Tracking and Registration in Augmented Reality

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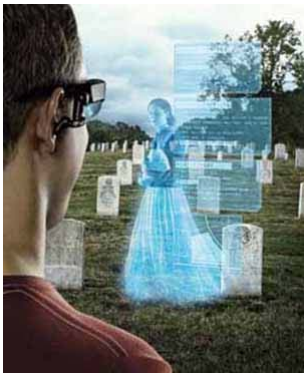
Outline

- What is an AR System
- Sensing modalities
- Scenarios
  - Indoor, controlled
  - Indoor, medical
  - Outdoor
- Registration errors
- Final thoughts
- References (partial)

What is an AR System

- A system that (Azuma et al., 2001)
  - Combines real and virtual objects in real environment
  - Runs interactively in real time
  - Registers (aligns) real and virtual objects with each other

AR display, courtesy Jannick Rolland



http://www.crystalinks.com/ar.html

Multiple Sensory modalities, merged together

- Real
  - Audio, visual, tactile, smell, temperature, temporal, etc.
- Virtual
  - Visual, visual, audio, tactile, temperature, etc.
  - Some more Visual

Visual

- Visual is the most important sense
- Visual capture(Welch, 1978)
  - Brain tends to believe what it sees
- Tracking, registration and other techniques for different AR scenarios
  - Indoor, controlled environment
  - Indoor, medical
  - Outdoor

Indoor, controlled environment

- Scenario:
  - Modification of environment
  - Rigid objects
  - Trade accuracy/speed for automatic control

Indoor, controlled environment

Tracking techniques:

- Those used in head-tracking (mechanical, electromagnetic, inertial, etc.)
- WiFi
- Marker tracking
- General template-based marker tracking
- Visual tracking

http://www.hitl.washington.edu/artoolkit/

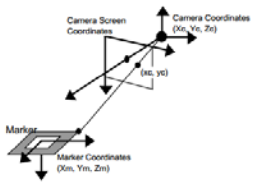
Indoor, controlled, environment

- Marker tracking:
  - Initially dots
  - 2D code
    - Detect lines, then quadrilateral, then read the marker
    - Object identification
    - Relationship between the marker and the camera
  - LED marker, etc.

Rekimoto, 1998

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = \begin{bmatrix} V_{11} & V_{12} & V_{13} & W_x \\ V_{21} & V_{22} & V_{23} & W_y \\ V_{31} & V_{32} & V_{33} & W_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_m \\ Y_m \\ Z_m \\ 1 \end{bmatrix}$$

H. Kato et al., 1999



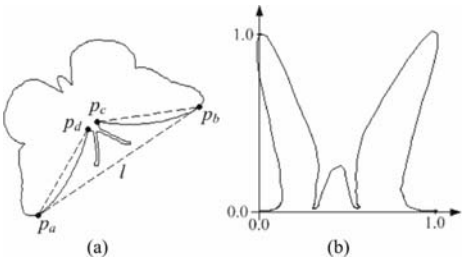
H. Kato et al., 1999

Marker toolkits

- ARToolkit, H. Kato et al. (UW, since 1999)
  - http://www.hitl.washington.edu/artoolkit/
- ARTag, M. Fiala et al. (Columbia, since 2004)
  - http://www.artag.net/
- Studierstube Tracker, D. Schmalstieg et al. (Graz, since 2007)
  - http://studierstube.icg.tugraz.at/handheld_ar/stbtracker.php
- Chillitags, Q. Bonnard et al. (EPFL, since 2013)
  - http://chili.epfl.ch/software

Indoor, controlled environment

- General template-based marker tracking
- Shapes are more natural (N. Hagbi et al., ISMAR 2009)
- Concavity invariance as feature



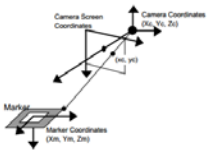
3 images from N. Hagbi et al., 2009

Indoor, controlled environment

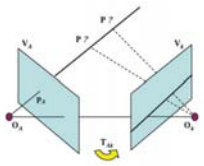
- Visual tracking
  - Detection + smoothing
  - Mean-shift, etc.

Indoor, controlled environment

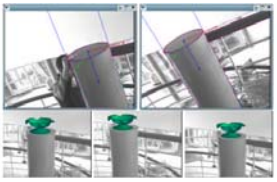
- Registration techniques:
  - Inertial sensor integral (accumulated error)
  - Solve projection matrix
  - Solve fundamental matrix (given reference frames)
  - Hybrid



H. Kato et al., 1999



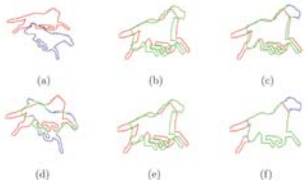
KW. Chia et al., 2002



A. Comport et al., 2003

Indoor, controlled environment

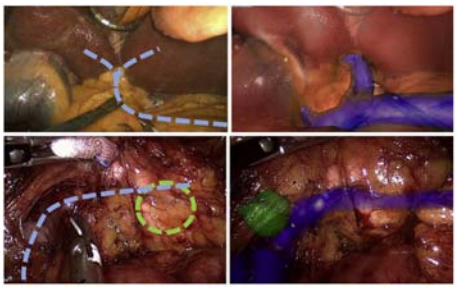
- Visual tracking, how to find feature correspondences
  - Feature descriptor + RANSAC
  - Iterative Closest Points
    - Find closest reference point for source point
    - Estimate transformation matrix
    - Map source points using the above matrix
    - Iterate
    - Point-to-point / point-to-plane



S. Du et al., **Robust iterative closest point algorithm for registration of point sets with outliers, 2011**

Indoor, medical

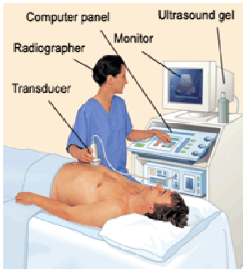
- Scenario:
  - Deformable objects (organs, skin, bones)
  - High intensity interaction (Inevitable obstruction)
  - Speed and accuracy requirement



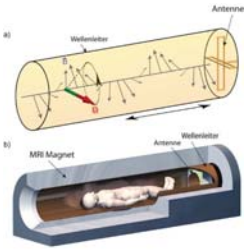
S. Nicolau et al., 2011

Indoor, medical

- Tracking techniques:
  - Ultrasonic probing
  - X-ray CT
  - Magnetic resonance imaging
  - Endoscope
  - Many other medical imaging



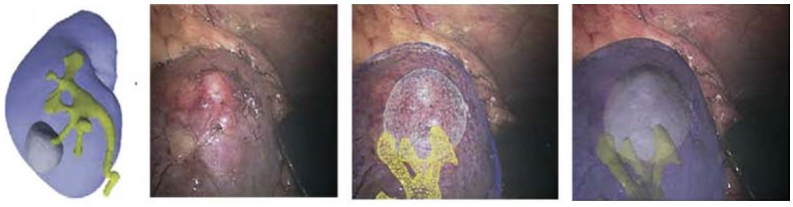
http://www.utswanesthesia.com/regional/?page_id=57



http://www.nature.com/nature/journal/v457/n7232/full/nature07752.html

Indoor, medical

- Registration techniques:
  - Interactive (manual) registration
  - Intra-operative imaging + structure extraction
  - Imposing pre-operative structure onto intra-operative information



S. Nicolau et al., 2011

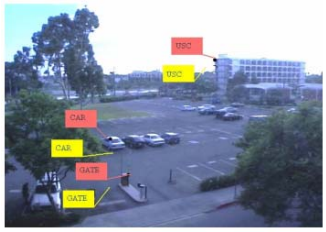
Outdoor

- Challenge:
  - Cannot instrument the environment
- Tracking techniques:
  - Magnetic (compass)
  - GPS/DGPS
  - Barometer
  - Cell phone station
  - Gyro/accelerometer/inclinometer
  - Vision tracking

Outdoor

- Registration techniques:
  - GPS + magnetometer + inclinometer
  - Inertial + vision
  - GPS + compass + video + reference frame

S. Feiner et al., 1997



S. You et al., 1999

V. Vlahakis et al., 2002

Outdoor

- Registration techniques:
  - GPS + magnetometer + inertial + vision + Kalman filter
  - Other combinations

Overview of tracking techniques

Technology	Range (m)	Setup (hour)	Resolution (mm)	Time (seconds) (in which useful tracking occurs, i.e., before drift)	Environment
Magnetic	1	1	1	∞	In/Out
Ultrasound	10	1	10	∞	In
Inertial	1	0	1	10	In/Out
Accelerometer	1000	0	100	1000	In/Out
UWB	100	10	500	∞	In
Optical: outside-in	10	10	10	∞	In
Optical: marker-based	10	0	10	∞	In/Out
Optical: markerless	50	0–1	10	∞	In/Out
Hybrid	10	10	1	∞	In
GPS	∞	0	1000	∞	Out
Wi-Fi	100	10	1000	∞	In/Out

Table 1. Comparison of tracking technologies (adapted from DiVerdi and Höllerer[58])

Registration errors

- Static
  - Optical distortion
  - Errors in tracking system
  - Mechanical misalignments
  - Incorrect viewing Parameters
- Dynamic
  - Lag
    - Make components faster
    - Delay video
    - Predict

http://www.ovt.com/applications/app_automotive.php

Partial references

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- R. Azuma et al., Recent Advances in Augmented Reality, 2001
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