SCALABLE OPTICAL TRACKING

A Practical Low-cost Solution for Large Virtual Environments

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Goal

- Navigating through a large virtual environment as if it was real
- User tracking is required
- Scalable in both size and number of users

Movement controls:

W: forward  Q: lean left
S: backward  E: lean right
A: left      P: prone
D: right     C: crouch
<: look left  Alt: sprint
>: look right Space: jump
^: look up
V: look down

America’s Army
Limited Range

- Most tracking systems today have a limited range

**Optical (OptiTrack)**

**Magnetic (Nest of Birds)**

**Mechanical (NASA)**
Locomotion

Circulafloor

VirtuSphere

CyberWalk
Redirected Walking

- Fool senses
- Larger VE
- Walking in circles with radius 23m
Related Work

HiBall (UNC CH)
VisTracker (Intersense IS-1200)
HIVE (Miami University)
HiBall (UNC CH)
Our System

- LED ropes arranged in a grid structure
- Parallel X- and Y-lines
- Head-mounted camera facing up
Camera Input

• Why LED ropes?
  - Cheap
  - Easy to place
  - Emit light
    • Easy detection
    • Low camera shutter
    • Less motion blur
    • High update rate
  - Only point lights
    • Faster undistorting
    • Faster line detection
    • Faster processing

• We consider intrinsic and distortion parameters known
  - Calibrated with the ‘GML Toolbox’
System Overview

- **Camera Image**
  - Detection of LED ropes
    - Orientation from Vanishing Points
    - Position with Known Orientation
  - 6 DOF camera pose
Detection of LED ropes

• Detect markers
  – Cluster pixels
    • Average position
    • Subpixel precision
  – Speeds up line detector

• Find line patterns
  – Hough Transform
Line Detection
Hough transform

Slope-intercept
- Lines
- Not stable with big slopes
- Easy analytical intersection

Normal
- Sinusoid
- Can represent all lines
- Difficult analytical intersection

Our parameterization
- Circles
- Can represent all lines
- Easy analytical intersection
Line Detection
Hough transform
• “Using vanishing points for camera calibration” [Caprile ‘90]

• Vanishing point of the line patterns correspond to the direction of the parallel lines

• Rotation can be estimated from 2 ‘vp – direction’ correspondences (e.g. X- and Y-axis on the ceiling)

\[
\lambda_i \begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} = K[R|T] \begin{bmatrix} x_{D,i} \\ y_{D,i} \\ z_{D,i} \end{bmatrix} \quad \lambda_i = \pm \frac{1}{|K^{-1}V_i|}
\]
• Undo known rotation on the LED points
  – Regular grid on plane parallel to camera plane

• Distance to ceiling estimated by known line interdistance

\[ \gamma \vec{D} = \beta \vec{D}_2 - \alpha \vec{D}_1 \]

• Translation in X and Y direction relative to previous frame
Results

- Virtual Set-up (8 x 10 x 2.5 meters)

*user viewpoint*  *camera viewpoint*
Results

- Comparison with the ground truth
- Accuracy (RMS error)
  - Orientation
    - 0.02° in Yaw
    - 0.035° in Pitch and Roll
  - Position
    - 4 millimeter
Results

- Lab Set-up (4 x 3 x 2.5 meters)

- Point Grey Flea Camera
  - 1024x768 at 30 fps
  - 1 ms shutter

- Standard laptop
  - 2 GHz CPU, 1 GB RAM

- 11 ms processing time
  - 9.5 ms for LED segmentation
Results

• Comparison with average of 2000 frames in a stationary pose

• Accuracy (RMS error)
  – Orientation
    • 0.16° in Yaw
    • 0.23° in Pitch and Roll
  – Position
    • 5 millimeter in X,Y
    • 8 millimeter in Z
Discussion

- Limit on speed
  - 7,5 m/s or 27 km/h
  - 2700°/s or 7,5 turns/s
  - not humanly possible
- No drift, but also no global pose
  - Global start beacon(s)
- No tracking if ceiling is not visible
  - Combining with inertial tracker
Future Work

- Mono-color infra-red LEDs
  - Lower camera bandwidth / higher fps
  - Faster computation
- Encoding position in LED strip
- Auto compensate for errors in LED placement
- Possible to expand this to ‘natural’ grid patterns, like tiles, ceiling panels, ...
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