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THE AUGMENTARIUM VIRTUAL AND AUGMENTED REALITY LABORATORY AT THE UNIVERSITY OF MARYLAND

COMPUTER SCIENCE UNIVERSITY OF MARYLAND



Motivation Popularity of VR and AR devices

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Motivation Popularity of VR and AR devices





Motivation Assorted VR and AR applications

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Motivation Assorted VR and AR applications

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These VR/AR applications have

Huge Data

requirements

These VR/AR applications have

Huge

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requirements

Where is the 3D data going to come from?

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These VR/AR applications have

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Automatically fusing multimedia data into virtual environments













Social Street View: Blending Immersive Street Views with Geo-tagged Social Media

Ruofei Du and Amitabh Varshney

{ruofei, varshney} @ cs.umd.edu www.SocialStreetView.com In Proceedings of the International Conference of Web3D 2016. (Best Paper Award)

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Introduction Social Media



But why is social media **so popular**?







Metadata are useful for understanding spatial relevance, amongst users, sentiment mining, and propagati relationship amongst users, sentiment mining, and propagation of influence.

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Related Work

inear narrative visualization







image courtesy: instagram.com, facebook.com, twitter.com

Related Work



image courtesy: pinterest.com

Related Work Natural Immersive Virtual Reality?

Related Work

Karnath et al. and Loomis et al.



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Behavior Research Methods, Instruments, & Computers

Immersive virtual environment technology as a basic research tool in psychology

JACK M. LOOMIS and JAMES J. BLASCOVICH University of California, Santa Barbara, California and

ANDREW C. BEALL Massachusetts Institute of Technology, Cambridge, Massachusetts

Immersive virtual environment (IVE) technology has great promise as a tool for basic experimental research in psychology. IVE technology gives participants the experience of being surrounded by the computer-synthesized environment. We begin with a discussion of the various devices needed to implement immersive virtual environments, including object manipulation and social interaction. We review the benefits and drawbacks associated with virtual environment technology, in comparison with more conventional ways of doing basic experimental research. We then consider a variety of examples of research using IVE technology in the areas of perception, spatial cognition, and social interaction.

Human history records a progression of artifacts for representing and recreating aspects of external reality, ranging from language, drawings, and sculpture in earlier times to the more modern artifacts of photographs, movies, television, and audio recordings. Relatively recently, the digital computer and its associated technologies, including three-dimensional (3-D) graphics, have given rise to increasingly realistic artifacts that blur the distinction between reality and its representation (Ellis, 1995).

The ultimate representational system would allow the observer to interact "naturally" with objects and other individuals within a simulated environment or "world," an experience indistinguishable from "normal reality." Although such a representational system might conceivably use direct brain stimulation in the future, it will more likely use digitally controlled displays that stimulate the human sensory organs, the natural conduits to the brain. Displays of this type, referred to as virtual displays (VDs), although far from ideal, exist today. Following the terminology of others (e.g., Durlach & Mavor, 1995; Stanney & Salvendy, 1998), we refer to the corresponding environment represented and stored in the computer and experienced by the user as a virtual environment (VE). Virtual environment technology (VET) refers inclusively both to VDs and to the VEs so created, including VEs produced by using conventional desktop computer displays.

With the support of Grant N00014-95-1-0573 from the Office of Naval Research (to J.M.L.) and National Science Foundation Grants SBR 9872084 (to J.J.B.) and SBR 9873432 (to J.M.L. and J.J.B.), and with additional support from the University of California, Santa Barbara, the authors have developed several immersive virtual displays, use of which has stimulated many of the ideas expressed here. The authors thank Florence Gaunet and Patrick Péruch for comments on an earlier version of the article. Correspondence concerning this article should be addressed to J. M. Loomis, Department of Psychology, University of California, Santa Barbara, CA 93106 (e-mail: loomis@psych.ucsb.edu).

(Virtual reality is widely used as an alternative term, but we prefer VE.) An immersive virtual environment (IVE) is one in which the user is perceptually surrounded by the VE. Ivan Sutherland (1965), one of the originators of 3-D computer graphics, was the first person to conceive and build an immersive VD system. For the history of IVEs,

see Ellis (1995), Kalawsky (1993), and Rheingold (1991). There are two usual implementations of an IVE. The first of these involves placing multiple projection screens and loudspeakers around the user. A popular design is the CAVE (Cruz-Neira, Sandin, & DeFantini, 1993), which involves back-projecting the computer-generated visual imagery onto the translucent walls, floor, and ceiling of a moderately sized cubical room, in which the user is free to move; shutter glasses provide stereoscopic stimulation, so that one sees the VE not as projections on the room surfaces, but as solid 3-D structures within and/or outside of the cube. The second and more common implementation of an IVE involves the use of a head-mounted display (HMD), used in conjunction with a computer and a head tracker (Barfield & Furness, 1995; Biocca & Delaney, 1995; Burdea & Coiffett, 1994; Durlach & Mavor, 1995; Kalawsky, 1993). The head tracker measures the changing position and orientation of the user's head within the physical environment, information that is communicated to the rendering computer, which has stored within it a 3-D representation of the simulated environment (Meyer, Applewhite, & Biocca, 1992). At any given moment, the computer generates and outputs the visual and auditory imagery to the user's HMD from a perspective that is based on the position and orientation of the user's head. The HMD consists of earphones and video displays attached to a support worn on the head; the video display component is based on cathode ray tube (CRT) displays, liquid crystal displays, or laser-based retinal scanners (Barfield, Hendrix, Bjorneseth, Kaczmarek, &

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Visualization of Geo-tagged Information

Very little work has been carried out in designing immersive interfaces that interleave visual navigation of our surroundings with social media content



Benjamin E. Teitler bteitler@cs.umd.edu

Twitter is an electronic medium that allows a large user populace to communicate with each other simultaneously. Inherent to Twitter is an asymmetrical relationship between friends and followers that provides an interesting social networklike structure among the users of Twitter. Twitter messages, called tweets, are restricted to 140 characters and thus are usually very focused. We investigate the use of Twitter to build a news processing system, called TwitterStand, from Twitter tweets. The idea is to capture tweets that correspond to late breaking news. The result is analogous to a distributed news wire service. The difference is that the identities of the contributors/reporters are not known in advance and there may be many of them. Furthermore, tweets are not sent according to a schedule: they occur as news is happening, and tend to be noisy while usually arriving at a high throughput rate. Some of the issues addressed include removing the noise, determining tweet clusters of interest bearing in mind that the methods must be online, and determining the relevant locations associated with the tweets.

Categories and Subject Descriptors H.3 [Information Storage and Retrieval]: Information

Storage and Retrieval

General Terms

Algorithms, Design, Performance

*This work was supported in part by the National Science Luis work was supported in part by the National Science Foundation under Grants EIA-08-12377, CCF-08-30618, and roundation under Grants EIA-08-1231(), CUT-08-30015, and IIS-07-13501, as well as NVIDIA Corporation, Microsoft Research, Google, the E.T.S. Walton Visitor Award of the Scisearch, Google, the E.T.S. Walton Visitor Award of the Sci-ence Foundation of Ireland, and the National Center for Geocomputation of freiand, and the National University of Ireland at

[†]Department of Computer Science, Center for Automation Research, Institute for Advanced Computer Studies, University of Maryland, College Park, MD 20742, USA. ⁴HUD Office of Policy Development & Research (PD&R), 451 7th St. SW, Room 8146, Washington, DC 20410, USA.

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Twitter, News, Geotagging, Online clustering

Twitter¹ is a social networking website that recently has 1. INTRODUCTION been gaining much attention and following. Twitter is composed of users who send messages (termed tweets) to each other, where each tweet contains a maximum of 140 characters. At this time, it is estimated that there are 6 to 7 million users who use Twitter a total of 134 million times a month [4], and this number is increasing at a rapid rate. For example, for the year of 2008, Twitter grew in terms of the number of tweets sent at a rate of 1382% [12] which is a testament to the immense popularity and wide adoption of this service. The popularity of Twitter stems from its availability on a number of different electronic devices (e.g., web, cell phones, etc.), as well as the prevalence of a subculture in Twitter that encourages users to acquire a large friend pool, as well as send tweets on a wide variety of subjects, typically several times a day. The restriction on the lengths of Twitter messages invariably means that the tweets do not necessarily contain well formed ideas, being rather brief, yet complete enough so that users can make sense of the ideas that they convey. Note that tweets also have a mechanism by which the user can link to other objects on the web such as articles, images, videos, etc. (termed artifacts) which is typically used

to link tweets to related material on the Internet. The goal of this paper is to demonstrate how to use Twitter to automatically obtain breaking news from the tweets

posted by Twitter users, and to provide a map interface for reading this news, since the geographic location of the user as well as the geographic terms comprising the tweets play as wen as the geographic terms compliants the owners play an important role in *clustering* tweets and establishing clusan important role in custering tweets and establishing ento-ters' geographic foci. In contrast to news aggregators such as Google News, Bing News, and Yahoo! News, we introduce a system called TwitterStand that works exclusively with only the tweets posted by the users of Twitter. The key novely behind TwitterStand is one of mobilizing the millions of users in Twitter to be our eyes and ears in the world, bearing in mind that geographically proximate users often tweet about the same breaking news. In other words, we rely on Twitter users to be either providers of original news content (e.g., the 2008 Southern California earthquake [13] and the 2009 Iranian election [3]), or expressers of opinions on current news topics (i.e., mini blogs), both of which enable TwitterStand to automatically identify current news topics and cluster the corresponding tweets into appropriate news stories. We also associate an importance score with each news topic which can

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Twitter is an electronic medium that allows a large user populace to communicate with each other simultaneously. Inherent to Twitter is an asymmetrical relationship between friends and followers that provides an interesting social networklike structure among the users of Twitter. Twitter messages, called tweets, are restricted to 140 characters and thus are usually very focused. We investigate the use of Twitter to build a news processing system, called TwitterStand, from Twitter tweets. The idea is to capture tweets that correspond to late breaking news. The result is analogous to a spond to rate oreaking news. The result is analogous to a distributed news wire service. The difference is that the identities of the contributors/reporters are not known in advance and there may be many of them. Furthermore, tweets are not sent according to a schedule: they occur as news is hapnot sent according to a schedule. Mey occur as news is hap pening, and tend to be noisy while usually arriving at a high throughput rate. Some of the issues addressed include removing the noise, determining tweet clusters of interest bearing ing one noise, accorning tweet clusters or interest ocaring in mind that the methods must be online, and determining the relevant locations associated with the tweets.

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ABSTRACT

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In this paper we investigate generic methods for placing photos uploaded to Flickr on the World map. As primary input for our methods we use the textual annotations provided by the users to predict the single most probable location where the image was taken. Central to our approach is a language model based entirely on the annotations provided by users. We define extensions to improve over the language model using tag-based smoothing and cell-based smoothing, and leveraging spatial ambiguity. Further we demonstrate how to incorporate GeoNames¹, a large external database of locations. For varying levels of granularity, we are able to place images on a map with at least twice the precision of the state-of-the-art reported in the literature.

Categories and Subject Descriptors

H.3.3 [Information Search and Retrieval]

General Terms

Algorithms, Measurement, Performance, Experimentation

Keywords

image localisation, language models, Flickr

1. INTRODUCTION

Due to the massive production of affordable GPS-enabled cameras and mobile phones [13, 16], location metadata such as latitude and longitude are automatically associated with the content generated by users. Users have the opportunity to spatially organise and browse their personal media, and photo sharing services are leading the growing enthusiasm for personal location-awareness [22]. Geo-referenced photos

*Research performed while the author was an intern at Yahoo! Research.

[†]Also affiliated with TU Delft, ICT Group ¹http://www.geonames.org visited Ma

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can be organised in a browsable taxonomy of major locations or pin-pointed on a map to identify very small regions. Some of the most popular examples are Flickr Places² and Google

While in theory every photo can be anchored to the location it was taken, in practice many photos are location agnostic. Furthermore, the majority of Flickr users do not own location-aware cameras. Thus a large proportion of photos uploaded to Flickr contain no location information even when the photo merits localizing. When uploading photos on Flickr users can still geo-tag their photos by dragging the photos to a particular point on the world map. This process is time-consuming and results in less accurate geo-tagging of photos compared to automatically geo-tagged photos from GPS-enabled cameras. When manually geo-tagging photos, Flickr initially suggests the location of the last uploaded photo or simply displays the world map. The objective of this paper is to provide a more accurate

starting point for geo-tagging photos, uploaded on Flickr, using the textual annotations provided by the user. According to recent literature [2, 21] users spend considerable effort to organise their "memory" geographically by describing photos with tags related to locations where they were taken. The location specific tags (such as Torre Agbar which is only located in Barcelona), and location related tags (such as elephants which are related to locations such as zoos, Africa and Asia) provide essential cues as to where a picture was taken. For photos that are location agnostic (such as dog), location information may or may not be provided, but it is normally not relevant to the context of the photo.

The literature related to geo-tagging of photos and its use is extensive. In particular the reverse problem of discovering important landmarks and events, given a geographic co-ordinate has been studied extensively [1, 17, 13]. However the problem of placing images on a map using the textual annotations provided by the user has received less attention.

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Placing Flickr Photos on a Map

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April 5-10, 2008 · Florence, Italy

Content Visualization and Management

In the last years, several algorithms and platforms for photo sharing have been developed. Usually, in order to index huge quantities of images for a fast and intuitive retrieval, additional textual tags attached to the pictures are considered. In this paper, we present a set of solutions for an effective management of geolocated images, i.e. pictures equipped with tags indicating the geographical coordinates of acquisition. This brings towards an intuitive content visualization and management of large geo-located image

Image categorization, geo-located images, interfaces

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Placing Flickr Photos on a Map Pavel Serdyukov +t Database Group Vanessa Murdock University of Twente Yahoo! Research Roelof van Zwol PO Box 217, 7500 AE Diagonal 177 Yahoo! Research Enschede, The Netherlands 08018 Barcelona, Spain serdyukovpv@cs.utwente.nl Diagonal 177 vmurdock@yahoo-08018 Barcelona, Spain roelof@yahoo-inc.com inc.com ABSTRACT In this paper we investig tos uploaded to Flickr o for our methods we use by the users to predict PhotoStand: A Map Query Interface for a Database of News where the image was ta language model based er by users. We defin Photos-Hanan Samet Marco D. Adelfio Brendan C. Fruin Michael D. Lieberman Jagan Sankaranarayanan Center for Automation Research, Institute for Advanced Studies, Department of Computer Science, University of Maryland College Park, MD 20742 USA {hjs, marco, brendan, codepoet, jagan}@cs.umd.edu ABSTRACT **Content Visualization** PhotoStand enables the use of a map query interface to retrieve of Geo-located Image news photos associated with news articles that are in turn associated with the principal locations that they mention collected as a result of monitoring the output of over 10,000 RSS news feeds, made available within minutes of publication, and stored in a PostgreSQL database. The news photos are ranked according to their relevance to the clusters of news articles associated with locations at which they are displayed. This work differs from traditional work in this field as the associated locations Abstrac database of articles currently containing about 300GB of data. and topics (by virtue of the cluster with which the articles In the las containing the news photos are associated) are generated auphoto sh tomatically without any human intervention such as tagging, to index and that photos are retrieved by location instead of just by intuitive keyword as is the case for many existing systems. In addition, the clusters provide a filtering step for detecting near-duplicate the pict set of s located 1. INTRODUCTION indicat A demo is presented of PhotoStand (see also the related This b NewsStand [9, 17, 21, 29], TwitterStand [6, 24], and STEWand n data

Key

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The rest of this paper is organized as follows. Section 2 discusses related work. Section 3 indicates how news articles (and consequently news photos) a

ARD [12] systems) which is an example application of a general framework we are developing for retrieving multimedia data (e.g., text, images, videos) using a map query interface from a database of news articles, photos, and videos (i.e., by location in real-time which differentiates it (

articles, enabling them to be accessed by spatial queries such as windowing or simple point location; and its clusterer [30], which groups articles about the same topic. A key to the News-Stand database system is its pipe server which coordinates its processing modules by assigning batches of articles to them. NewsStand's user interface enables the retrieval of clusters of news articles for display using its map user interface by executing what we term top-k window queries. At present, NewsStand handles about 50K articles per day and has a large underlying

The PhotoStand and TweetPhoto [3] demos are related in the sense that PhotoStand uses photos from news articles in NewsStand, while TweetPhoto uses photos from news tweets in TwitterStand [24]. In addition, the PhotoStand demo demonstrates the database querying capability of NewsStand as well as its capability to do similarity searching for news photos where the first step in the similarity detection process is based on the text associated with the photos, while the second step involves use of the actual image features (e.g., texture, color) to enable detecting near duplicates, thereby avoiding the combinatorial complexity of comparing every photo with every other



All these systems are limited by the 2D world map



Visualization of Geo-tagged Information (cont.)

Previous research also advances server **3D** solutions.

uting a viewing specification, octerining dering parameters, and deciding how to issue for each frame. Some of these Registers user-annotated text and images to a particular point in 3D space.

ABSTRACT We describe a view-management component for interactive e describe a view-management component for interactive user interfaces. By view management, we mean 3D user interlaces. By view management, we mean maintaining visual constraints on the projections of objects maintaining visual constraints on the projections of objects on the view plane, such as locating related objects near each on the view plane, such as locating related objects near each other. Our other, or preventing objects from occluding each other. His origination of the other viewmanagement component accomplishes this by modifying selected object properties, including position, modifying selected object properties, including position, size, and transparency, which are tagged to indicate their constraints. For example, some objects may have econverting size, and transparency, which are tagged to indicate their constraints. For example, some objects may have geometric to the object of the obje simulation and which cannot be modified, while other objects may be annotations whose position and size are We introduce algorithms that use upright rectangular announce augurations that use upright rectangular ands to represent on the view plane a dynamic and present on the view plane a dynamic and similation of the occupied space containing nortions of 3D objects, as well as ets can be placed to

avoid occlusion. Layout accisions from previous traines are laken into account to reduce visual discontinuities. We present automated reality and visual reality avanuate to taken into account to reduce visual discontinuities. We present augmented reality and virtual reality examples to using the presence and the second s present augmented reality and virtual reality examples to which we have applied our approach, including a which we have applied our approach, it. dynamically labeled and annotated environment. CR Categories and Subject Descriptors: H.5.1 CK Categories and Subject Descriptors: H.5.1 Information Interfaces and Presentation] Multimedia Information Interfaces—Artificial automated and virtual (Information Interfaces and Presentation) Multimedia Information Interfaces—Artificial, augmented, and virtual material uses to be a superface and the super reatines, H.5.2 [Information Interfaces and resentation] User Interfaces—Graphical User Interfaces, Serien decion: 1.2.6 [Commuter Completed Neutrolation] Fresentation] User Interfaces—Graphical User Interfaces, Screen design, 13.6 [Computer Graphics] Methodology and Techniques—Interaction Techniques, 13.7 (Computer Screen aesign; 1.3.0 [Computer Graphics] Methodology and Techniques—Interaction Techniques, 1.3.7 [Computer Graphics] Thread-Dimensional Graphics and Paulianand Techniques-Interaction Techniques, 1.3.7 [Computer Graphics] Three-Dimensional Graphics and Realism-United Baseline Additional Keywords and Phrases. view management, Additional keywords and Phrases: view management, environment management, annotation, labeling, wearable environment management, annotation, labering, w computing, augmented reality, virtual environments 1. INTRODUCTION Designing a 3D graphical user interface (UI) requires creating a set of philorete and their preventing according them Designing a 3D graphical user interface (UI) requires creating a set of objects and their properties, arranging them sung a set of objects and men properties, anangang trean scene, setting a viewing specification, determining

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Blaine Bell

UIST 2001 (ACM Symp. on User Interface Software and Technology). Orlando, FL, November 11-14, 2001, pp. 101-110

View Management for Virtual and Augmented Reality

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Related Work Visualization of Geo-tagged Information

(cont.)



We introduce algorithms that use upright rectangular introduce argonums that use upright recumguar ats to represent on the view plane a dynamic and or une occupied space stations of 3D objects, as well as ets can be placed to

CR Categories and Subject Descriptors: H.5.1 CR Categories and Subject Descriptors: H.5.1 Information Interfaces and Presentation] Multimedia Information Interfaces—Artificial automated and virtual [Information Interfaces and Presentation] Multimedia Information Interfaces—drifficial, augmented, and virtual reatines, H.5.2 [Information Interfaces and resentation] User Interfaces—Graphical User Interfaces, Serien decion: 1.2.6 [Commuter Completed Neutrolation] Presentation] User Interfaces—Graphical User Interfaces, Screen design, 13.6 [Computer Graphics] Methodology and Techniques—Interaction Techniques, 13.7 (Computer Screen design, 1.3.0 [Computer Graphics] Methodology and Techniques—Interaction Techniques, 1.3.7 [Computer Graphics] Three-Dimensional Graphics and Pealine and Techniques-Interaction Techniques, 1.3.7 [Computer Graphics] Three-Dimensional Graphics and Realism-Additional Keywords and Phrases: view management, Additional Keywords and Phrases: view management, environment management, annotation, labeling, wearable environment management, annotation, tabeling, w computing, augmented reality, virtual environments

1. INTRODUCTION Designing a 3D graphical user interface (UI) requires creating a set of objects and their properties are an interface. Designing a 3D graphical user interface (UI) requires creating a set of objects and their properties, arranging them ung a set of objects and men properties, arranging men scene, setting a viewing specification, determining write a viewing spectrication, accounting

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Both the 3D model and the annotation are predefined for rendering such a scene.

Visualization of Geo-tagged Information (cont.)





ABSTRACT We describe a view-man 3D user interfaces. By maintaining visual constr on the view plane, such a other, or preventing obje view-management modifying selected obj size, and transparency, constraints. For examp properties that are simulation and which objects may be anno flexible. We introduce algo extents to represen efficient approximat the projections of v the unoccupied spi

We present a system for interactively browsing and exploring large unstructured collections of photographs of a scene using a novel 3D interface. Our system consists of an image-based modeling front end that automatically computes the viewpoint of each photograph as well as a sparse 3D model of the scene and image to model correspondences. Our photo explorer uses image-based rendering techniques to smoothly transition between photographs, while also enabling full 3D navigation and exploration of the set of images and world geometry, along with auxiliary information such as overhead maps. Our system also makes it easy to construct photo tours of scenic or historic locations, and to annotate image details, which are automatically transferred to other relevant images. We demonstrate our system on several large personal photo collections as well

and viewpoints (b) to enable novel ways of browsing the photos (c).

as images gathered from Internet photo sharing sites. CR Categories: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems-Artificial, augmented, and virtual realities I.2.10 [Artificial Intelligence]: Vision and Scene Understanding-Modeling and recovery of physical attributes Keywords: image-based rendering, image-based modeling, photo

browsing, structure from motion

Introduction

1

al of image based rendering is to evoke a visceral sense

Photo Tourism: Exploring Photo Collections in 3D Microsoft Research

University of Washington Noah Snavely University of Washington



Steven M. Seitz

(c)

Figure 1: Our system takes unstructured collections of photographs such as those from online image searches (a) and reconstructs 3D points

is that these approaches will one day allow virtual tourism of the During this same time, digital photography, together with the Inworld's interesting and important sites. ternet, have combined to enable sharing of photographs on a truly massive scale. For example, a Google image search on "Notre Dame Cathedral" returns over 15,000 photos, capturing the scene from myriad viewpoints, levels of detail, lighting conditions, seasons, decades, and so forth. Unfortunately, the proliferation of shared photographs has outpaced the technology for browsing such collections, as tools like Google (www.google.com) and Flickr (www.flickr.com) return pages and pages of thumbnails that the

In this paper, we present a system for browsing and organizing large photo collections of popular sites which exploits the common

3D geometry of the underlying scene. Our approach is based on computing, from the images themselves, the photographers' locations and orientations, along with a sparse 3D geometric representation of the scene, using a state-of-the-art image-based modeling system. Our system handles large collections of unorganized photographs taken by different cameras in widely different conditions. We show how the inferred camera and scene information enables

the following capabilities: Scene visualization. Fly around popular world sites in 3D by

- Object-based photo browsing. Show me more images that
- contain this object or part of the scene. Where was 1? Tell me where I was when I took this picture. What am I looking at? Tell me about objects visible in this
- image by transferring annotations from similar images.
- image-based



Visualization of Geo-tagged Information (cont.)





We describe a view-man ABSTRACT 3D user interfaces. By maintaining visual constri on the view plane, such a other, or preventing obje view-management modifying selected ob, size, and transparency, constraints. For examp properties that are simulation and which objects may be anne flexible. We introduce algo extents to represen efficient approxima the projections of v the unoccupied sp.



Noah Snavely University of Washington



Figure 1: Our system takes unstructured coll and viewpoints (b) to enable novel ways of

Abstract

We present a system for interactively bro unstructured collections of photographs 3D interface. Our system consists of front end that automatically computes th graph as well as a sparse 3D model of th correspondences. Our photo explorer techniques to smoothly transition betw enabling full 3D navigation and explo world geometry, along with auxiliary maps. Our system also makes it ea scenic or historic locations, and to are automatically transferred to oth strate our system on several large p as images gathered from Internet p

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Keywords: image-based rends browsing, structure from motic

Introduction

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Social Snapshot: A System for Temporally Coupled **Social Photography**

Robert Patro, Cheuk Yiu Ip, Sujal Bista, and Amitabh Varshney - University of Maryland, College Park

ince the invention of photography, taking pictures of people, places, and activities has become integral to our lives. In the past, only purposeful, precious moments were the primary subjects of photography. But technological advances have brought photography to our everyday lives in the form of compact cameras and even cell phone cameras. The next phase in the photog-

raphy revolution, 3D photogra-

phy, can bring users together to

socialize and collaboratively take

pictures in an entirely new way.

However, transforming a pho-

tographic scene from 2D to 3D

requires introducing multiple im-

ages of the same underlying ge-

ometry from different viewpoints.

The reconstruction of 3D geom-

etry from multiple overlapping

images is the classic structure-

Social Snapshot actively acquires and reconstructs temporally dynamic data. The system enables spatiotemporal 3D photography using commodity devices, assisted by their auxiliary sensors and network functionality. It engages users, making them active rather than passive participants in data acquisition.

from-motion (SFM) problem in computer vision. Typically, the instruments used to acquire photographs are tediously calibrated to produce precise measurements.

To simplify 3D photography, our Social Snapshot system performs active acquisition and reconstruction of temporally dynamic data. Using multiple users' cell phone cameras and no preliminary calibration, it achieves approximate but visually convincing renderings of 3D scenes even though

Social Snapshot's Contributions

Social Snapshot's contributions fit naturally into two categories: technical and social The technical contributions are improved algo-

rithms and techniques that enhance our system's novelty and scalability. For example, Social Snapshot produces a textured and colored-mesh reconstruction from a loosely ordered photo collection, rather than the sparse or dense point reconstructions produced by related approaches. In addition, it features locally optimized mesh generation and viewing. Finally, it provides camera network capabilities to support synchronized capture of temporally dynamic data.

The social contributions lead to a new way of thinking about the interplay between data acquisition and social interactions. They also let us define social photography as an active, rather than a passive, endeavor. For example, Social Snapshot encourages collaborative photography as a social endeavor, letting users capture dynamic action by synchronizing their photographs. It leverages social trends such as online media sharing and event organization to spur a novel data acquisi-

For a look at some of the previous research on which Social Snapshot is based, see the "Related Work in Scene Visualization and Computer Vision" sidebar on pages 78-79.

Visualization of Geo-tagged Information (cont.)





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Photo Tourism: E

Noah Snavely University of Washington



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> compute struments used to acquire calibrated to produce pred To simplify 3D photog system performs activ struction of temporall tiple users' cell phone calibration, it achiev convincing rendering the -

Figure 1: Given a reference text describing a specific site, for example the Wikipedia article above for the Panheon, with objects in the model linked to where they are mentioned in the text. The user interface enables coordinated Figure 1: Given a reference text describing a specific site, for example the Wikipedia article above for the Pantheon, we automatically create browsing of the text with the visualization (see video). We introduce an approach for analyzing Wikipedia and other text, together with online photos, to produce annotated 3D models of We introduce an approach for analyzing Wikipedia and other text together with online photos, to produce annotated 3D models of famous transfer estace. The annovation is accounted and models of logether with online photos, to produce annotated 3D models of famous tourist sites. The approach is completely automated, and loweraoec online text and about co-occurrences via Google Image famous tourist sites. The approach is completely automated, and leverages online text and photo co-occurrences via Google mage coarch. It enables a number of new interactions, which we demon. leverages online text and photo co-occurrences via Google Image Search. It enables a number of new interactions, which we demon-strate in a new 3D vienalization tool. Tove can be enloced to move Search. It enables a number of new interactions, which we demon-strate in a new 3D visualization tool. Text can be selected to move the compare to the compared optimized which a the selected to move strate in a new 3D visualization tool. Text can be selected to move the camera to the corresponding objects, 3D bounding boxes pro-vide anchore back to the text theorithing them and the owerall new the camera to the corresponding objects, 3D bounding boxes pro-vide anchors back to the text describing them, and the overall nar-rative of the text provides a temporal ender for automatically flying vide anchors back to the text describing them, and the overall nar-rative of the text provides a temporal guide for automatically fiving through the ecome to viewalize the world as you read about it. We fative of the text provides a temporal guide for automatically flying through the scene to visualize the world as you read about it. We CR Categories: H.S.I Information Interfaces and Presentation Information Stretame Assistant and Presentation CR Categories: H.5.1 Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and viewed tion]: Multimedia Information Systems_Artificial, augmented, and virtual realities 1.2.7 [Artificial Intelligence]: Natural Language perconceina_Tover analysis 1.2 10 (Artificial Intelligence]: Vision and virtual realities I.2.7 [Artificial Intelligence]: Natural Language Processing—Text analysis I.2.10 [Artificial Intelligence]: Vision and Scene Understandino—Modelino and recovery of nhveical and Vision Processing—Text analysis 1.2.10 [Artificial Intelligence]: Vision and Scene Understanding—Modeling and recovery of physical at-Keywords: image-based modeling and rendering. Wikipedia, natural language processing, 3D visualization Links: DL PDF

Abstract

Bryan C. Russell1

Tourists have long relied on guidebooks and other reference texts to learn about and navigate sites of interest. While guidebooks Tourists have long relied on guidebooks and other reference texts to learn about and navigate sites of interest. While guidebooks are nacked with interacting historical force and descriptions of sites to learn about and navigate sites of interest. While guidebooks are packed with interesting historical facts and descriptions of site specific objects and spaces, it can be difficult to fully viewdies the are packed with interesting historical facts and descriptions of site-specific objects and spaces, it can be difficult to fully visualize the scenes they present. The neimary cross come from images movided specific objects and spaces, it can be difficult to fully visualize the scenes they present. The primary cues come from images provided with the text. but coverage is snarse and it can be difficult to un. scenes they present. The primary cues come from images provided with the text, but coverage is sparse and it can be difficult to un deretand the enarial relationshine between each image viewoning with the text, but coverage is sparse and it can be difficult to understand the spatial relationships between each image viewpoint. For example, the Berlitz and Lonely Planet ouides Reditive Inderstand the spatial relationships between each image viewpoint. For example, the Berlitz and Lonely Planet guides (Berlitz In tornational 2003: Garwood and Hole 2012) for Rome each con-For example, the Berlitz and Lonely Planet guides [Berlitz In-ternational 2003; Garwood and Hole 2012] for Rome each con-rain incr a cinola physics of the Danthovm and have a cimilar lack ternational 2003; Garwood and Hole 2012] for Rome each con-tain just a single photo of the Pantheon, and have a similar lack of nhotooranhic coverance of other sites Fuen online sites such tain just a single photo of the Pantheon, and have a similar lack of photographic coverage of other sites. Even online sites such as Wikinedia which do not have enace restrictions have cimilarly of photographic coverage of other sites. Even online sites such as Wikipedia, which do not have space restrictions, have similarly snarse and disconnected visual coverage. Instead of relying exclusively on static images embedded in text, suppose vou could create an interactive nhotomalictic visualiza. Instead of relying exclusively on static images embedded in text suppose you could create an interactive, photorealistic visualiza-tion where for example a Wikinedia naoe is shown next to a desuppose you could create an interactive, photorealistic visualiza-tion, where, for example, a Wikipedia page is shown next to a de-tailed aD model of the described site. When you select an object tion, where, for example, a withpedia page is snown next to a de-tailed 3D model of the described site. When you select an object tatieg 3D model of the described site. When you select an (e.g., "Raphaels tomb") in the text, it flies you to the correspondence

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3D Wikipedia: Using online text to automatically

²University of Washington

Steven M. Seitz²

Luke Zettlemoyer2

label and navigate reconstructed geometry

UIST 2001 (ACM Symp. on User

View Manag

Visualization of Geo-tagged Information (cont.)



Social Snapshot: A System for Temp Social Photograp



They use offline 3D reconstruction algorithm or existing 3D models for registering the photos onto the meshes. Such methods usually suffer from hours of processing time for a single location.

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We describe a view-man ABSTRACT 3D user interfaces. maintaining visual constra on the view plane, such a other, or preventing obju view-management modifying selected ob, size, and transparency constraints. For examp properties that are simulation and which objects may flexible. We introduce algo extents to represen efficient approxima the projections of the unoccupied :

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Introduction

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cell phone cameras.

Social Snapshot actively acquires and reconstructs temporally dynamic data. The system enables spatiotemporal 3D photography using commodity devices, assisted by their auxiliary sensors and network functionality. It engages users, making them active rather than passive participants in data acquisition. from-mo

> compute struments used to acquire calibrated to produce pre-To simplify 3D photog system performs activ struction of temporall tiple users' cell phone calibration, it achiev convincing rendering

leverages online text and photo co-occurrences via Google Image Search. It enables a number of new interactions, which we demon. Automation produces to produce announced of interest of the approach is completely automated, and an and advance of the announces of the angle of th he photos, to produce annotated 3D models of Teverages online text and photo co-occurrences via Google Image Search. It enables a number of new interactions, which we demons errate in a new 3D viewalization tool. Text can be colocited to move Search. It enables a number of new interactions, which we demon-strate in a new 3D visualization tool. Text can be selected to move the compare to the compared optimized which a the selected to move strate in a new 3D visualization tool. Text can be selected to move the camera to the corresponding objects, 3D bounding boxes provide vide anchors back to the text describing them and the overall new the camera to the corresponding objects, 3D bounding boxes pro-vide anchors back to the text describing them, and the overall nar-rative of the text provides a temporal outde for automatically flying vide anchors back to the text describing them, and the overall nar-rative of the text provides a temporal guide for automatically fiving through the ecome to viewalize the world as you read about it. We fative of the text provides a temporal guide for automatically flying through the scene to visualize the world as you read about it. We through the scene to visualize the world as you read at show compelling results on several major tourist sites. CR Categories: H.S.1 [Information Interfaces and Presenta-tion]. Multimodia Information Systems Artificial augmented CR Categories: H.5.1 Information Interfaces and Presenta-tion]: Multimedia Information Systems—Artificial, augmented, and wirewal easilities 1 2 7 I Aerificial Interfaces Information tion]: Multimedia Information Systems—Artificial, augmented, and virtual realities 1.2.7 [Artificial Intelligence]: Natural Language perconceina Tove analysis 1.2 to rAntificial Intelligence]: Vision and virtual realities I.2.7 [Artificial Intelligence]: Natural Language Processing—Text analysis I.2.10 [Artificial Intelligence]: Vision and Groma Understandino—Modelino and recovery of nhveired at Processing—Text analysis I.2.10 [Artificial Intelligence]: Vision and Scene Understanding—Modeling and recovery of physical at-Keywords: image-based modeling and rendering, Wikipedia, nat-inal lanonaoe newsescing. 3D visualization ural language processing, 3D visualization Links: DL PDF

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So what about **our approach**?

Social Street View

Social Street View



Demonstration

The Augmentarium, UMIACS 6000 x 3000 pixels

Ct. C.L.

Natural Immersive Virtual Reality?

almost never in a natural immersive virtual reality settings.

Algorithm

Adding depth & normal map & maximal Poisson-disk sampling

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#Japanese Classic #sweets #dessert #nyc #datenight @kerse

Social Street View enables users to see-through the nearby restaurants.

Plt.

21/20

Ser. C

Conception, architecting & implementation



Social Street View

A mixed reality system that can depict geo-tagged social media in immersive 3D web environments

Blending multiple modalities of



Street View + Social Media

Depth maps, normal maps, and road orientation GPS coordinates and time creation

Enhancing visual augmentation



Maximal Poisson-disk sampling

Evaluated by image saliency metrics

Achieving cross-platform compatibility by



WebGL + Three.js

smartphones, tablets, desktop, high-resolution largearea wide field of view tiled display walls, as well as head-mounted displays.

Technical Challenges?

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Street View Cars - Cameras, LIDARs and GPS

Image courtesy from Google Street View



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Normal Map Decoded from Google Maps API v3
Road Orientations Decoded from Google Maps API v3

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image courtesy: Instagram





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Haversine Formula Andrew, 1805

$\alpha_{ij} = \sin^2\left(\frac{\varphi_i - \varphi_j}{2}\right) + \cos\varphi_i \cdot \varphi_j \cdot \sin^2\left(\frac{\lambda_i - \lambda_j}{2}\right)$ The distance between social media and street view panorama **Haversine formula**, which defines the distance on the surface of a sphere. $\beta_{ij} = 2 \cdot atan^2\left(\sqrt{\alpha_{ij}}, \sqrt{(1 - \alpha_{ij})}\right)$

$$d_{ij} = R \cdot \beta_{ij}$$

Social Street View Augmentarium Depth Augmentarium Baseline Oculus VR





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Council-Shopping Center

A MEM'S World

9 St [N.Q.P]

Radio City Apartments

Cort Theatre

Welcome to Social Street View!

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com 5, G.1



How can we **render and layout** the social media?





$$\varphi_i = (u_i - \frac{1}{2})\pi, \ \lambda_i = (2v_i - 1)\pi$$

 $x_i = \cos \varphi_i \cos \lambda_i, \ y_i = \sin \varphi_i, \ z_i = \cos \varphi_i \sin \lambda_i$



Without uniform random sampling

Without uniform sampling Accumulation

RESTAURANT

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With uniform random sampling



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LIKE YO

Add depth map



Sky: $\Omega_s = \{q_i \mid \forall q_i \in \Omega \land d_i = \infty\}$ Distance Limit: $\forall \tilde{p}_i \in T, D_{min} < \tilde{d}_i < D_{max}$





Can we ensure each image **aligns with** the building geometries?

Add normal map



Define the ground region: $\Omega_g = \{q_i \mid \forall q_i \in \Omega \land \|\mathbf{n}_i - \mathbf{n}_g\| < \delta\}$



Can we further reduce **visual clutter** and **occlusion**?

Maximal Poisson-disk Sampling

Gamito et al. Remove visual clutter and occlusion

$\forall \tilde{p}_i \in \tilde{P}, \tilde{P} \in Poisson-disk distribution is$ **uniform**. di (10)

Minimum distance between each pair of social media is greater than R.11)

 $S(X) = \{ \tilde{p} \in T : || \tilde{p} = \tilde{p} || \geq r \quad \tilde{p} \in \tilde{P} \} : S(X) = \emptyset$ Terminates the sampling when it reaches the **maximal coverage**. (12)

Dart-throwing Algorithm PixelPie by Ip et al. using vertex and fragment shaders



Algorithm 1 Maximal Poisson-disk sampling by dart-throwingInput:The minimum distance r between sampled pointsOutput:A set \tilde{P} of points which satisfy equation (10)-(12)

1: Set $\tilde{P} \leftarrow \emptyset$, empty region $\tilde{R} \leftarrow T$

Pixel-Pie by Ip. et al. uses GPU depth-testing feature for efficient sampling.

circular disks into a depth map in vertex shader.

- 4: Remove any point $\tilde{p} \in \tilde{P}'$ whose corresponding point \tilde{q} violates $\tilde{q} \in \Omega_g \lor D_{min} < \tilde{d} < D_{max}$
- 5: Identify and remove the occluded disks from \tilde{P} by reading the depth map in the shader.
- 6: $\tilde{P} \leftarrow \tilde{P} \cup \tilde{P}'$
- 7: Update the empty region *R* in the fragment shader.
- 8: **until** $R \leftarrow \emptyset$

Project Social Media Pictures

By Maximal Poisson-disc Sampling

ALGORITHM 1: Social Media Layout using Poisson-disk Samples

Input: N sorted social media images $\hat{S} = \{s_i \mid i = 1 \dots N\}$, acquired from SSV servers.

Output: A set of image planes to display social media: $I = I_1 \dots I_M, M \leq N$.

Generate the set of candidate sample points $\tilde{\mathbf{P}}$ by the PixelPie algorithm;

Sampling in regions which are not *Sky* nor *Ground*, and with a limitation of depth values;

depth map D so that the closest sample point is laid out first;

Place social media as **billboards upon** the building geometries;

Place I_i with texture from $s_i \in \hat{S}$ at the projected position $\tilde{\mathbf{q}}_i \leftarrow \mathscr{P}(\tilde{\mathbf{p}}_i)$;

Cast soft shadows as if lighting were 45 degree to the normal vectors.

perspective visual effects:

Rotate I_i so that it is perpendicular to the normal vector $\mathbf{n_i} \leftarrow \mathbf{N}(u_i, v_i)$;

Add I_i to the result set: $I \leftarrow I \cup I_i$;

end





Algorithm

Adding depth & normal map & maximal Poisson-disk sampling

RESTAURANT 📰 JUJHIDEN

In addition, our system allows users to walk around and explore live social media streams.

Lit.

 $2\rho_1$

This algorithm works well in **dense urban areas** such as the Manhattan District,

What if there are **no buildings** in the scene?

Scenic Landscapes

Using orientation of the road

Input: |O| road orientations with $o_i \in [0, 2\pi]$. K social media to be placed for each orientation. Typically, |O| = 2 for a road with two orientations. **Output:** A set of image planes to display social media: $I = I_1 \dots I_M, M \ge K \cdot |O|$ for $i \leftarrow 1 \dots |O|$ do We use only the orientations of the road (Optional based on user's preference) Add a frontal image plane to I at q_i ; Set the translation $\mathbf{t} \leftarrow (T \cos(o_i + \frac{\pi}{2}), 0, T \sin(o_i + \frac{\pi}{2}))$ with constant T: for $k \leftarrow 1 \dots K$ do Set $\tilde{\mathbf{q}} \leftarrow (kR \cos o_i, h, kR \sin o_i);$ Add a left side image plane to I at position $\mathbf{q}' \leftarrow \mathbf{\tilde{q}} + \mathbf{t}$; Add a right side image plane to I at position $\mathbf{q}' \leftarrow \mathbf{\tilde{q}} - \mathbf{t}$; end

end

Scenic Landscapes Using orientation of the road





Scenic Landscapes Using orientation of the road

What if ... Temporal information is used for filtering and rendering?



image courtesy: mindtheproduct.com



Users can use temporal or distance filters to narrow down their interested queries.






Immersive high-resolution screens

Pixels	Resolution /	Number of tiles	File size
88.6M	13312×6656	26×13	$\sim 5M$
22.2M	6656×3328	13×7	$\sim 2M$
5.5M	3328×1664	7×4	$\sim 800K$
1.4M	1664 × 832	4×2	$\sim 300K$
0.3M	832 × 416	2×1	$\sim 90K$

Common Consumer-level Displays



After Prefetching

¾ - ¼ time reduced

Initialization Time After Prefetching





Initialization Time

Panorama takes a while to load

Rendering Time Almost 58~60 FPS

Rendering Time Based on Resolution



After initialization, the system runs in real time at about 58~60 FPS.



How effective is the Maximal Poisson-disk Sampling for reducing the visual clutter?



How much social media covers the salient regions of the panorama?





Saliency maps use color, intensity, and orientation contrasts to estimate where humans will look at.





We prefer the social media to cover less high-saliency regions.



Social Media Coverage 100 panoramas for each algorithm

Social Media Coverage of Saliency Map



Social Media Coverage 100 panoramas for each algorithm

Social Media Coverage of Saliency Map



The first two algorithm occupies 30% - 50% of the high-saliency regions.



Social Media Coverage 100 panoramas for each algorithm

Social Media Coverage of Saliency Map



The last two algorithm largely reduce the coverage of saliency map to less than 20%.



In the last algorithm, all the images are separated with each other and uniformly distributed on the building surfaces.

What could be the **potential applications** of Social Street View?



Stuck in traffic on our way to Cabo with this awesome view

#roadtrip #cabo #view #mexico

Daniela on *Instagram* July 12, 2014



Application

Immersive story telling



However, we can hardly enjoy the view given the small posted image.

Business Advertising Museum, restaurant, real-estate ...

-

... dinner started off with amazing oysters paired with my favorite Ruinart blanc de blancs champagne

By frankiextah on Instagram



Museum, restaurant, real-estate ...

Social Street View enhances future consumers' visual memories and makes it easier for them to seek the "amazing oysters" around this place.

Business Advertising

1

Lesprit de Patis stan 29 rue de Rivoli.

April 12/8.

Museum, restaurant ...



Crowd-sourced Tourism

Crowd-sourced Tourism

Social Street View allows users to explore **novel views** (e.g. from top of buildings), where you cannot see with only the panoramas.

In conclusion, **Social Street View** provides a novel solution for automatically fusing geo-tagged social media in an immersive 3D environments.

CLEIT

We envision **social media** and **panoramic videos** are significant parts of the **big data** for VR and AR applications

Ct. Cut.





The social media layout is re-generated, every time, when users walk around the street views.



Challenges Registration of billboards

> How are we going to ensure that the billboards **are registered, and stays** with building geometries, when users change the viewpoints?



Proposed Work

image courtesy: Lu et al.

Proposed Work

Estimate simple **3D building geometries** from the depth and normal maps.

image courtesy: Lu et al.







How to register some of the social media images with the immersive panoramas, to create a novel layout?





Storytelling Baja California Sur, Mexico

Develop fast algorithms for reconstructing simple geometries, feature matching, and navigating the social street views without resampling.










How to efficiently generate the **saliency map for panoramas**?



Traditional saliency methods can hardly deal with spherical rotations and horizontal clipping





The sliding-window approach is too slow since it has to **cut the panorama into pieces**, and **stitch the saliency maps back**.







Spherical Harmonics, a complete set of orthogonal functions on the sphere, can be used for estimating the **panoramic** saliency maps **in one pass**.



Proposal Fusing Multimedia Data Into Dynamic Virtual Environments



Montage4D: Interactive Seamless Fusion of Multiview Textures





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Resea





COMPUTER SCIENCE UNIVERSITY OF MARYLAND





Fusing multiview video textures onto dynamic meshes with real-time constraint is **a challenging task**



of the participants does not believe the 3D reconstructed person looks real







3D Texture Montage





non-rigid correction functions for all images. All parameters are

stimized jointly to maximize the photometric consistency of the

but this optimization can be per-

However, capturing an object's geometry is not sufficient for reproet al. 2013]. ducing its appearance. A visually faithful reconstruction must also organ the apparent color of every point on the object. In this











Figure 1: Examples of reconstructed free-viewpoint video acquired by our system.

Abstract

Ra

We present the first end-to-end solution to create high-quality freeviewpoint video encoded as a compact data stream. Our system records performances using a dense set of RGB and IR video cameras, generates dynamic textured surfaces, and compresses these to a streamable 3D video format. Four technical advances contribute to high fidelity and robustness: multimodal multi-view stereo fusing RGB, IR, and silhouette information; adaptive meshing guided by automatic detection of perceptually salient areas; mesh tracking to create temporally coherent subsequences; and encoding of tracked textured meshes as an MPEG video stream. Quantitative Our goal is to transform free-viewpoint video from research prototype into a rich and accessible form of media. Several system components must work together to achieve this goal: capture rigs must be easy to reconfigure and support professional production workflows; reconstruction must be automatic and scalable to high processing throughput; and results must be compressible to a data rate close to common media formats. Visual quality from any angle must be on par with traditional video, and the format must be renderable in real-time on a wide range of consumer devices.

In this paper, we discuss how we address these challenges to create an end-to-end system for realistic, streamable free-viewpoint video at significantly higher quality than the state of the art. Our approach not require prior knowledge of the scene content. It handles



162

isterduced in computer graphics as ame rates.

To take advantage of the continuing progress in graphics hardware capabilities for realistic rendering, ever more detailed model descriptions are needed. Because creating complex models with conventional modeling and animation tools is a time-consuming and expensive process, direct modeling to a unconsuming and expensive process more investigation techniques from real-world examples are an attractive alternative. By scanning, or reconstructing, the 3D geometry of an object or scene and capturing its visual appearance using photos or video, the goal of direct modeling techniques is to achieve photo-realistic 3D rendering results at interactive

Unfortunately, acquiring highly accurate 3D geometry and calibrated images turns out to be at least as tedious results. and time-consuming as model creation using software tools. and unreconsuming as mover creation using sourware toors. In response, a number of different image-based rendering (IBR) techniques have been devised that make do with more approximate geometry. With a mere planar rectangle nore approximate geometry, with a mere planar rectangle as geometry proxy, Light Field Rendering arguably constitutes the most "puristic" image-based rendering technique [LH96]. Here, many images are needed to avoid blurring or ghosting artefacts [CCST00]. If more appropriate depth maps are additionally available, Lumigraph rendering mensue for parallax between images to yield con-

geometry and sufficiently many, well-calibrated and registered images are given, image-based modeling techniques. like [WAA*00, LKG*03], achieve impressive 3D rendering

ADSITACI We present a novel multi-view, projective texture mapping technique. While previous multi-view texturing ap-multi-view burging and shorting artifacts if 3D generative multi-view outlineation are immediate and We present a novel mutti-view, projective texture mapping technique. While previous multi-view texturing ap-propose lead to blurring and ghosting artefacts if 3D geometry and/or camera calibration are imprecise, we provote a texturing algorithm that warms ("floate") projected textures during run-time to preserve error data. proaches lead to blurring and ghosting artefacts if 3D geometry and/or camera calibration are imprecise, we propose a texturing algorithm that warps ("floats") projected textures during run-time to preserve crisp, detailed to the method is were interactive to real-time frame rates. The method is were propose a texturing algorithm that warps ("floats") projected textures during run-time to preserve crisp, detailed texture appearance. Our GPU implementation achieves interactive to real-time frame rates. The method is very appendix amplicable and can be used in combination with monv image-based rendering methods or projective texture appearance. Our GPU implementation achieves interactive to real-time frame rates. The method is very generally applicable and can be used in combination with many image-based rendering methods or projective texturing applications. But using Election Textures in conjunction with a gravitated bull conduction lists fold on texturing applications. seneratly applicable and can be used in combination with many image-based rendering methods or projective seturing applications. By using Floating Textures in conjunction with, e.g., visual hull rendering, light field rendering dering or free-view point video, improved rendering results are obtained from fewer input impress lass accurately lexturing applications. By using Floating Textures in conjunction with, e.g., visual huil rendering, tight jueld ren-dering, or free-viewpoint video, improved rendering results are obtained from fewer input images, less accurately culturated connects, and concerner 3D econnects provine Categories and Subject Descriptors (according to ACM CCS): 1.3.3 [Computer Graphics]: Picture/Image Generation calibrated cameras, and coarser 3D geometry proxies. Laregures and subject Descriptors (according to ACM CCS): 1.5.5 [Com/ L3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism

Computer Graphics Lab, TU Braunschweig, Germany 2Hasselt University - Expertise Centre for Digital Media - Transnationale Universiteit Limburg, Belgium

(Guest Editors) Floating Textures M. Eisemann¹, B. De Decker², M. Magnor¹, P. Bekaert², E. de Aguiar³, N. Ahmed³, C. Theobalt⁴, A. Sellent¹

EUROGRAPHICS 2008 / G. Drettakis and R. Scopigno

Related Work

3D Texture Montage

Volume 27 (2008), Number 2

intelicitly or explicitly

Screen-space optical flow could fix some misregistration issues, but heavily relies on **RGB features**, and

fails when **changing viewpoints**.

3D Texture Montage

Up to now, few systems but Holoportation could fuse dynamic meshes with multiple cameras in real time. This recent SIGGRAPH 2017 paper produces excellent dynamic reconstruction results, but uses a single RGBD camera.

Real-time Geometry, Albedo and Motion Reconstruction Using a

KAIWEN GUO and FENG XU, Tsinghua University TAO YU, Beihang University and Tsinghua University XIAOYANG LIU, QIONGHAI DAI, and YEBIN LIU, Tsinghua University This paper proposes a real-time method that uses a single-view RGBD input

to simultaneously reconstruct a casual scene with a detailed geometry model. surface albedo, per-frame non-rigid motion and per-frame low-frequency lighting, without requiring any template or motion priors. The key observation is that accurate scene motion can be used to integrate temporal information to recover the precise appearance, whereas the intrinsic appearance can help to establish true correspondence in the temporal domain to recover motion. Based on this observation, we first propose a shading-based scheme to leverage appearance information for motion estimation. Then, using the reconstructed motion, a volumetric albedo fusing scheme is proposed to complete and refine the intrinsic appearance of the scene by incorporating information from multiple frames. Since the two schemes are iteratively applied during recording, the reconstructed appearance and motion become increasingly more accurate. In addition to the reconstruction results, our experiments also show that additional applications can be achieved, such as relighting, albedo editing and free-viewpoint rendering of a dynamic scene, since geometry, appearance and motion are all reconstructed by our CCS Concepts: • Computing methodologies → Reconstruction; Mo-

Additional Key Words and Phrases: single-view, surface reconstruction, real-

ACM Reference format: Kaiwen Guo, Feng Xu, Tao Yu, Xinoyang Liu, Qionghai Dai, and Yebin Liu. 2017. Real-time Geometry, Albedo and Motion Reconstruction Using a Single RGBD Camera. ACM Trans. Graph. XX, X, Article XX (March 2017), 13 pages.

INTRODUCTION

Dynamic scene reconstruction involves capturing and reproducing various aspects of the real visual world, including static geometry, detailed motion, and intrinsic or observed appearance. Simultane-

ously reconstructing all of these aspects or even part of them enables This work was supported by the National key foundation for exploring scientific

This work was supported by the reaction key romannon or exporting science instrument No. 2013YQ140517 and NSPC (No. 61671268, 61522111 and 61531014). anstrument ivo. 201519/190117 and roars (ivo. nior1200, 01022111 and 0102010), Authors' addresses: K. Guo, X. Lin; email: [gfcw11, liu-xy14]@mails.tringhua.edu.cn; Q. Dai, Y. Liu (corresponding author); emails: [qhdai, huyebin]@esinghua.edu.en;



Fig. 1. Our system can capture fast and natural motions, geometry, and face albedo and simultaneously render them in new lighting environme

important applications in computer vision and graphics. For example ple, reconstructed geometry and surface motion as well as observe appearance can be used for free-viewpoint video. Reconstructe kinematic motion can be transferred to new objects or used to get erate new photo-realistic animations. The intrinsic appearance of dynamic scene/object can be used in applications such as appearance editing and relighting. The real-time reconstruction of geometry, motion and appearance enables more realistic rendering for virtual reality scenarios, for example, Holoportation [7].

Although considerable efforts have been devoted to dynamic

scene reconstruction, the problem remains challenging because of the extraordinarily large solution space, necessitating a carefully designed capture environment [5, 34], high-quality lighting equipment [3, 9] and many video cameras [15]. Several recent works have successfully eliminated various constraints on adquisition by using convenient capture equipment, such as a single Kinect [32] or binocular camera [37]. However, they routing many

3D Texture Montage

Holoportation: Virtual 3D Teleportation in Real-time W. Chang

S. Orts Escolano C. Rhemann Y. Degtyarev O. Cai

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Microsoft Research (contact:shahrami@microsoft.com)









Figure 1. Holoportation is a new immersive telepresence system that combines the ability to capture high quality 3D models of people, objects and environments in real-time, with the ability to transmit these and allow remote participants wearing virtual or augmented reality displays to see, hear

and interact almost as if they were co-present.

We present an end-to-end system for augmented and virtual reality telepresence, called Holoportation. Our system demonstrates high-quality, real-time 3D reconstructions of an entire space, including people, furniture and objects, using a set of new depth cameras. These 3D models can also be transmitted in real-time to remote users. This allows users wearing virtual or augmented reality displays to see, hear and interact with remote participants in 3D, almost as if they were present in the same physical space. From an audio-visual perspective, communicating and interacting with remote users edges closer to face-to-face communication. This paper describes the Holoportation technical system in full, its key interactive capabilities, the application scenarios it enables, and an initial qualitative study of using this new communication medium.

Author Keywords

T-lapmonce: Non-rigid

from delivering an experience close to physical co-presence. For example, despite the myriad of telecommunication technologies, we still spend over \$1 trillion/year globally on business travel, with the US making up \$300 billion/year and over 482 million flights/year¹. And this is without counting the cost on the environment. Indeed telepresence has been cited as key in battling carbon emissions in the future2.

However, despite the promise of telepresence, clearly we are still spending a great deal of time, money, and CO2 getting on planes to meet face-to-face. Somehow much of the subtleties of face-to-face co-located communication - eye contact, body language, physical presence - are still lost in even high-end audio and video conferencing. There is still a clear gap between even the highest fidelity telecommunication tools and physically being there.

In this paper, we describe Holoportation, a system that attempts to close this gap. Holoportation is a new communica-I that human are consumer augmented reality (AR) and

Normal Weighted Blending

$$w_{i} = V \cdot \max(0, \hat{n} \cdot \hat{v}_{i})^{\alpha}$$
Visibility test
Normal vector
Texture camera view direction

Majority Voting for color correction

For each vertex, and for each texture, test if the projected color agrees with more than half of the other textures, if not, set the texture weight field to 0.

What is our approach for real-time **seamless** texture fusion?

Workflow Identify and diffuse the seams



Figure 2: The workflow of the Montage4D rendering pipeline.

What are the **causes** for the *blurring* and *seams*?



Causes for blurring



Blurring



Texture projection errors Inaccurate camera calibration



Normal-weighted blending



Causes for blurring



Texture projection errors



Blurring



Normal-weighted blending View-dependent rendering



Causes for Seams







Majority-voting



Field-of-View





Self-occlusion

One or two vertices of the triangle are occluded in the depth map while the others are not.





Raw projection mapping results



Seams after occlusion test





Majority Voting

The triangle vertices have different results in the majority voting process, which may be caused by either mis-registration or self-occlusion.





Raw projection mapping results



Seams after majority voting test

Seams after occlusion test





Field of View

One or two triangle vertices lie outside the camera's field of view or in the subtracted background region while the rest are not.





Raw projection mapping results



Seams after field-of-view test





For a static frame, how can we **get rid of** the annoying seams at interactive frame rate?

How can we spatially smooth the **texture** (weight) field near the seams so that we cannot see visible seams in the results?
Workflow Identify and diffuse the seams



Figure 2: The workflow of the Montage4D rendering pipeline.



Geodesic is the **shortest** route between two points on the surface.

Geodesics For diffusing the seams



On triangle meshes, this is challenging because of the computation of **tangent directions**. And shortest paths are defined on **edges** instead of the vertices.

Geodesics For diffusing the seams



Figure 5: Illustration of computing the approximate geodesics. (A) shows the concept of the geodesic window from a single source vertex. (B) shows the components within a window. (C) shows the merging process of two overlapping windows for approximiation.

We use the algorithm by *Surazhsky* and *Hoppe* for computing **the approximate geodesics**. The idea is to maintain **only 2~3 shortest paths** along each edge to reduce the computational cost. Approximate Geodesics



Figure 6: *Examples of the initial seam triangles and the propagation process for updating the geodesics.*

View-dependent Rendering

Spatially highlight the close views



Workflow Identify and diffuse the seams



Figure 2: The workflow of the Montage4D rendering pipeline.



Temporally smooth the texture fields

Temporal smoothing factor of 0.02 $\mathscr{T}_{\mathbf{v}}^{i}(t) = \mathscr{T}_{\mathbf{v}}^{i}(t-1) + \lambda \nabla \mathscr{T}_{\mathbf{v}}^{i}(t)$ Texture field of the previous frame

The gradient between the ideal texture field of the *current* frame, and the value of the *previous* frame



Color Scheme for the Texture Fields











With additional computation for seams, geodesics, and temporal texture fields, is **our approach** still in real time? Exmperiment RMSE = Root mean squared error FPS = frames per second

Table 1: Comparison of root-mean-square error (RMSE) and frame rates between Holoportation and Montage4D methods

Detect	Enomos	Haranting / from a	ttuion alaa / fuoma	Holoporation		Montage4D	
Dataset	Frames	#vertices / frame	#utangles / frame	RMSE	FPS	RMSE	FPS
Timo	837	131K	251K	5.63%	227.2	3.27%	135.0
Yury	803	132K	312K	5.44%	222.8	3.01%	130.5
Sergio	837	215K	404K	7.74%	186.8	4.21%	114.
Girl	1192	173K	367K	7.16%	212.56	3.73%	119.4
Julien	526	157K	339K	12.63%	215.18	6.71%	120.

Exmperiment RMSE = Root mean squared error FPS = frames per second

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Girl	1192	173K	367K	7.16%	212.56	3.73%	119.4
Julien	526	157K	339K	12.63%	215.18	6.71%	120.6

The root-mean-squared-error of the rendering results have been great **reduced**.

Exmperiment RMSE = Root mean squared error FPS = frames per second

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Julien	526	157K	339K	12.63%	215.18	6.71%	120.6

Our frame rate is slower, but still capable at **over 90 FPS**, for dynamic VR rendering.

Experiment Break-down of a typical frame

Table 2: Timing comparison between Holoportation and Mon-tage4D for a typical frame

Procedure	Timing (ms)			
Flocedule	Holoportation	Montage4D		
Communication between CPU and GPU	4.83	9.49		
Rendering and Texture Sampling	0.11	0.30		
Rasterized Depth Maps calculation	0.14	0.13		
Seams Identification	N/A	0.01		
Approximate Geodesics estimation	N/A	0.31		
Other events	0.12	0.18		
Total	5.11	10.40		

Most of the time is used in communication between CPU and GPU





In conclusion, Montage4D provides a practical texturing solution for real-time 3D reconstruction systems. In the future, we envision that Montage4D is useful for fusing the massive multi-view video data into VR applications like remote business meeting, immersive education, and family gathering.

Proposal Fusing Multimedia Data Into Dynamic Virtual Environments



Saliency-guided Fusion



Depth Estimation and Segmentation



Volumetric Fusion

Saliency-guided Fusion



Full RGBD information and segmentation

Colored Volumetric Fusion

Colors Terms Optimizing Energy Functions

$$E(G) = \lambda_{depth} E_{depth}(G) + \lambda_{color} E_{color}(G) + \lambda_{corr} E_{corr}(G) + \lambda_{rot} E_{rot}(G) + \lambda_{smooth} E_{smooth}(G)$$

$$E_{depth}(G) = \sum_{n=1}^{N} \sum_{m \in V_n(G)} \min_{x \in P(Depth_n)} ||Depth(v_m; G) - x||^2$$

$$E_{color}(G) = \sum_{n=1}^{N} \sum_{m \in V_n(G)} \sum_{c \in P(Color_n)} ||Color(v_m; G)_{LAB} - c_{LAB}||^2$$





Quantitative Comparison Between Fusion4D (Depth Only) and Intrinsic4D (Depth + Color)

Depth Only
 Depth + Color

The frame rate **drops** from 30 FPS to 10 FPS with the color term...

How to **speed up** the dynamic reconstruction procedure, with the performance improvement?

Mesh Saliency Lee, Varshney, Jacobs. SIGGRAPH 2005





Use color-term optimization and more voxels for reconstructing **high-saliency** regions

Saliency is the vital key to balance the tradeoff between quality and speed.

Proposal Fusing Multimedia Data Into Dynamic Virtual Environments



Video Fields: Fusing Multiple Surveillance Videos Into a Dynamic Virtual Environment

Ruofei Du, Sujal Bista, and Amitabh Varshney www.Video-Fields.com www.Augmentarium.com

Augmentarium | Department of Computer Science | UMIACS University of Maryland, College Park In Proceedings of the 21st Annual ACM SIGGRAPH Web3D Conference, 2016

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COMPUTER SCIENCE UNIVERSITY OF MARYLAND



Proposal Fusing Multimedia Data Into Dynamic Virtual Environments



VRSurus: Enhancing Interactivity and Tangibility of Puppets in Virtual Reality (CHI 2016)



Ruofei Du and Liang He

University of Maryland, College Park



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Date	Project
Oct. – Nov. 2017	Spherical Harmonics Videos ACM I3D 2018
Nov. – Feb. 2018	Geo-spatial Registration with Social Street View ACM ToG / IEEE TVCG
Mar. – Aug. 2018	Saliency-guided Real-time 3D Reconstruction ACM ToG / IEEE TVCG
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NIDIA Microsoft[®] **Research**





Thank you

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Committee: Dr. Varshney, Dr. Zwicker, and Dr. Huang

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Fusing Multimedia Data Into Dynamic Virtual Environments

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