5
Actuator	micro geared DC motor × 2

Figure 12 shows the marker including the five values captured by the sensors attached on the bottom side of the robot.

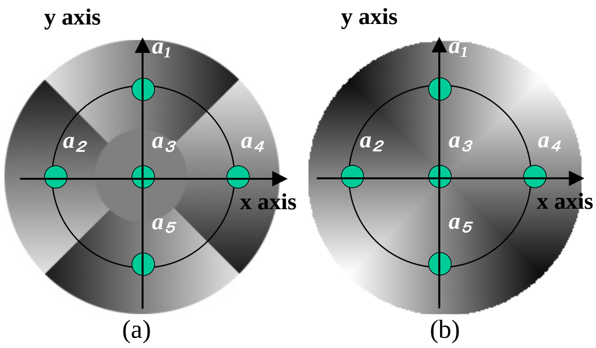


Figure 12: Five values are used for calculating the relative position and orientation.

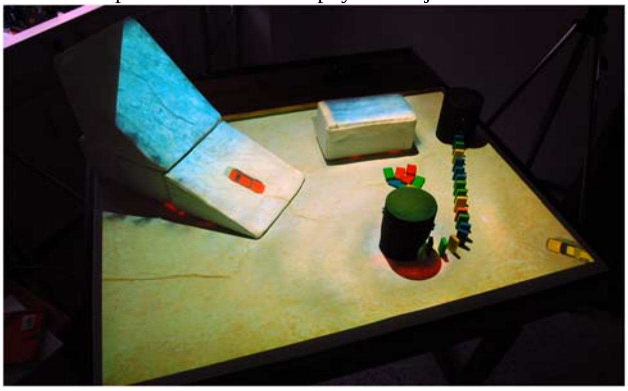
Four out of five brightness values are used for calculating the relative position and direction between the robot and the marker image. The values a1, a2, a4, a5 are each sensor's output values and from that equations robot knows the relative displacement. The sensor in the center (cf. Figure 11) is for future extension, such as serial data communication. The differences *dx* and *dy* on the x- and y-axes, and the angle differences *dΘ* are calculated as follows:

$$dx = a_1 - a_5$$
$$dy = a_4 - a_2$$
$$\sin(d\theta) = a_1 - a_4 + a_5 - a_2$$

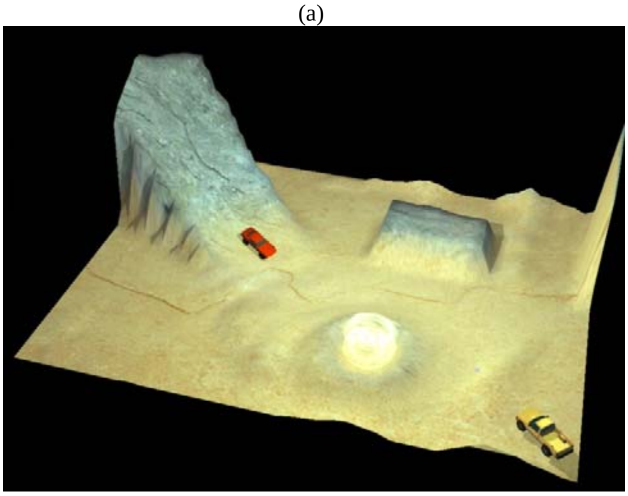
After the normalization of the brightness values, *dx* and *dy* can be accurately calculated from the fiducial marker and the robot can move along the x- and y-axes.

4.5 Depth Sensing

In IncreTable, we use a ZCam, a depth sensing camera from 3DV Systems, Ltd. to recognize the physical surface of the table, which can be manipulated with real and physical objects.



(a)



(b)

Figure 13: The real scene (a) and a synthetic view (b) which can be easily created using the depth tracking camera data.

The result, an 8 bit 320×240 depth image is used to modify the digital terrain. Players can use any kind of physical objects (e.g. ramps, or even folded paper) to modify the terrain. The integrated depth camera can provide a depth map in an interactive rate of 30 fps. Its depth sensing capability relies on a time of flight of infrared rays. Figure 13 depicts the mesh in a 3d environment which can be easily created by the depth image from the depth tracking camera. It shows the ramp and other obstacles placed on the table surface. The jumping cars react accordingly with a physical car simulation.

When an emitted ray collides with an obstacle which makes it being reflected back to the sensor, a high speed shutter will slice it into a set of short segments. A depth value of each pixel can be then calculated with a length of time its ray has spent for a return. It scales from 0 to 255, which is drawn with black or white color respectively in a gray-scaled image. A resultant depth map, however, may contain several artifacts which often hinder stable interaction (cf. Figure 14).

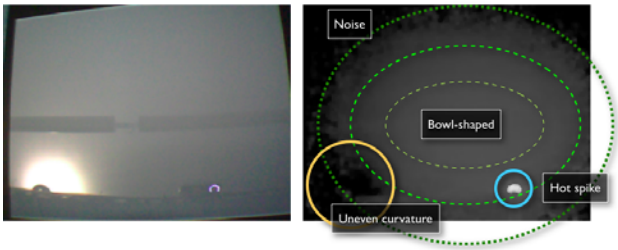


Figure 14: The left image shows an RGB image of our table surface, while the right visualizes the corresponding depth map showing the different problems.

One of the most apparent problems was temporal noise of the depth values. While it could be still alleviated with a smoothness filter built in the camera, we had to implement a more versatile accumulator for controlling a balance between stability and responsiveness of interaction (cf. Figure 14).

Other problems occurred due to the special properties of our own tabletop configuration. Since the flat surface of the table is being tracked from an almost perpendicular position, the corresponding depth map is also supposed to be flat or painted with a plainly black color. Due to a strong reflectance property of the surface, it was however detected as a bowl-shaped surface (see Figure 14). As the surface covers up an almost entire image, a large number of rays might get reflected back from around the center. Due to a larger angle it took longer for the shutter tracking, which mainly occurred at boundaries. Finally, peculiar reflectance properties caused another problem. A too strong illumination removed reflecting rays which was recognized as a hot spike (cf. Figure 14).

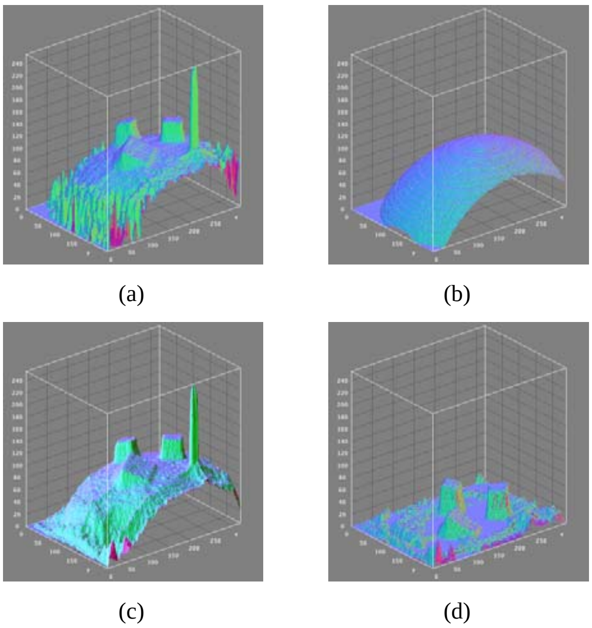


Figure 15 From the raw data to the calibrated depth image. (a) Raw depth image of the camera. (b) Modeled ground depth. (c) Accumulated depth image. (d) Finally, the calibrated depth image.

Therefore, it is not possible to take the raw data from the depth camera (cf. Figure 15 (a)). To eliminate glitches, the depth map of the table is modeled as a surface equation (cf. Figure 15 (b)). When the system has to be calibrated, the table is cleaned up without any object placed on top of it. The corresponding depth map provides an initial set of values for the model estimation. The size of the surface is assumed to be same as the one of the depth map (in this case 320 by 240). After each point is matched up with a corresponding depth value, the model can be fitted as a quadratic surface by using the method of least squares. This estimation process continues even when the table is being used for user interaction.

There may be some regions which produce higher depth values than the ground surface due to occlusion caused by objects placed on the table. A simple heuristic method changes each depth value accordingly (the value is either achieved from the surface or raised by the real obstacles). If a depth value, observed between two consecutive frames, is under a given threshold, it is considered to be a small fluctuation so that the value is reliable enough to be used for the surface fitting. In the other case, it is presumed that the depth value is caused by real objects; thus, the value no longer represents a depth of the surface, but of the object. At the end of each frame, hot spikes can be further removed by applying an image in-painting algorithm to the regions found with a Laplacian filter and a blob detector (cf. Figure 15 (c)). Finally, the depth map acquired at each frame is subtracted by the estimated ground depth map to form a calibrated depth (Figure 15 (d)).

5. USER FEEDBACK

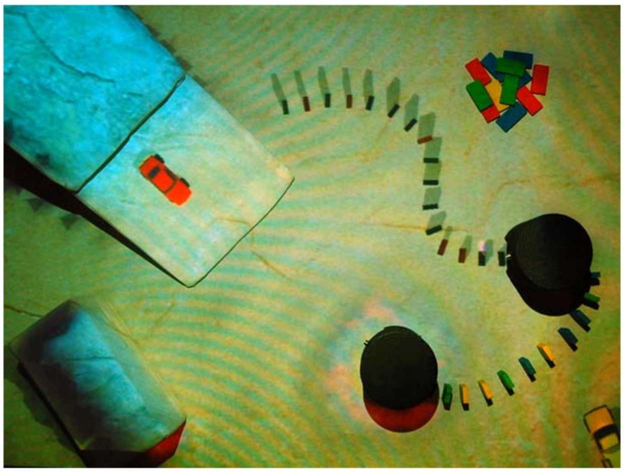
IncreTable has been demonstrated and tested in different festivals and conferences (e.g. Virtual Laval 2008, RTT conference). The overall participants' reaction was highly positive. Users really liked the idea of playing with a tabletop interface that combines the real physical objects with a digital (augmented) environment. The interface was perceived as very responsive and intuitive.

Using real objects in the game also worked as a catalyst for more people to try the game. Compared to other projects which were played in a purely virtual environment, the combination of real and virtual game components attracted also very young children and elderly people to get involved in the game.

Figure 16: Multiple users can play together to solve the puzzle.

IncreTable also encouraged the close collaboration between the players (see Figure 16). In order to solve the task, all involved players have to discuss their strategy and be aware of what the co-player is doing. Users also had no problems to use the digital pens for placing the virtual domino pieces. The tracking results of the Anoto pens are fast and allow users to perform an accurate interaction.

One of the design goals was to avoid HMDs and heavy, cumbersome devices for tracking the users' head position and orientation. Consequently, we had to find a rendering perspective which was suitable for tabletop projection while still looking fine for most perspectives. In some special cases (if the users are looking to the scene with a really flat angle) users can have a distorted view of the scene (see Figure 17). This however in no case was reported to be a big problem for the players.



(a)

(b)

Figure 17: From the top view it is hard to distinguish between the real domino stones and the augmented stones (a). In contrast if the user is looking to the scene with a really flat angle, the digital domino stones (in the back) are viewed from a different angle (b).

During our demonstrations, we noticed that the augmented shadow has been observed to be a really essential part for getting a better understanding of the distance between the jumping car and the terrain (see Figure 18).

Figure 18: Using shadows help a lot for estimating the distance from the car to the table's surface.

Finally, Figure 19 depicts the interaction using the transparent tangible toolbar (e.g. control panel), which allows users to interact with the game (e.g. change the interaction mode). Like the tabletop surface the toolbar can be used with the digital pens. Since only one toolbar was present during the demonstration sessions, people reported having problems to sometimes find the toolbar or quickly access the necessary tools when other players where using the toolbar at the same time.

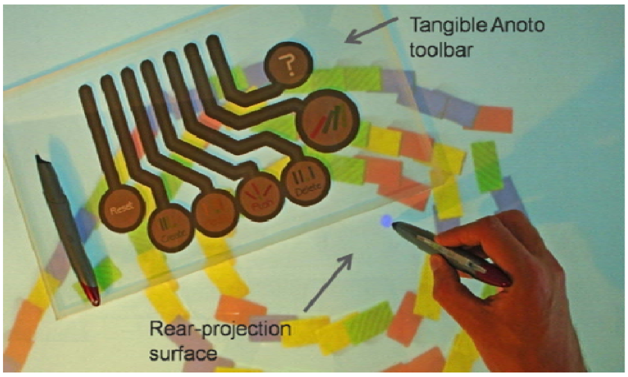


Figure 19: The transparent tangible toolbar allows participants to use special functions. Again on top of a Plexiglas, we put a pattern marker, which can be easily tracked with the digital pen.

6. CONCLUSIONS & FUTURE WORK

In this paper, we have presented a new tabletop game, where both the real and digital world has to be connected to solve various puzzles in the game. The presented IncreTable game allows users to play with real and digital domino tiles, physical robots and virtual cars. First informal observational studies during various exhibitions showed that the integration of the digital content in the real environment was considered to be an entertaining and interesting concept.

Our ongoing work will continue to add additional interfaces in the game to even further explore the possibilities of multimodal interfaces in tabletop scenarios. Moreover, we are planning to start a formal user study for improving the current application.

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