Augmented Reality im praktischen Einsatz

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10. Oktober 2012

Servicing im Weltraum
Workshop zu interaktiven VR-Technologien für On-Orbit-Servicing

Videos not attached, please see our YouTube Channel http://www.youtube.com/AugmentedRealityTUM
Augmented Reality Definition

- Real + virtual
- Interactive in real-time
- Registered in 3 Dimensions

[Azuma 98]

Mixed Reality Continuum:

[ECRC 93]

[Milgram and Kishino 94]
Augmented Reality
Virtual Information as Part of the Physical World

G. Klinker, D. Reiners, D. Stricker, Fraunhofer IGD 1998
Augmented Reality
Tangible Virtual Objects

G. Klinker, D. Reiners, D. Stricker, Fraunhofer IGD 1998
Augmented Reality
Graspable Information ("Begreifbar")
Augmented Reality
Technical Requirements

• Tracking of users and/or objects
• 3D information presentation schemes (metaphors)
• 3D interaction (gestures)

Issues
• Mobile users
• Distributed information
• Real-time
• Precision, accuracy
• Understandability/usability, security/safety, user acceptance
Multimedia Combination of Reality and „Virtuality“

Physicality

Virtual World (Computer network)

Real World Physical

System Architecture  Real-Time  Distributed Systems

Wearable Devices

Data security

Dynamic Modelling

Dynamic Visualization

Simulation

AR-System

Multi-modal HCI

User

Information

Sensor data

Manipulation of Real Objects

Scene Analysis

Tracking

Wearable Devices

Wireless Communication

Ergonomics

Adaptation

Augmented Reality im praktischen Einsatz
Augmented Reality Tracking Devices

Time-frequency measurements (ToF): GPS, Sound
Spatial scan (Optical): Outside-In, Inside-Out
Inertial sensing (IMU)
Mechanical linkages (Robot arm)
Direct-field sensing (Electro-magnetic)

Hybrid systems
Augmented Reality
Different Approaches

Head-based
Hand-based
Desktop-based
Object-based
Hybrid

Youtube Channel: AutmentedRealityTUM
Usability and Utility of Augmented Reality

- **Utility**
  - Gartner’s „Hypecurve“ (2011)
  - Precision
  - Wide-range use
  - Authoring
- **Usability**
  - Production ergonomics
    - Product life cycle
    - Virtual model vs. physical mockup
  - Product ergonomics
    - Usability of interactive devices and techniques/metaphors
    - Cognitive capture
    - Perceptual tunneling
Practical Scenarios

1. Intelligent Welding Gun
Utility of Augmented Reality
- Stud welding in prototypical construction (BMW) -

Task
• Weld 300-500 studs to the car frame
• Max. 1mm error (position)
• 4 minutes/stud

Idea
• Use AR to help users see the stud positions on the car frame

Utility of Augmented Reality
- Stud welding in prototypical construction (BMW) -

System design options

A problem in search of a solution!

Involved devices/resources

- Display
- Sensors (cameras)
- Markers

Positions

- on the user (HMD)
- on the tool (IWG)
- on the object (Projector)
- nowhere (marker-less)

In principle, $4^3 = 64$ potential solutions
Utility of Augmented Reality
- Stud welding in prototypical construction (BMW) -

Solution space (focus on displays)

- HMD (on user)
- IWG (on the tool)
- Projector (on the object)
Utility of Augmented Reality
- Stud welding in prototypical construction (BMW) -

Setup, expected precision

<table>
<thead>
<tr>
<th>HMD</th>
<th>Projector</th>
<th>IWG</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Diagram1.png" alt="Diagram" /></td>
<td><img src="Diagram2.png" alt="Diagram" /></td>
<td><img src="Diagram3.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

In: *Virtual and Augmented Reality Applications in Manufacturing* (Ong and Nee, eds.), Springer Verlag, 2003.
Utility of Augmented Reality
- Stud welding in prototypical construction (BMW) -

Solution: Intelligent Welding Gun (IWG)

- **Task**
  - Weld 300-500 studs to the car frame
  - Max. 1mm error (position)

- **Apparatus**
  - Stationary (outside-in) tracking (6 cameras)
  - Stationary computer
  - (Tethered) mobile intelligent gun with display

- **Process**
  - Display and selection of welding points by the computer
  - 3D-presentation of the current welding point on the gun (notch and bead metaphor)
  - Search and weld
  - Continue with next point via button press on the welding gun

4 minutes / stud → < 1 minute / stud

Utility of Augmented Reality
- Stud welding -

Further steps:

- Productization by BMW, ART, Tucker and viception
- Similar concepts installed at Volkswagen (with metaio)
  - Replace optical tracking with mechanical tracking (higher precision at the cost of reduced mobility)
  - Present information on a nearby display
Utility of Augmented Reality
- Stud welding -

Further research at TUM-FAR:
Extension of the welding area
  • Access to occluded areas
    – Dynamic inclusion of a second, mobile camera system
    – Dynamically (re)configurable sensor fusion

Explicit error analysis and visualization
  • Modeling the spatial relationships between objects and sensors
  • Spatially varying error/noise analysis
  • Error propagation regarding established spatial relationships

Pustka, Huber, Bauer and Klinker: *Spatial Relationship Patterns: Elements of Reusable Tracking and Calibration Systems*, ISMAR 06, Oct. 2006. AWARD.

Ubiquitous Augmented Reality (UAR)

Our approach:
Mobile AR – embedded in stationary wide-range, multi-media environments (*ubiquitous / pervasive / ambient computing*)

- Ubiquitous tracking
  - Mobile: head-worn camera, gyroscope, …
  - Stationary: room-based cameras, RFIDs, GPS, …
- Ubiquitous informations presentation and UIs
  - Mobile: Displays on users‘ heads, in their hands, on devices, in cars, shown by a head-worn projector, …
  - Stationary: Wall-based, table-based displays, projectors, …
Spatial Relationship Graph (SRG)

3D World

SRG

- ART
  - Marker on HMD
    - 6DoF
  - Marker on Door
    - 6DoF

- Eye
  - 6DoF

- Car
  - 6DoF
Spatial Relationship Graph (SRG) - Edge Attributes

- Estimation method (direct →, derived ←→)
- Degrees of freedom (6 DoF, 3 DoF, 2 DoF, …)
- Transformation parameters (pose, translation, rotation, projection 3D → 2D, …)
- Dependence on time (static, dynamic)
- Time stamps
- Synchronization (push, pull)
- Precision
Automatic Compilation into Data Flow Networks

- Spatial Relationship Graph (SRG)

- Data Flow Netzwerk (DFN): SRG edges = DFN nodes
Spatial Relationship Patterns

- Inversion
- Concatenation
- Sensor Fusion

- 3D-3D Pose Estimation
- 2D-3D Pose Estimation
- Hand-Eye Calibration

Pustka, Huber, Bauer and Klinker: *Spatial Relationship Patterns: Elements of Reusable Tracking and Calibration Systems*, ISMAR 06, Oct. 2006. AWARD.
Integration Concept for Applications

- trackframe Manager
- UbiTrack Server
  - Plant-wide-SRG
- Database Server
- Sensor Client
- Application
- Application Client
  - Application-SRG

Plant-wide Installations of Sensors

Huber, Pustka, Keitler, Echtler and Klinker: *A System Architecture for Ubiquitous Tracking Environments*, to be presented at ISMAR 07, Nov. 2007.
Becker, Fex and Huber: *Using RFIDs for Indoor Large-Area Tracking*, to be submitted to Pervasive 08.
Automated Sensor Fusion

Patterns/algorithms for
- **Calibration**
  - Camera estimation
  - Hand-eye calibration
  - Display calibration (SPAAM)
- **Registration**
  - 3D-3D pose estimation
- **Sensor fusion**
  - Complementary
    - Functionally complementary
    - Temporally/spatially complementary
  - Competitive
    - Binary competitive (“winner take all”)  
    - Mixed competitive (error reducing: Kalman)
  - Co-operative
    - Independent co-operation (concatenation, correction)
    - Dependent co-operation (initialization)
Error Estimation and Propagation in SRGs

- Computation of sensor error
  - Gaussian errors
  - High-precision ART tracking
  - Simple marker tracking

- Fusion algorithm
  - Kalman filter
  - Fully integrated into framework
Dynamic Reconfiguration

- Scenario: AR-equipped person enters room with high-precision tracking
- Client and application should automatically connect
- Idea: Use low-precision tracking to change SRG
Tracking manager
Usability and Utility of Augmented Reality

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Practical Scenarios

2. Navigational Guidance (Commissioning)
Usability in Real Applications
- Navigation Support in Picking Tasks -

- Collection of large assortments in series production
  - Large storage area, many objects, varying size
  - Flexible arrangement in the storage area
  - Changing staff

- Several phases
  - Course navigation
  - Fine navigation

- Existing systems
  - Mobile data terminal with scanner
  - Pick-by-light
  - Pick-by-voice
Usability in Real Applications
- Navigation Support in Picking Tasks -

Pick-by-Vision
- Omni-directional support of object selection
- HMD-based
- Visualizations
  - Direct: rectangle
  - Meta: tunnel
- Ubiquitous tracking

Usability in Real Applications
- Navigation Support in Picking Tasks -

Important issues

• Quality and understandability of the 3D display: uniqueness (Arrow vs. frame)
• Support for estimating appropriate speed of motion (rotation) (Arrow/rubber band vs. tunnel)
• Occlusions
Usability in Real Applications  
- Navigation Support in Picking Tasks -

Long series of user tests
- Several evaluations (objective and subjective data, plus informal comments)
- Informal comments from exhibits, fairs, open houses.
- Collaboration with occupational scientists (analysis of heart rate variability)

Experiences
- Special (non-standard) initial learning phase („try-and-ask“)
- Optional interruptions by the supervisor
- Initially many „formative“ tests, expert interrogations with few people
Usability of Augmented Reality
Evaluations of 2D UIs versus 3D UIs

• Well-established techniques in 2D HCI research
  – Many transferrable to 3D UI research

• Yet, not quite
  – 3D devices (e.g. HMD) extremely novel
    • Test persons are confused/fascinated/...
    • Test persons don’t know what they should expect (complain about)
      – Proper setup/calibration is critical (has to be checked)
  – Comparison with traditional UIs unfair (apples and oranges)
    • Learning effects cannot be fully discounted by randomization
  – How can the environment be instrumented without influencing the results?
Usability of Augmented Reality
VR versus AR

<table>
<thead>
<tr>
<th></th>
<th>VR</th>
<th>AR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Properties</td>
<td>Engineered (safe) physical reality</td>
<td>Cluttered (dangerous) physical reality</td>
</tr>
<tr>
<td>Goal</td>
<td>Immerse in a secondary reality</td>
<td>Add secondary information to the primary (physical) reality</td>
</tr>
<tr>
<td>Problems</td>
<td>Lack of presence</td>
<td>Lack of situation awareness</td>
</tr>
<tr>
<td></td>
<td>- Degree of realism</td>
<td>- Perceptual tunnelling, information overload, cognitive capture.</td>
</tr>
<tr>
<td></td>
<td>- Simulator sickness</td>
<td>- Tracking, occlusion of physical objects</td>
</tr>
<tr>
<td>Approach</td>
<td>Exploit human sensing limitations</td>
<td>Analyze potential distractions</td>
</tr>
<tr>
<td></td>
<td>- e.g. Change blindness</td>
<td>- e.g. Eye tracking</td>
</tr>
<tr>
<td>Convergence</td>
<td>Use AR to enhance VR</td>
<td>Use VR to evaluate AR</td>
</tr>
</tbody>
</table>
Practical Scenarios

3. Molecular Chemistry (3D Interaction)
Augmented Chemical Reactions (Intelligence Amplification)

- Example: Design of catalysts for metal-organic reactions
- Problem:
  Generally, more than two hands are required to control the chemical process
  - Selection of a binding
    - Distance-based selection
    - Shake-based selection (linear processing of a list)
  - Committing the action

Maier, Tönnis, Klinker, Raith, Drees, Kühn: What Do you Do When Two Hands Are not Enough? Interactive Selection of Bonds Between Pairs of Tangible Molecules
International Symposium On 3D User Interfaces (3DUI), Waltham, MA, March 2010.
Summary

- Augmented Reality has great potential
- Watch out for creating a „Solution in Search of a Problem“
- Engineering-like exploration of a design space of options and requirements
- User-centered evaluations of system usability are important, yet need extreme diligence
  - In-depth focus on only the critical aspects
  - Need for a robust test environment

- Burning issues:
  - Ubiquitous infrastructure for wide-range use of AR on mobile devices („AR-ready building“)
  - To what extent will humans be able to act „normally“ in their physical environment while also interacting with a virtual world?
Thank you!