An Augmented Reality Weather System

Marko Heinrich
University of Koblenz-Landau
marko.heinrich@uni-koblenz.de

Bruce H. Thomas
University of South Australia
Wearable Computer Lab
Bruce.Thomas@unisa.edu.au

Stefan Mueller
University of Koblenz-Landau
stefan.mueller@uni-koblenz.de

Christian Sandor
University of South Australia
Wearable Computer Lab
christian@sandor.com

ABSTRACT

This paper presents ARWeather, a simulation application, which can simulate three types of precipitation: rain, snow, and hail. We examined a range of weather phenomenon and how they may be simulated in a mobile augmented reality system. ARWeather was developed and deployed on the Tinmith wearable computer system to enable autonomous and free movement for the user. The user can move freely inside the simulated weather without limitation. The result of this work, the ARWeather application, has been evaluated with a user study to determine the user's acceptance and draw conclusions to the applicability of augmented reality simulated weather.

Categories and Subject Descriptors

I.3.7 [**Three-Dimensional Graphics and Realism**]: Virtual reality - Animation; I.6.8 [**Types of Simulation**]: Animation, Visual

General Terms

Design and Human Factors

Keywords

Augmented Reality, Multimodal Weather Simulation

1. INTRODUCTION

The addition of weather adds texture and realism to the gameplay of many current computer games. This paper explores the use of outdoor augmented reality (AR) to provide the impression of simulated weather to a mobile user. Imagine it is a bright sunny day, and with the flick of a switch it starts pouring rain (see Figure 1). A user equipped with a wearable computer can walk and move freely inside the artificial weather and enjoy a new experience. They get a 360 degree impression of being in the middle of the occurring weather. We envision this ability to be embedded into outdoor AR applications. A visual change of the real weather conditions may be used as a supplement to training simulations for search and rescue teams or military training [4]. AR weather may also be used in education to show people the different aspects of weather, or in entertainment, such as in pervasive gaming, to intensify the atmosphere. People can experience different types of weather, which usually do not occur in their region (for example snowfall in some parts of the world). To date, there have been a limited number of investigations into the simulation of weather for outdoor AR.

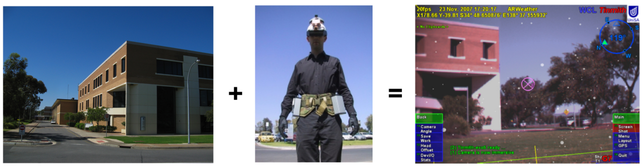

Figure 1: Using our wearable augmented reality system, we can transform the user's perception of a bright sunny day into being inside a hailstorm.

The aim of this investigation is the development of an AR weather simulation (ARWeather) that allows a real time and spatial simulation of rain, snow, and hail, independent of the physical weather conditions. The user should be offered a memorable experience. A wearable computer AR system is employed to provide the user a full 360 degree visualization. ARWeather is designed to be an experience in itself or as an additional feature for existing outdoor AR applications. Additional features of ARWeather are as followings: operation without 3D environmental information, precipitation rendering in a continuous area, different precipitation densities, image preprocessing to change light under different precipitation, a stochastic model for particle calculation, sound integration, multiple textures, and ground behavior of hail bouncing.

The next section provides an overview of related work. This is followed by a definition of the concept for ARWeather. Next, the key implementation concepts are described. Then, our user study is presented. The paper concludes with a summary of this work.

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(a) Rain (b) Snow (c) Hail

Figure 2: The user's view through the head-worn display. We can simulate three different precipitations.

2. BACKGROUND

Of importance for this investigation is precipitation in the form of rain, snow, and hail. A typical raindrop has a diameter of 1 to 2 mm, in thunderstorms this maybe 5 to 8 mm [1], in drizzle they are smaller than 0.5mm. The size of the raindrops determines its terminal velocity that are as follows: large drops up to 9 m/s, typical sized raindrop 6.5 m/s [1], and drizzle 2 m/s [2]. Heavier rain generally falls straight in one direction and is only slightly influenced by wind. Rain is mostly recognized as transparent strokes, because of the speed the drops fall and the hence occurring motion blur. Snowflakes fall down very gently, and the size of a snowflake is about 5 mm but varies with temperature. Snowflakes fall at about 1 m/s independent of their size [2]. Snowflakes fall down with a movement from side to side. Hail is a solid form of precipitation. A hailstone normally has a diameter of between 5 and 50 mm. Hail appears mostly as ice spheres, which are transparent on the outer layer (clear ice), but almost white around the core (opaque ice) [1]. Falling hail is often indistinguishable from falling rain, and the only difference is when both hit the ground.

Investigations with virtual environments dealing with the topic of weather simulation are almost exclusively performed within the domain of virtual reality [5]. Trembilskii [8] presents naturalistic methods for cloud and sky visualizations. Trembilski describes algorithms for the geometrical modeling of clouds in an AR application, which renders an artificial sky and clouds with correct lighting conditions matching the real world lighting. Gliet's [3] AR Weather Cam provides a framework for the visualization of georeferenced weather data. AR Weather Cam allows the user to create a mashup of a webcam image and additional spatial and textual data, such as rain probability or areas of temperature change. To our knowledge, there has not been any known investigations concerning simulating weather in a mobile outdoor AR setting. Sims [6] employed a particle system to simulate natural effects like snow.

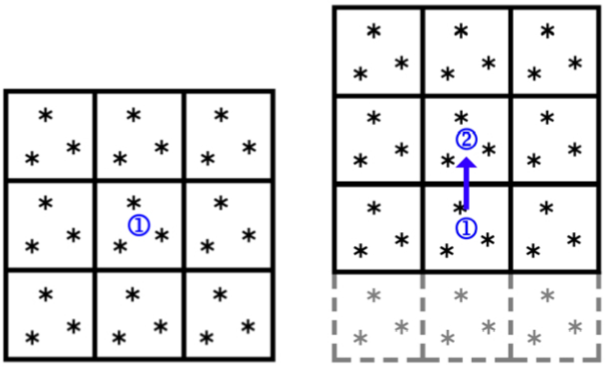
Outdoor AR is often realized with a portable AR system which consists of three basic components: technology for displaying the information (Head Mounted Displays), technology for delivering the position of the user (GPS and orientation sensors), and computational technology for registration and rendering (portable computing system and software). A wearable computer system with a spatial tracking offers the possibility to move freely outside. In the area of entertainment, AR has been employed with version of Quake called ARQuake, where the virtual monsters were brought into the real world [7]. Figure 1 depicts the Tinmith wearable AR system. The system is based on a modified Toshiba Tecra M5 with a Pentium-M 2.0 GHz, 2 GB RAM, NVIDIA GeForce 6600 graphics chipset, 802.11 wireless networking, and Bluetooth. The computer is mounted on the back of the belt, with battery power for 2-3 hours. Headphones are fixed to the inside the helmet, so ambient sounds can still be heard. The Tinmith system employs video see-through technology. A 640x480 pixel 30fps Point Gray Firefly firewire video camera is attached on the front of the helmet. A GPS antenna and an InterSense InertiaCube3 inertial orientation sensor are mounted on the helmet. The GPS receiver has sub-50 cm accuracy and is used to track the position of the user's head outdoors.

3. ARWEATHER CONCEPT

ARWeather simulates a change from a sunny or cloudy day to one that is raining, snowing, or hailing (see Figure 2). We are not attempting the removal of the real occurring weather conditions first. For example changing from real falling snow into augmented rain. A solution needs to be found to remove the actual weather conditions before rendering an augmented type of weather. In the case of clouds, they are already visible when rain, snow, hail, or fog is occurring. This is not a trivial task and outside of the scope of this paper. To ensure the weather simulation system is completely independent of the real-world weather conditions, the natural weather would need to be automatically detected and removed. Even if the visual task of removing a real precipitation could be achieved, another unpleasant part of the weather with falling precipitation would still be left: The user would still get wet in rain or snow.

4. IMPLEMENTATION

This section provides an overview of the implementation of ARWeather. The major technical features implemented are: particle system, sound, visual features, weather rendering and image preprocessing. ARWeather was developed in C++ under the Linux operating system. As with Tinmith, the graphics were developed with OpenGL. Additional functionality was provided with the following libraries: GLSL,



(a) Static grid (b) Moving grid

Figure 3: Particle emitter grid viewed from the top.

DevIL, and OpenAL. The ARWeather simulation is realized with a 3D particle system, and the three different types of precipitation can all be realized with the same particle system. We implemented a custom particle system in ARWeather for graphics hardware found in notebook class computers. Precipitation can be simulated in 2D or 3D. A 2D simulation of precipitation would simply involve overlaying the weather on the captured video image and providing a better performance than a 3D simulation. However, a 2D simulation does not support all viewing angles for our simulation. In case of rain, when the user is viewing straight ahead, the raindrops are falling down in front of their eyes. When the user looks straight up into the sky, the raindrops should be falling towards their face, but on the video would continue to move from the top of the display down to the bottom of the display.

4.1 Emission Grid

The area where the precipitation will be simulated needs to be limited for real-time operation. An easy way to limit the rendering area is to generate a fixed region, in which the user can move around freely. With this solution, the user experiences a realistic 3D movement of the particles, but only within a fixed simulation area. A second possibility is that the limited rendering area that moves synchronous with the user. If the user moves in a direction, the rendering area moves in the same direction. With this solution, the user is able to walk endlessly without reaching the borders of the rendering area. The perceived density is constant, because the user is always standing in the centre of the simulation area. The falling particles have a realistic vertical movement but move horizontally with the user.

We implemented an emission grid system for the simulation area (see Figure 3). In this grid system, the simulated area is divided into smaller subareas. The size and number of emitters in the emitter grid system has to be chosen carefully to avoid unwanted effects. If the number of rows or columns is too small, and the size of the main emitter is not large enough, discontinuities in the visual simulation can occur. We found that a good balance between rendering speed and simulation quality was to use a 5x5 grid and a main emitter size of 5 metres. As the user moves out of the centre grid square, the rows or columns are moved from behind the user and replaced in the direction they are walking, see Figure 3(b).

(a) Original video image (b) Preprocessed video image

Figure 4: Simulating a change of illumination: brightness, contrast, and blue saturations are reduced.

4.2 Sound

Sound plays a very important role when creating the impression of immersion in weather. Hearing precipitation falling is part of the whole simulation and is a critical element of ARWeather. We support the sound of the impact of falling precipitation like rain and hail on the ground. During heavy rain, lightning strikes cause a thunderclap a few second later. No audible sound is created for falling snow. The sound of wind blowing is supplied while all three precipitations are falling (impact sound can be combined with a wind sound). Each of the three forms of precipitation has a different sound loop from an audio file.

4.3 Visual Features

The different types of precipitation are presented with different visual features. The snowflakes and hailstones are rendered with a partly transparent texture. We employ billboarding because snowflakes and hailstones have a spherical symmetrical shape. Rain can not be rendered with billboarding and a texture because a single raindrop can not be easily observed and typically appears as a line caused by the motion blur due of the fast falling speed. Therefore the rain is rendered as a line colour fading from partially transparent to fully transparent. The result of the rendered precipitations can be seen in Figure 2. During rainstorms/thunderstorms, lightning bolts themselves are not rendered, but a lightning effect is visualized with a universal flash illumination. Ground accumulation for hail only is simulated in the ARWeather application by using particles, which stay on the ground for 2 seconds.

4.4 Image Preprocessing

To improve the lighting conditions to a more realistic illumination when precipitation is falling, the natural lighting of the environment needs to be darkened and the intensity of the blue sky needs to be reduced. Before the video stream is displayed to the user, every frame is processed. Because this processing is computationally intensive, this is implemented with a fragment shader written in GLSL. The frame processing of ARWeather is performed in three steps: 1)

The brightness is reduced by subtracting a certain amount from the colour of each fragment. 2) The contrast is reduced by thresholding and adjusting the contrast value. 3) The amount of blue saturation for some fragments is reduced. Step 3 is performed by converting the values from the original RGB colour space into the HSV colour space. The conversion into the HSV colour space allows the easy detection of blue areas (sky) in a frame. The reduction of blue saturation is performed by decreasing the saturation value (S) of all the fragments with a hue (H) angle between 160 and 290 degrees (blue range). This enables the reduction of illumination of a bright blue sky without knowing where the sky is located on the video frame.

5. USER STUDY

We have conducted a qualitative user study to evaluate our system. Our main goal for this study was to gather initial feedback and identify trends of user preferences. We have employed a questionnaire for gathering data. A group of 30 people participated in the user study (5 male, 25 female), from the University of South Australia. The ages of participants in the group ranged between 19 years and 49 years (mean 29). Because the study took place in South Australia, only a small number of participants (7 out of 30) stated that they had experienced snow and hail regularly. The remaining participants knew snow and hail from television, movies, pictures, and computer games.

5.1 Design and Procedure

The user study was conducted over eight days in grassy area surrounded by a few trees, buildings, and a street. The real weather conditions did not differ much during the user study period. The weather was sunny in 27 of the 30 tests conducted. For each participant, a session consisted of the following steps: 1) Giving the participant a brief explanation of the overall system. 2) Fitting the wearable computer to the participant. 3) Showing the participant the difference between filtered and unfiltered video images. 4) Showing all weather simulations (hail, rain, snow) to the participant. For each precipitation, different densities were shown. 5) Letting the participant fill out a questionnaire. The questionnaire mostly consisted of questions that could be answered by a scale from 1 to 4; 1 referred to *very good*, 2 to *good*, 3 to *bad*, and 4 to *very bad*. There were also open questions included.

5.2 Results and Discussion

In the questionnaire, participants were asked to rank the precipitation in order of preference. Most of the participants ranked the rain first (23 participants), snow second (20 participants) and hail as least favorite (24 participants), $p<0.001$ Wilcoxon matched-pairs signed-ranks. Overall, rain was rated to be the most realistic with a mean value of 1.27 (SD 0.73), then snow with a mean of 1.77 (SD 0.45), and finally hail with a mean of 2.53 (SD 1.01). This ranking was statistically significant ($p<0.05$) by a set of Wilcoxon matched-pairs signed-ranks tests. The questionnaire contained a question about the movement of the particles as a whole. In the case of snow and rain, the recognition rate was 100%. However, only 83% recognized hail. The hail was not recognized by 4 out of 30 participants, 3 assumed to see snow, 1 assumed to see rain. The usage of the color filter was endorsed by 87% of the participants. Only four participants found that the filter was not beneficial for the lighting simulation. Users really liked the realism that sound added to the simulation: mean value 1.5 (SD 0.21).

6. CONCLUSIONS

In this work, a method for simulating rain, snow, and hail with a wearable AR system was presented. The Tinmith system was employed as the wearable AR platform for the development of ARWeather. ARWeather can simulate various densities of precipitation up to the magnitude of a storm. A custom particle system based on a moving grid system provided a feasible solution for simulating the large quantity of precipitation particles in three dimensions and an unbounded outdoor area. Different matching sounds were played for every type and density of simulated precipitation. Preprocessing of the video images further enhanced the realism of the simulation. Overall ARWeather was liked by the partcipants. Our preliminary user study has shown that applying a color filter to simulate changing light conditions was beneficial. Additionally, playing matching sounds for each weather condition could further help to enhance realism. The participants' favorite simulated weather type was rain, followed by snow, and the third favorite weather type was hail.

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