Online Environment Reconstruction from Multiple 2D Views and Range Data

Philipp Michel <pmichel@cs.cmu.edu>

Digital Human Research Center

The Robotics Institute, Carnegie Mellon

Motivation / Prior Work

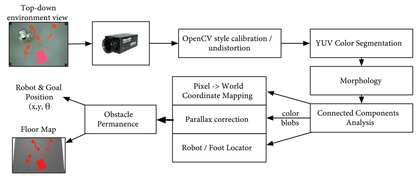
Vision-guided Footstep Planning

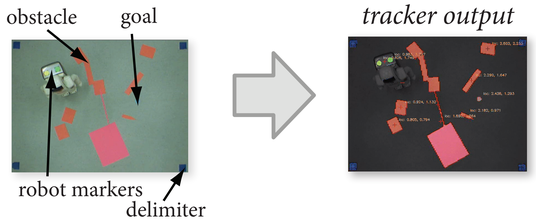
At Carnegie Mellon, we have used computer vision techniques to locate and track obstacles moving dynamically in a biped humanoid robot's vicinity during a walking sequence.

Together with a footstep planner capable of efficient dynamic re-planning, we have enabled a Honda ASIMO robot to navigate autonomously and safely through changing, obstacle-filled environments in real-time.

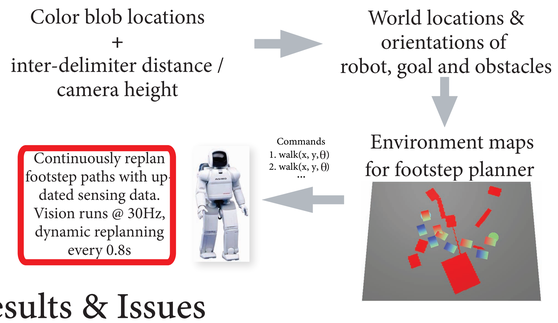
Vision processing for ASIMO

- Ceiling-based vision
- Segment colored markers in YUV (fast!)



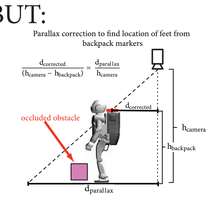


Reconstructing the Environment



Results & Issues

- ASIMO successfully navigates dynamically changing environment
- Ceiling vision localizes globally, BUT:
  - is affected by parallax
  - robot can occlude obstacles
  - not 'realistic'



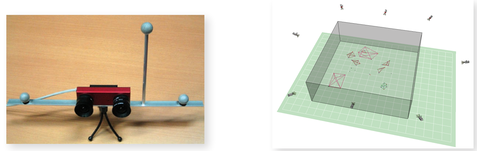
Research at DHRC

- Local, on-body (HRP2) environment reconstruction using:
  - Multiple 2D views of a calibrated camera
  - Range data from Swissranger SR2 TOF sensor

Reconstruction from multiple 2D views

Hardware

- SVS stereo camera on motion capture frame
- Motion Analysis motion capture system



Recovered 3D position & orientation of camera

Recovering projection matrix

$$M = \overset{3x3}{K}\left[\overset{3x3}{R} \quad \overset{3x1}{t}\right]$$

from camera calibration

from motion capture

Reconstructing virtual top-down view

- Points **p** = (u1, v1, 1) in image related to points **q** = (u2, v2, 1) on floor by 3x3 *ground-image homography* **H**
- **Assumption:** planar obstacles
- Makes ground plane recovery possible

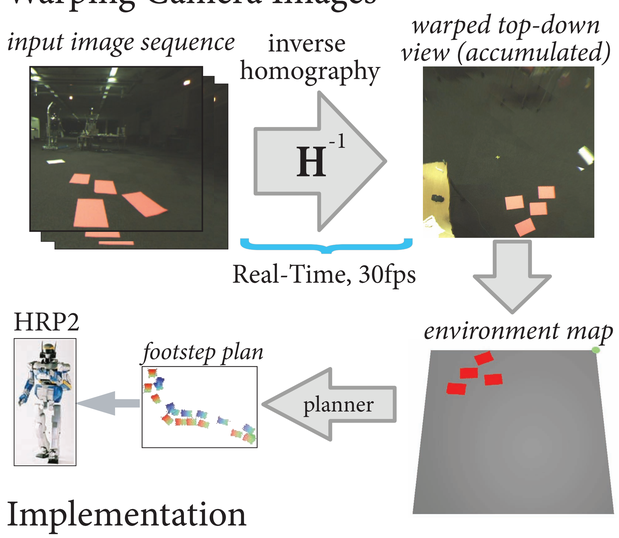
$$\mathbf{p} \equiv \mathbf{H}\,\mathbf{q}$$

3x3 homography

Planar Scene! z = 0

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} & \cancel{m_{13}} & m_{14} \\ m_{21} & m_{22} & \cancel{m_{23}} & m_{24} \\ m_{31} & m_{32} & \cancel{m_{33}} & m_{34} \end{bmatrix}$$

Warping Camera Images



Implementation

- Uses HRP2's head-mounted cameras
- Works like a "flashlight", gathering environment information as the robot looks around while walking

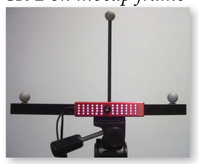
Calibrating the Swissranger SR-2 Sensor

Hardware

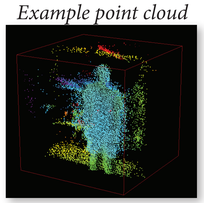
Problem: NOT CALIBRATED

- 124x160 CMOS CCD
- Emits (near-) infrared light
- Time of flight (TOF) of emitted light measured at each pixel
- Range: 0 - 7.5m
- Accuracy: a few cm down to sub-cm
- USB 2.0 interface

SR-2 on mocap frame

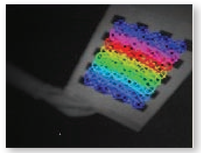


Example point cloud



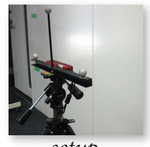
Calibration: Intrinsics / Lens Distortion

- OpenCV / Zhang-style checkerboard calibration (online implementation)
- Works even with SR-2's low resolution
- Once calibrated, images can be rectified

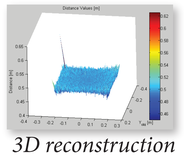


Calibration: Distance Offset

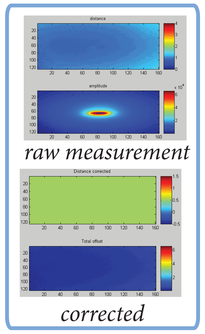
- Raw distance readings from camera don't reflect true distance
- Each reading must be corrected with a separate distance offset
- Offsets computed from measured range data of plane at known distance from SR2



setup



3D reconstruction of wall surface



raw measurement

corrected

Reconstruction using the Swissranger

Reconstructing 3D World Coordinates

- Motion capture yields location & orientation of Swissranger as 4x4 transformation matrix **T**
- Calibrated Swissranger gives (x, y, z) in camera coordinates
- Reconstruct world coordinates of measured points by:

$$\underbrace{\begin{bmatrix} x_w \\ y_w \\ z_w \\ w \end{bmatrix}}_{world} = \mathbf{T}^{-1} \underbrace{\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix}}_{camera}$$

Implementation on a Humanoid Robot

- Mount Swissranger on HRP2's torso or hand
- Use 3D data for detection / avoidance of non-planar obstacles while walking
- Possibly use computed height data for stair climbing
- **Advantage** over stereo: does not require texture, better data at object discontinuities
- **Disadvantage:** Sensitive to environment conditions, noisy data towards edges of sensor