TDDC17
Robotics/Perception I

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To start with...

Monty the robot

Outline

- Introduction
- Camera model & Image formation
- Stereo-vision
  - Example for UAV obstacle avoidance
- Optic flow
- Vision-based pose estimation
  - Example for indoor UAVs
- Object recognition
  - Example for outdoor UAVs
- Kinect: Structured Light
- (Laser Range Finder)

Definition of a Robot

The **word** first appeared in the play RUR published in 1920 by Karel Capek - "robota" meaning "labor"

A **robot** is a mechanical device which performs automated physical tasks

The task can be carried out according to:
- Direct human supervision (teleoperation)
- Pre-defined program (industrial robots)
- Set of general higher-level goals (using AI techniques)

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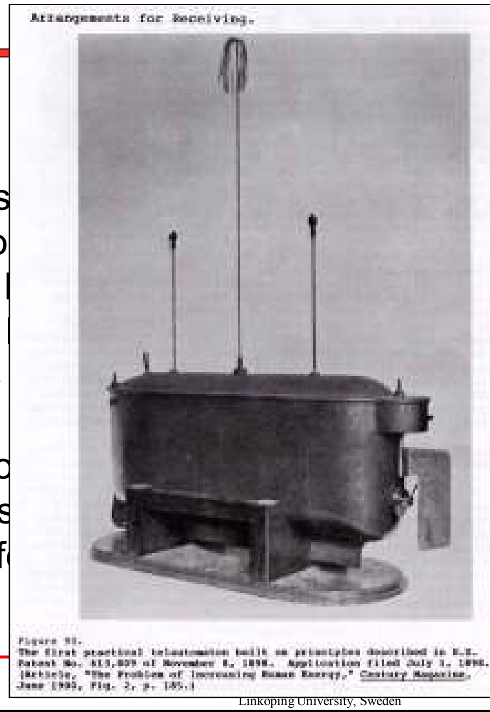

Shakey

Shakey was one of the first autonomous mobile robots, built at the SRI AI Center during 1966-1972. Many techniques present in Shakey's system are still under research today!

Video

http://www.sri.com/about/timeline/shakey.html

Why we use robots

The DDD rule:

Dangerous, Dirty, and Dull (or FUN - art)

Some usage areas:

- Industry
- Search and Rescue
- Space Exploration
- Military
- Research
- Entertainment
- ....

Why is (AI) robotics hard?

- Real-life robots have to operate in unknown dynamic environments
- It is a multi-disciplinary domain - from mechanics to philosophy...
- It involves many practical problems:
  - it is very technical,
  - it takes a long time from an idea to a built system,
  - debugging can be difficult,
  - expensive.

Anatomy of Robots

Robots consist of:

- Motion mechanism
  - Wheels, belts, legs, propellers
- Manipulators
  - Arms, grippers
- Sensors
- Computer systems
  - Microcontrollers, embedded computers

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Perception

In order for the robots to act in the environment a suite of sensors is necessary.

Two types of sensors:

- Active
  - Emit energy (sound/light) and measure how much of it comes back or/and with how large delay.
- Passive
  - Just observers, measuring energy "emitted" by the environment.

Proprioceptive Sensors

Inform robot about its internal state.

- Shaft encoders
  - Odometry (measurement of traveled distance)
  - Positions of arm joints
- Inertial sensors
  - Gyroscope (attitude angles: speed of rotation)
  - Accelerometers
- Magnetic
  - Compass
- Force sensors
  - Torque measurement (how hard is the grip, how heavy is the object)

Position Sensors

Measure placement of the the robot in its environment.

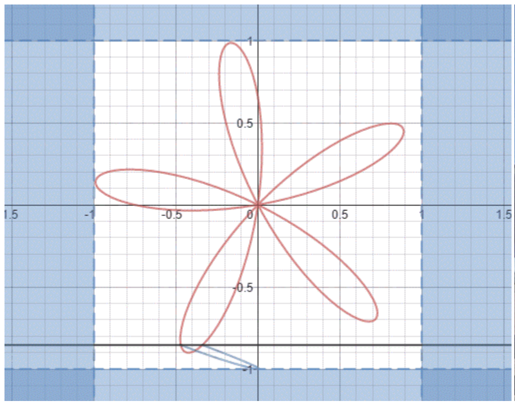
- Tactile sensors (whiskers, bumpers, etc.)
- Sonar (ultrasonic transducer)
- Laser range finder
- Radar
- (D)-GPS

Imaging Sensors (Cameras)

Deliver images which can be used by computer vision algorithms to sense different types of stimuli.

- Output data
  - Color
  - Black-White
  - (Thermal)
- Configuration
  - Monocular
  - Stereo
  - Omnidirectional
  - Stereo-omnidirectional
- Type of sensor (exposure)
  - CCD
  - CMOS

CMOS problem



Source: http://petapixel.com/2015/11/14/this-is-how-cameras-glitch-with-photos-of-propellers/

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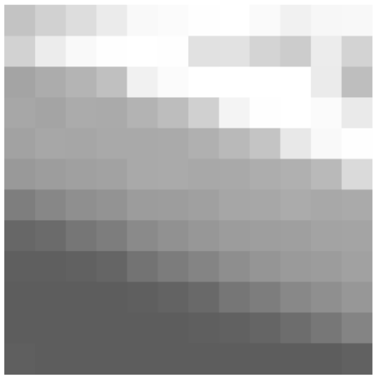
Image composition



195	209	221	235	249	251	254	255	250	241	247	248
210	236	249	254	255	254	225	226	212	204	236	211
164	172	180	192	241	251	255	255	255	255	235	190
167	164	171	170	179	189	208	244	254	255	251	234
162	167	166	169	169	170	176	185	196	232	249	254
153	157	160	162	169	170	168	169	171	176	185	218
126	135	143	147	156	157	160	166	167	171	168	170
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I(x, y, t) is the intensity at (x, y) at time t

CCD camera 1,000,000 pixels; human eyes 240,000,000 pixels i.e., 0.25 terabits/sec

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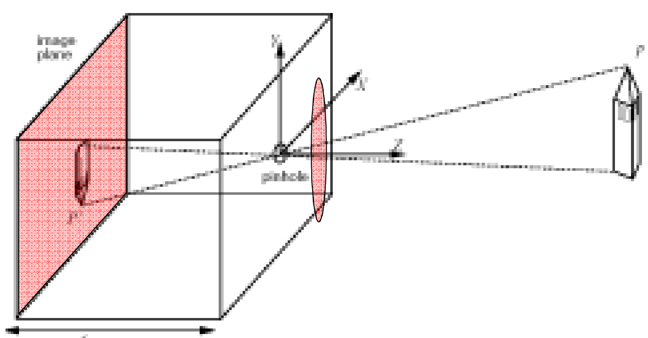
Pinhole Camera Model



P is a point in the scene, with coordinates (X, Y, Z)
P′ is its image on the image plane, with coordinates (x, y)

$x = fX/Z$, $y = fY/Z$ - perspective projection by similar triangles.

Scale/distance is indeterminate!

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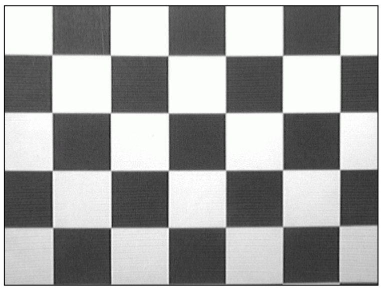
Lens Distortion

Happens when light passes a lens on its way to the CCD element.




Lens distortion is especially visible for wide angle lenses and close to edges of the image.

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Omnidirectional Lens


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Camera Calibration

Estimate:

- camera constant f,
- image principle point (optical axis intersects image plane),
- lens distortion coefficients,
- pixel size,

from different views of a calibration object

Lens Distortion 2

Why is computer vision hard

- Noise and lighting variations are disturbing images significantly.
- Difficult color perception.
- In pattern recognition - objects changing appearance depending on their pose (occlusions).
- Image understanding involves cognitive capabilities (i.e. AI).
- Real-time requirements + huge amount of data.
- ...

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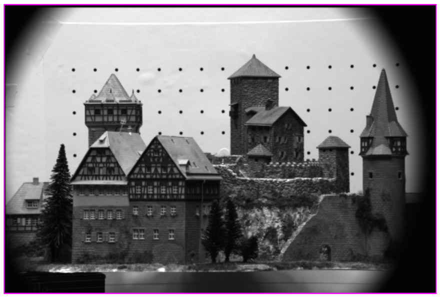
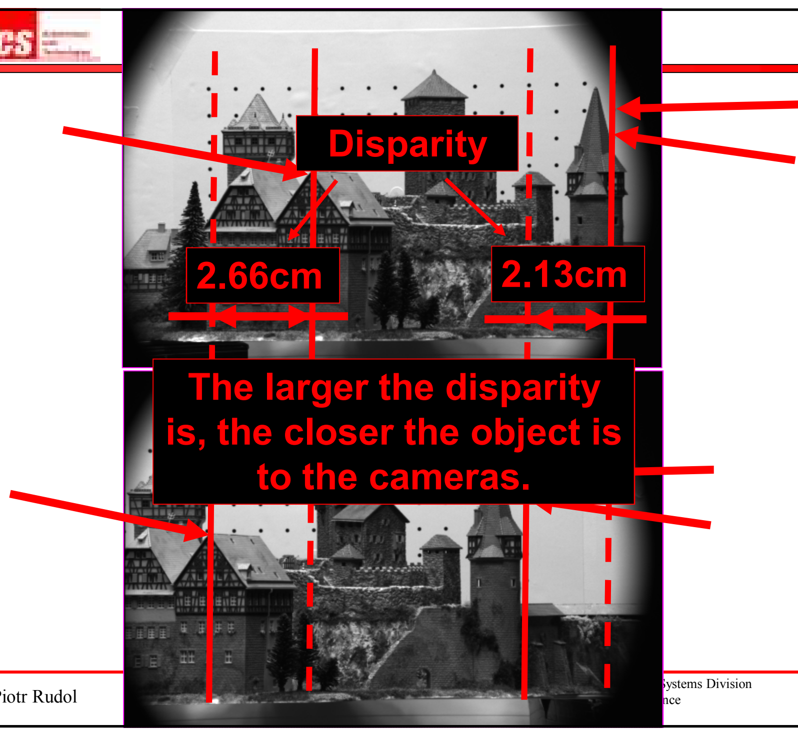
Stereo vision

A scene is photographed by two cameras

- What do we gain?



CMU CIL Stereo Dataset: Castle sequence
http://www-2.cs.cmu.edu/afs/cs/project/cil/ftp/html/cil-ster.html



Stereo processing

To determine depth from stereo disparity:

1) Extract the "features" from the left and right images
2) For each feature in the left image, find the corresponding feature in the right image.
3) Measure the disparity between the two images of the feature.
4) Use the disparity to compute the 3D location of the feature.

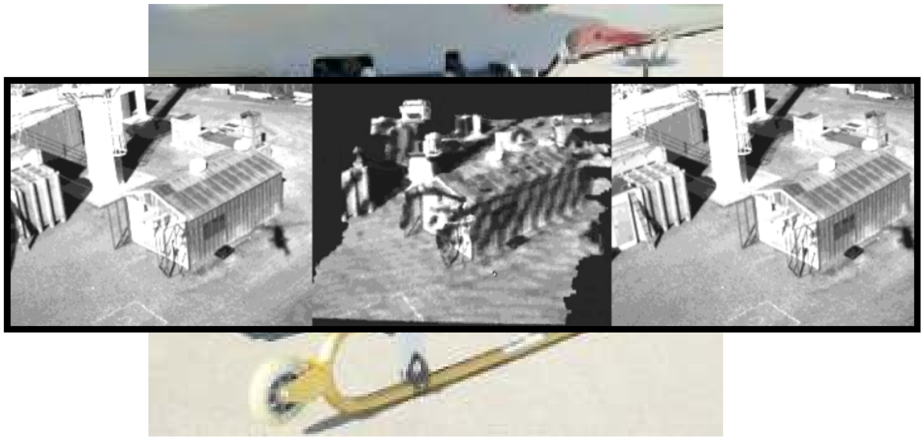
Stereo Example I

Real-time people tracking.

Video1

http://labvisione.deis.unibo.it/%7Esmattoccia/stereo.htm#3D_Tracking

Stereo Vision for UAVs



Stereo pair of 1m baseline – cross-shaft for stiffness

Stereo Vision for UAVs at LiU

DEMO

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Optic Flow

Optical flow methods try to calculate the motion between two image frames which are taken at times t and $t + \delta t$ at every pixel position.

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Optic Flow

http://people.csail.mit.edu/lpk/mars/temizer_2001/Optical_Flow/

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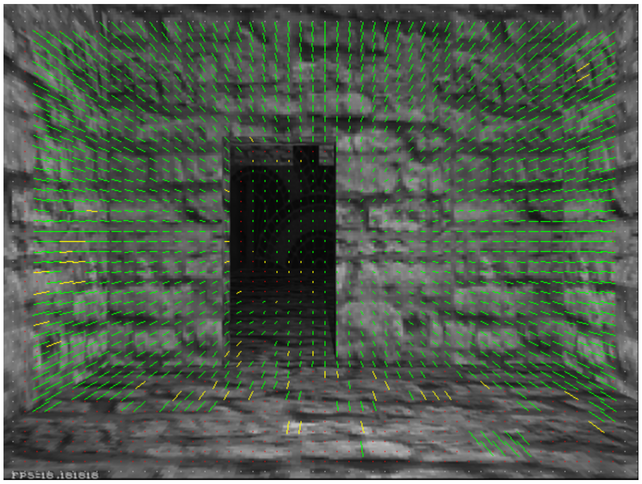
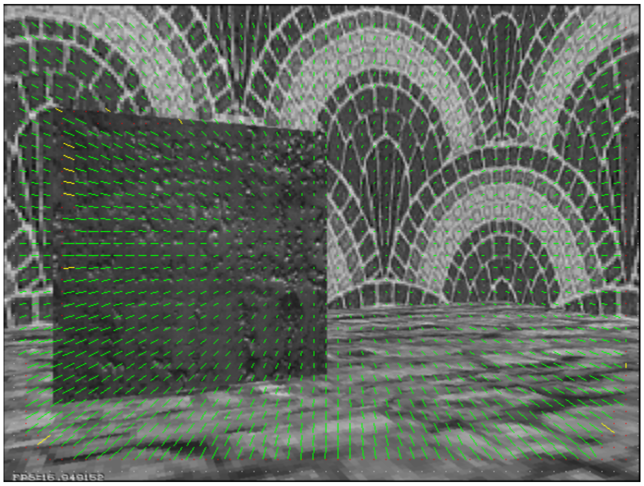
Optic Flow



http://people.csail.mit.edu/lpk/mars/temizer_2001/Optical_Flow/

Optic Flow Navigation Obstacle Avoidance



Optic Flow Indoor Navigation

Video I Video II

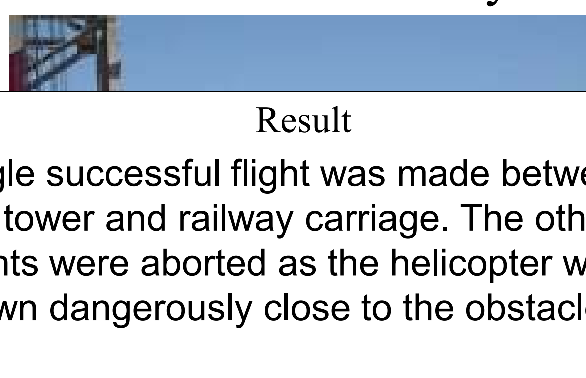
Obstacle Avoidance Example

Combined Optic-Flow and Stereo-Based Navigation of Urban Canyons for a UAV [Hrabar05]

- Optic flow-based technique tested on USC autonomous helicopter Avatar to navigate in urban canyons.

USC Avatar in Urban Canyon

USC Avatar in Urban Canyon cont'd

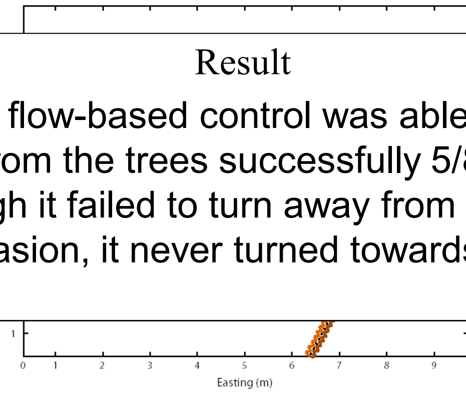


Result

A single successful flight was made between the tower and railway carriage. The other flights were aborted as the helicopter was blown dangerously close to the obstacles.

Urban Search and Rescue training site. The helicopter was flown between a tall tower and a railway carriage to see if it could navigate this 'canyon' by balancing the flows.

USC Avatar in Urban Canyon cont’d



Result

The optic flow-based control was able to turn it away from the trees successfully 5/8 times. Although it failed to turn away from the trees on occasion, it never turned towards the trees.

Open field lined by tall trees on one side. The helicopter was set off on a path parallel to the row of trees at the first site to see if the resultant flow would turn it away from the trees.

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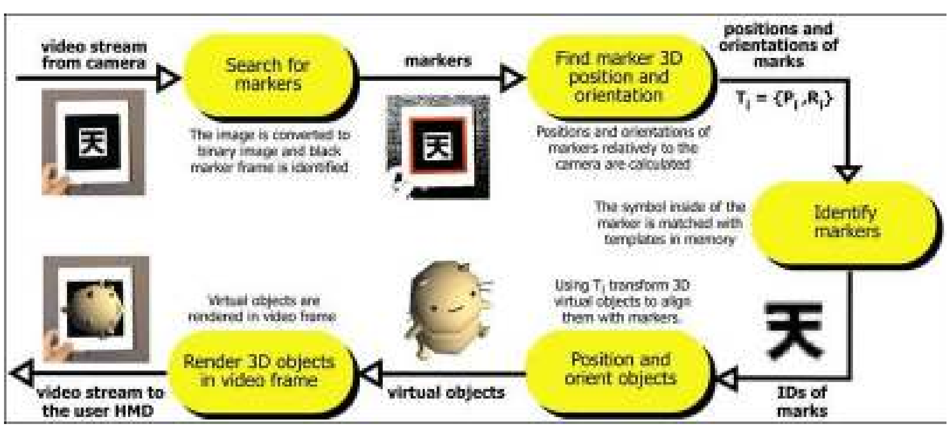
Pose Estimation

It is not always possible to directly measure robots pose in an environment (e.g. no GPS indoor). For a robot to navigate in a reasonable way some sort of position and attitude information is necessary. This is the goal of pose estimation algorithms.

Example of ARToolkit (Hirokazu Kato *et.al.*)

- ARToolKit (Plus) video tracking libraries calculate the real camera position and orientation relative to physical markers in real time.

ARToolkit



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Teapot

Cube

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Pose Estimation for Indoor Flying Robots

Motivation:

- Indoor-flying robots cannot use GPS signal to measure their position in the environment.
- For controlling a flying robot fast update of readings is required.
- The operation range should be as big as possible in order to be able to fly – not just hover.
- Micro-scale robots have very little computation power on board.

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LinkMAV

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Ground Robot

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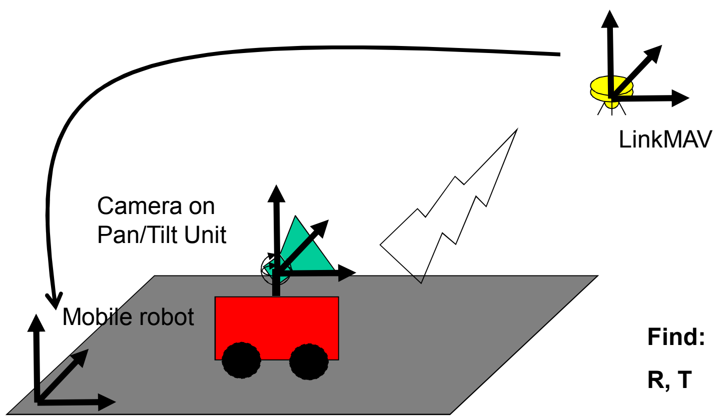
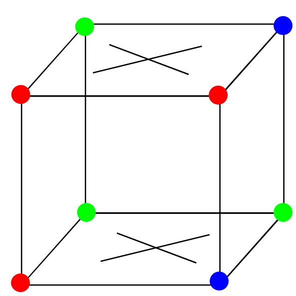
Solution



The pattern

The cube-shaped structure consists of four faces - only one required for pose estimation

There is a high-intensity LED in each corner; three colors (RGB) code uniquely four patterns. During the flight at least one (at most two) face is visible for the ground robot



The pattern cont'd

Cube made of carbon fiber rods

16 LEDs

Total weight: 60g

SuperFlux LEDs

90deg viewing angle

7.62x7.62mm

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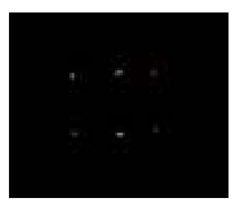
Image processing

Video camera operates with closed shutter for easy and fast diode identification

Video

Four identified diodes from one face of the cube go through the "Robust Pose Estimation from a Planar Target" [Schweighofer05] algorithm to extract the pose of the face



Knowing which face is visible and the angles of the PTU unit, the complete pose of the UAV relative to the ground robot can be calculated

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Control

Four PID loops are used to control lateral displacement, yaw and altitude of the UAV

Control signal (desired attitude + altitude) is sent up to the UAV to be used in the inner loop onboard

Pan-Tilt unit of the camera mounted on the ground robot is controlled by a simple P controller, which tries to keep the diodes in the center of an image

Video

Video1 Video2

On-board processing

Video 3 Video 4

Vision-based landing

Video 5

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Object recognition

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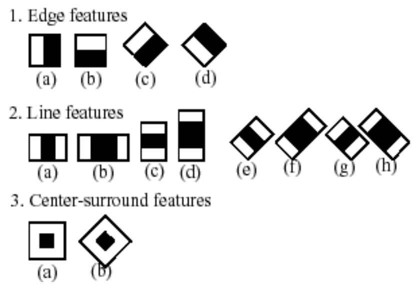
Object recognition

Cascade of boosted classifiers working with Haar-like features



Paul Viola and Michael J. Jones. Rapid Object Detection using a Boosted Cascade of Simple Features. IEEE CVPR, 2001.

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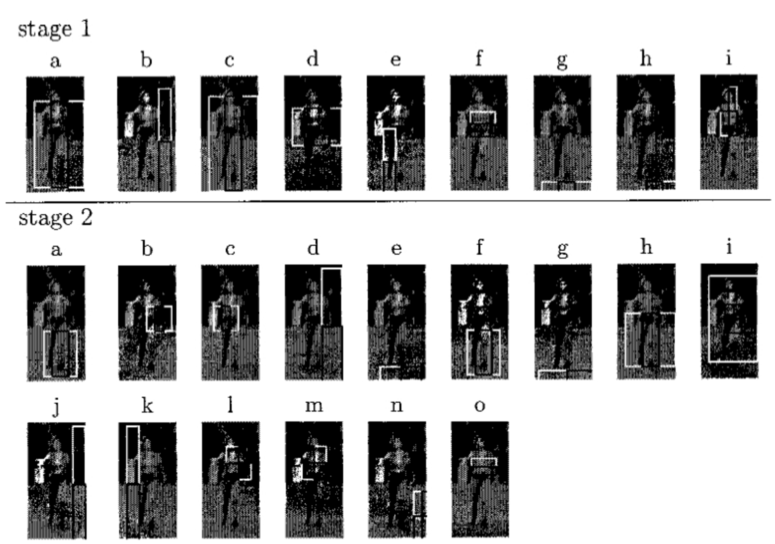
Object recognition– Human bodies



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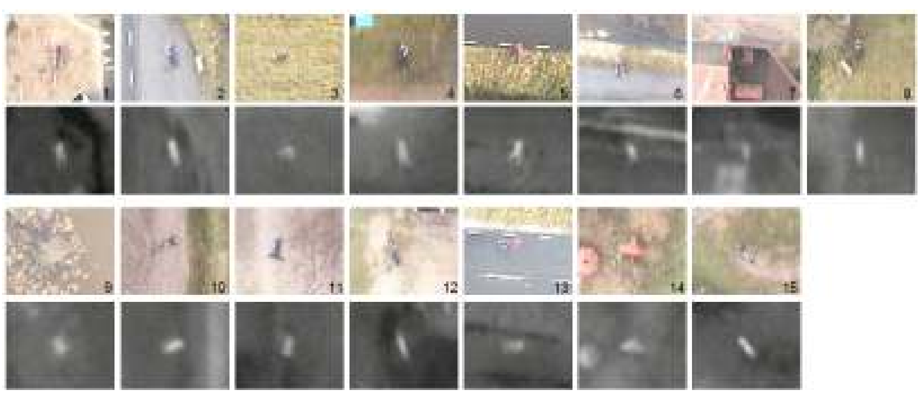
Human body detection with UAVs

Video1 Video2

Object detection – Human bodies

Results



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Object detection – Human bodies

Results

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Kinect

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Kinect

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Structured Light

http://mesh.brown.edu/3DPGP-2009/homework/hw2/hw2.html

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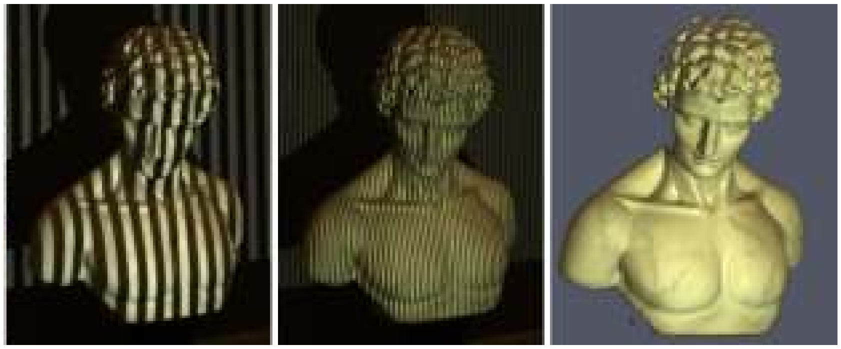
Structured Light



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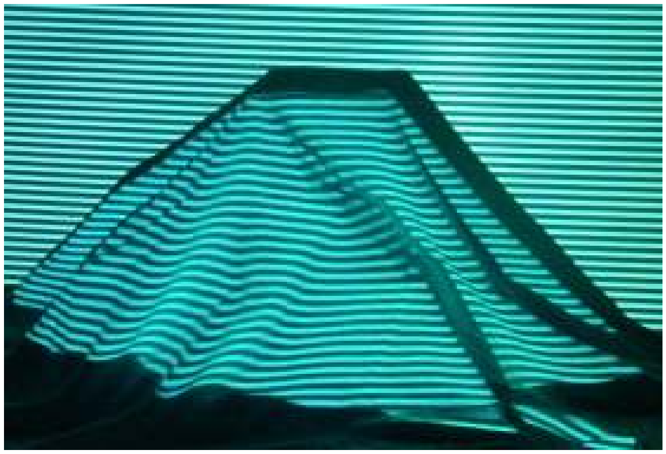

http://automodellingandvideomapping.blogspot.com/2010/05/structured-light-continuity-vs.html

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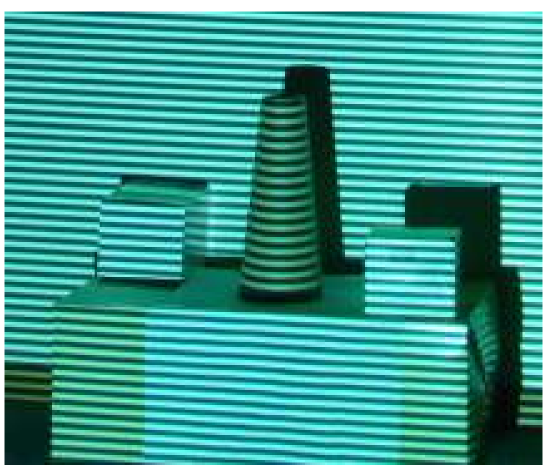
Structured Light



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10.4LTS, /home/pioru/kinect/OpenKinect-libfreenect-dbfd4ce/build/bin/glpclview

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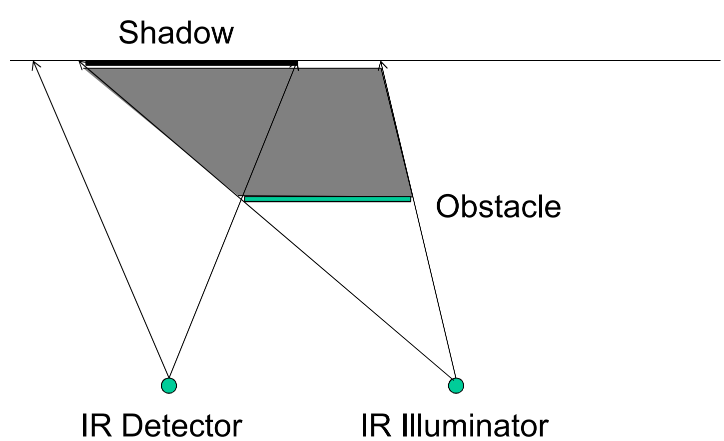
Shadows



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Kinect and UAVs

Video

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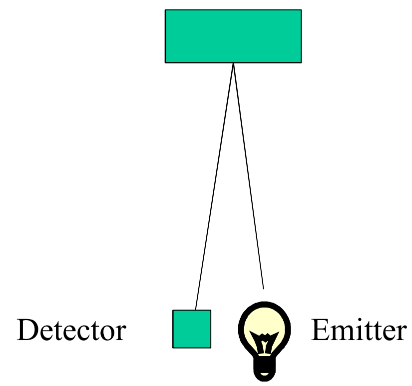
Laser Range Finder – 1D



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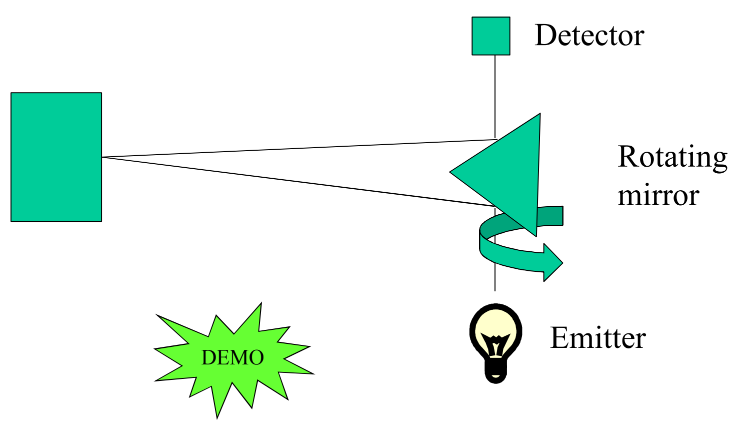
Laser Range Finder - Sweeping



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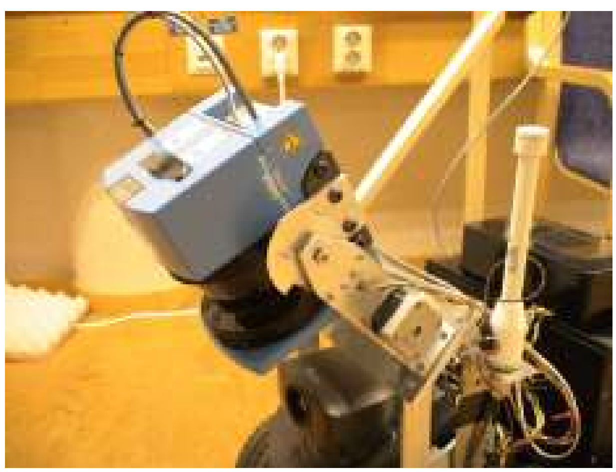
3D Laser On a UAV

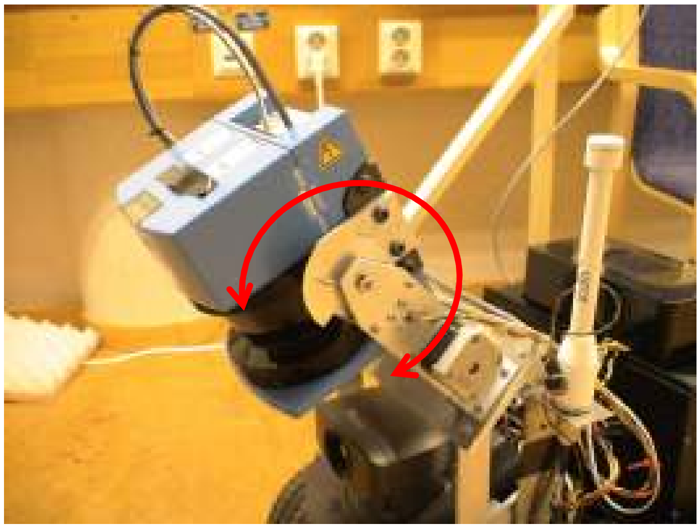
3D Laser Scaner can be mounted on a UAV to map the environment as the UAV flies.

Video

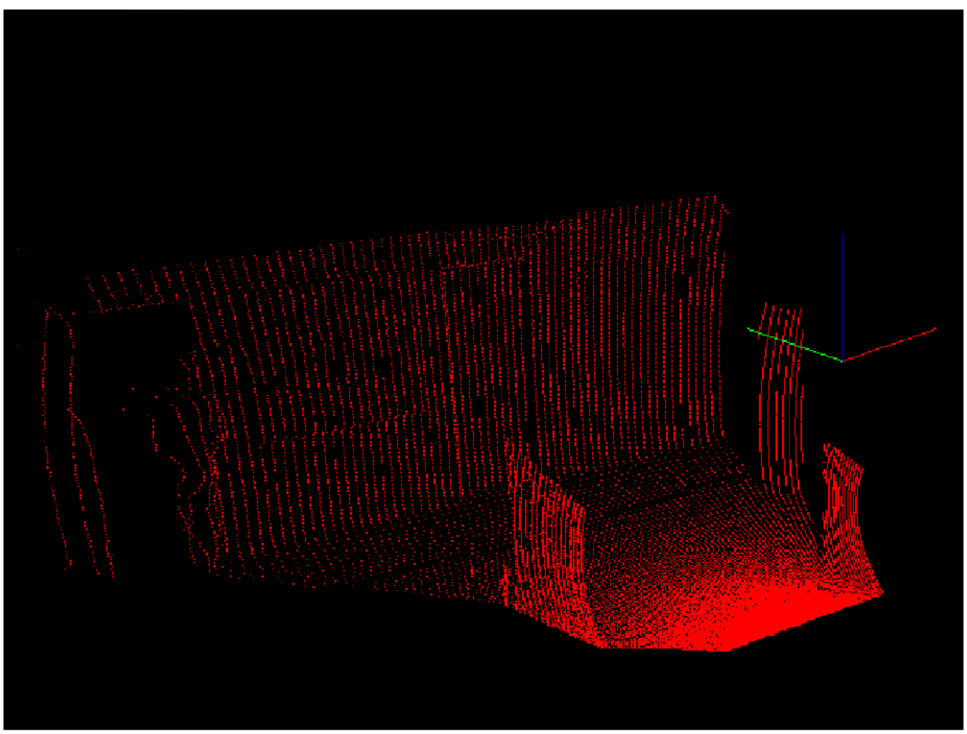
Laser Range Finder

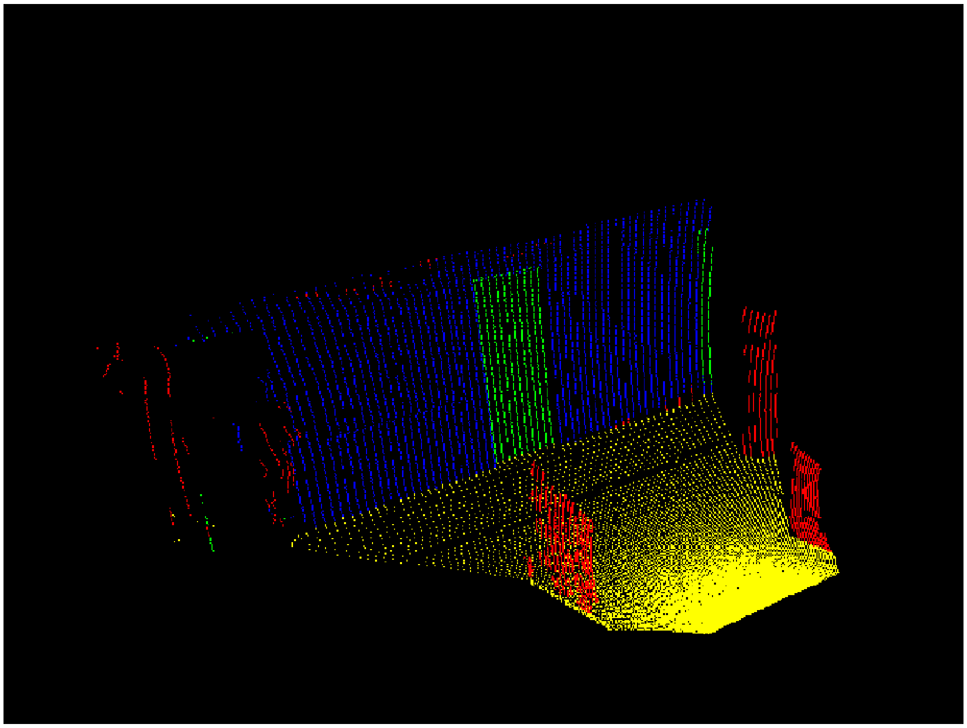


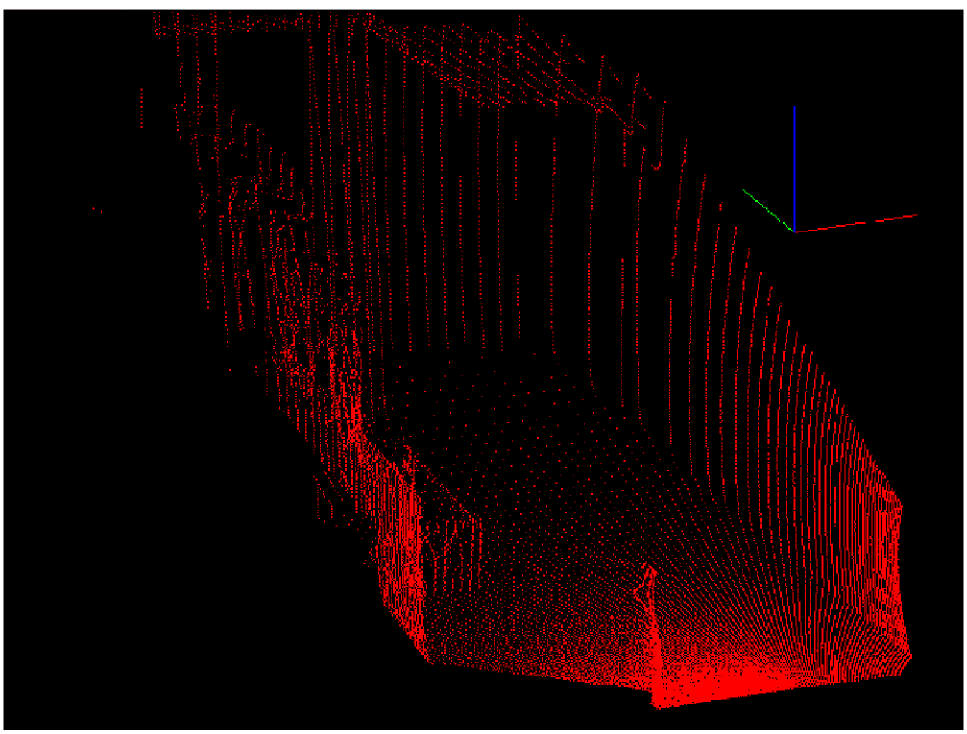
The principle

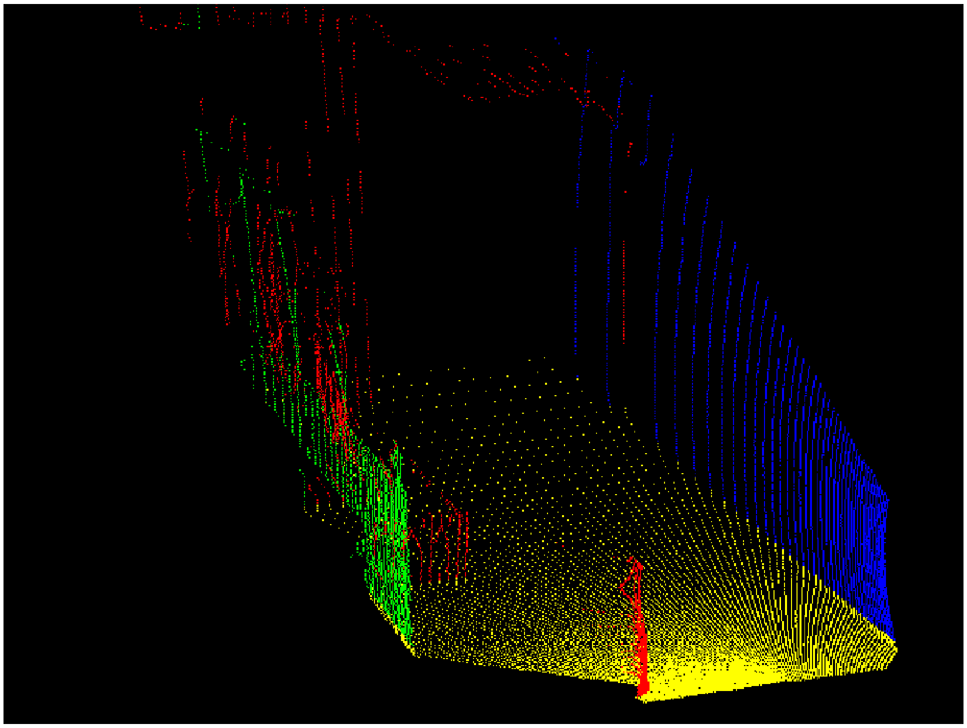


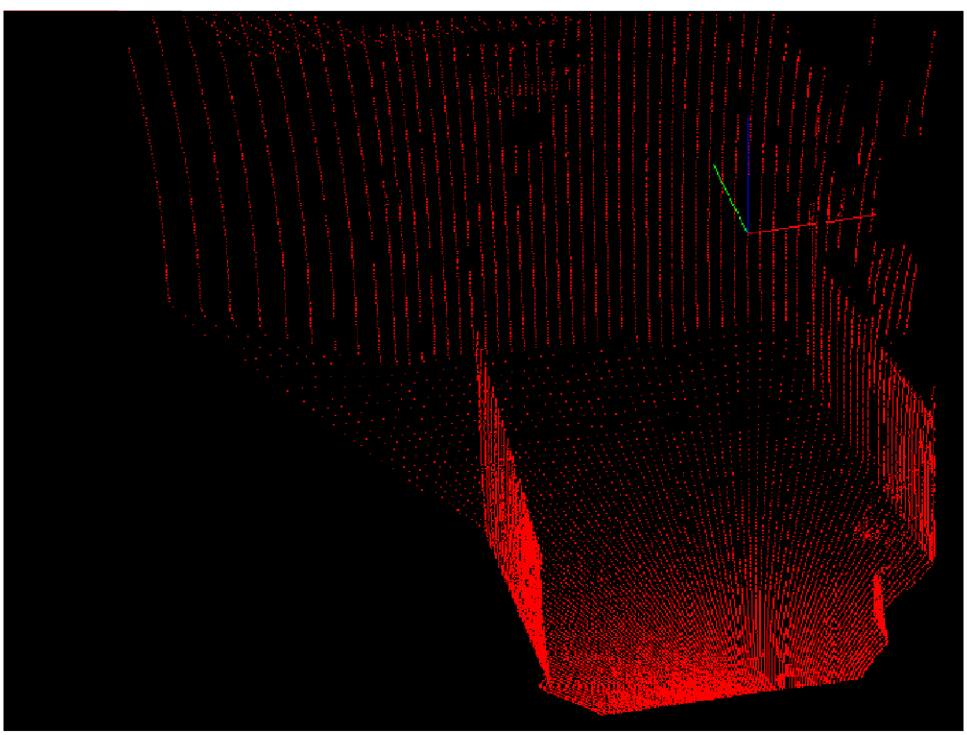
Video

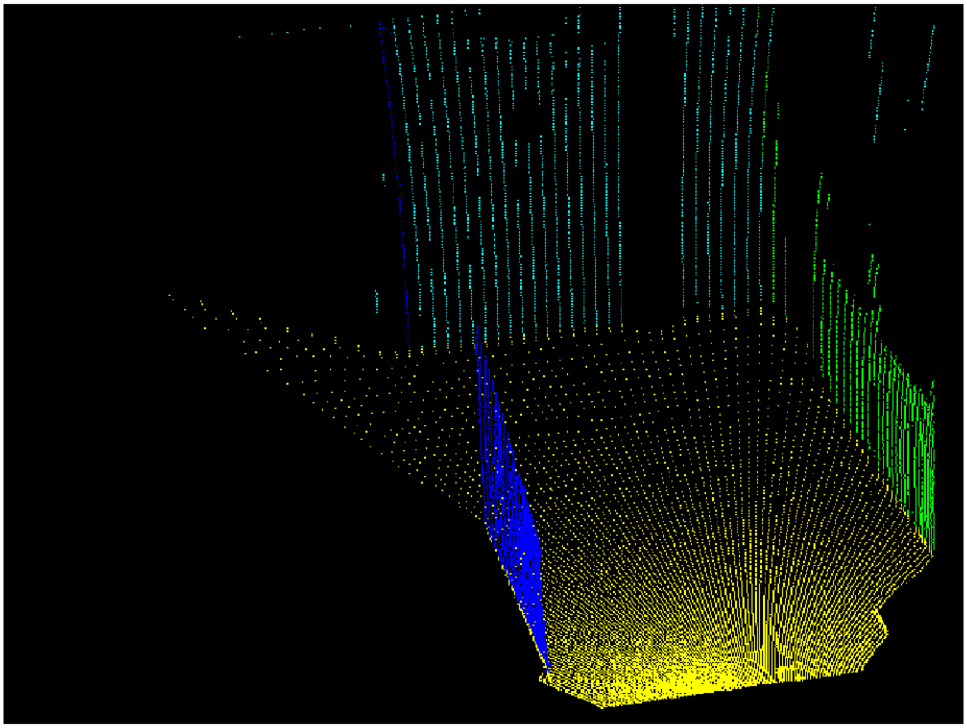












3D Laser Scanner On a UAV at LiU

Video

3D Laser Scanner On a UAV at LiU

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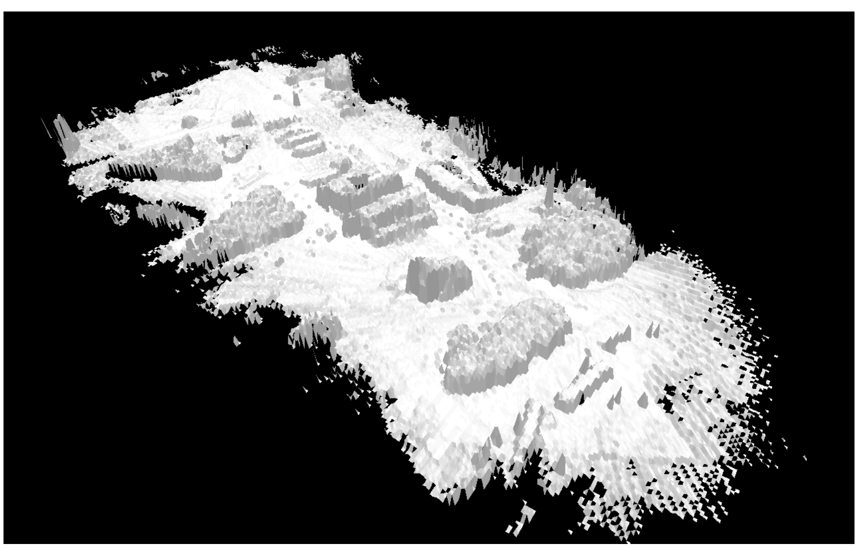

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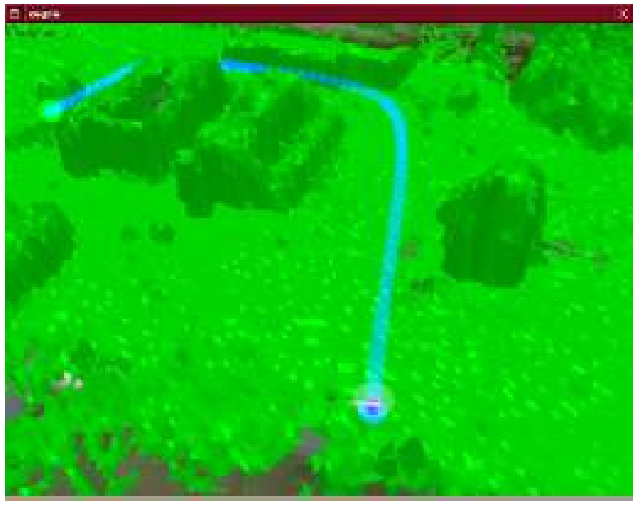

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3D Laser Scanner On a UAV

Scanning Result

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Summary

- Camera model & Image formation
- Stereo-vision
- Optic flow
- Vision-based pose estimation
- Object recognition
- Kinect: Structured Light
- (Laser Range Finder)
- Next lecture: Localization, planning, hardware...

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Questions?

Exjobb Opportunities

We are always looking for bright students who want to do their Exjobbs at AIICS.

If you are interested in any topics you've heard today, let us know!

Links

- **ARToolkit**:

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

- **OpenCV (Open Computer Vision):**

http://opencv.org

- **OpenKinect**:

http://openkinect.org/wiki/Main_Page

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