TDDC17
Robotics/Perception I

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IDA/AIICS

Outline

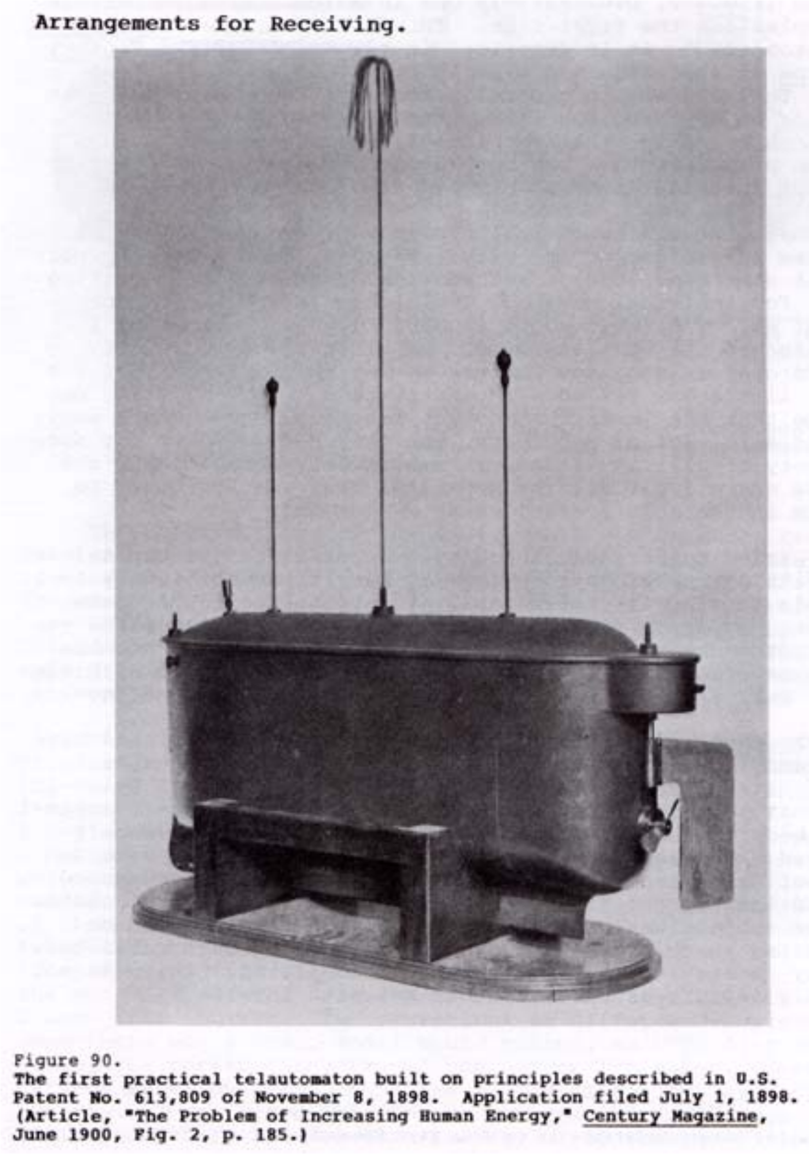
- Introduction
- Camera model & Image formation
- Stereo-vision
  - Example for UAV obstacle avoidance
- Optic flow
- Vision-based pose estimation
  - Example for indoor UAVs
- Object recognition
  - Example for outdoor UAVs
- Kinect: Structured Light
- Laser Range Finder

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)

Definition of a Robot

Many consider the first robot in the modern sense to be a teleoperated boat, similar to a modern ROV (Remotely Operated Vehicle), devised by Nikola Tesla and demonstrated at an 1898 exhibition in Madison Square Garden. Based on his patent 613,809 for "teleautomation", Tesla hoped to develop the "wireless torpedo" into an automated weapon system for the US Navy.



Arrangements for Receiving.

Figure 90.
The first practical telautomaton built on principles described in U.S. Patent No. 613,809 of November 8, 1898. Application filed July 1, 1898. (Article, "The Problem of Increasing Human Energy," Century Magazine, June 1900, Fig. 2, p. 185.)

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!

http://www.ai.sri.com/shakey

Why do we use robots?

- The DDD rule:
    - Dangerous, Dirty, and Dull
- Some usage areas:
    - Industrial
    - Military
    - Search and Rescue
    - Space Exploration
    - Research
    - Entertainment
    - ....

Why is (AI) robotics hard?

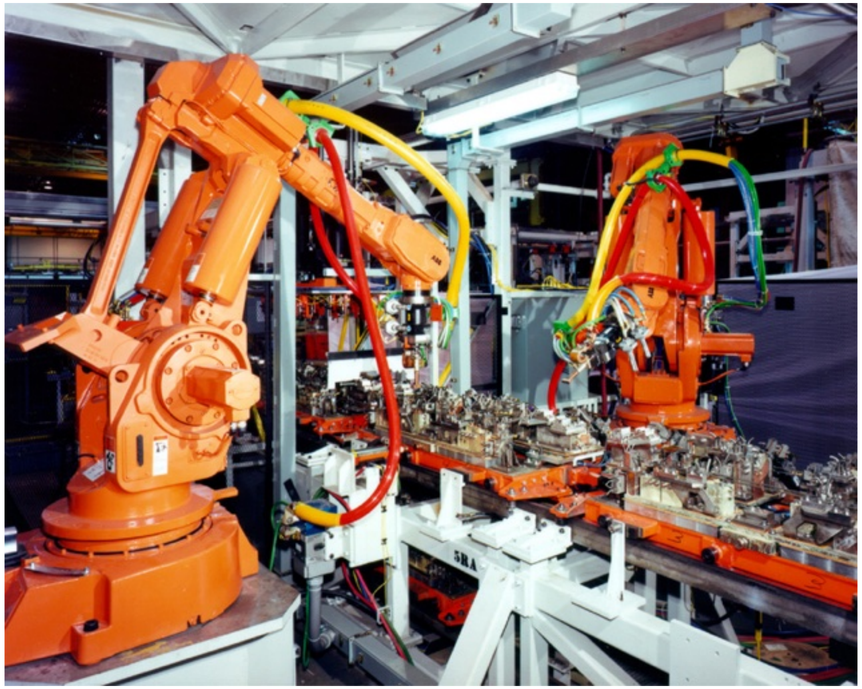
- Real-life robots have to operate in unknown dynamic environments
- It is a multi-disciplinary domain - from mechanics to philosophy...
- It involves many practical problems:
  - it is very technical,
  - it takes a long time from an idea to a built system,
  - debugging can be difficult,
  - expensive.

Categories of robots

- Industrial robots:
  - Mostly stationary
  - Some mobile used for transportation
- Mobile robots:
  - Ground robots – legged, wheeled (UGV – legged)
  - Aerial – rotor-craft – fixed-wing (UAV)
  - (Under) water (AUV)
  - Space
- Humanoids:
  - Atlas, Nao, Asimo

Categories of robots

Industrial robots:



Categories of robots

Mobile robots: legged

BigDog, 2009

BostonDynamics: https://www.youtube.com/watch?v=3gi6Ohnp9x8

Categories of robots

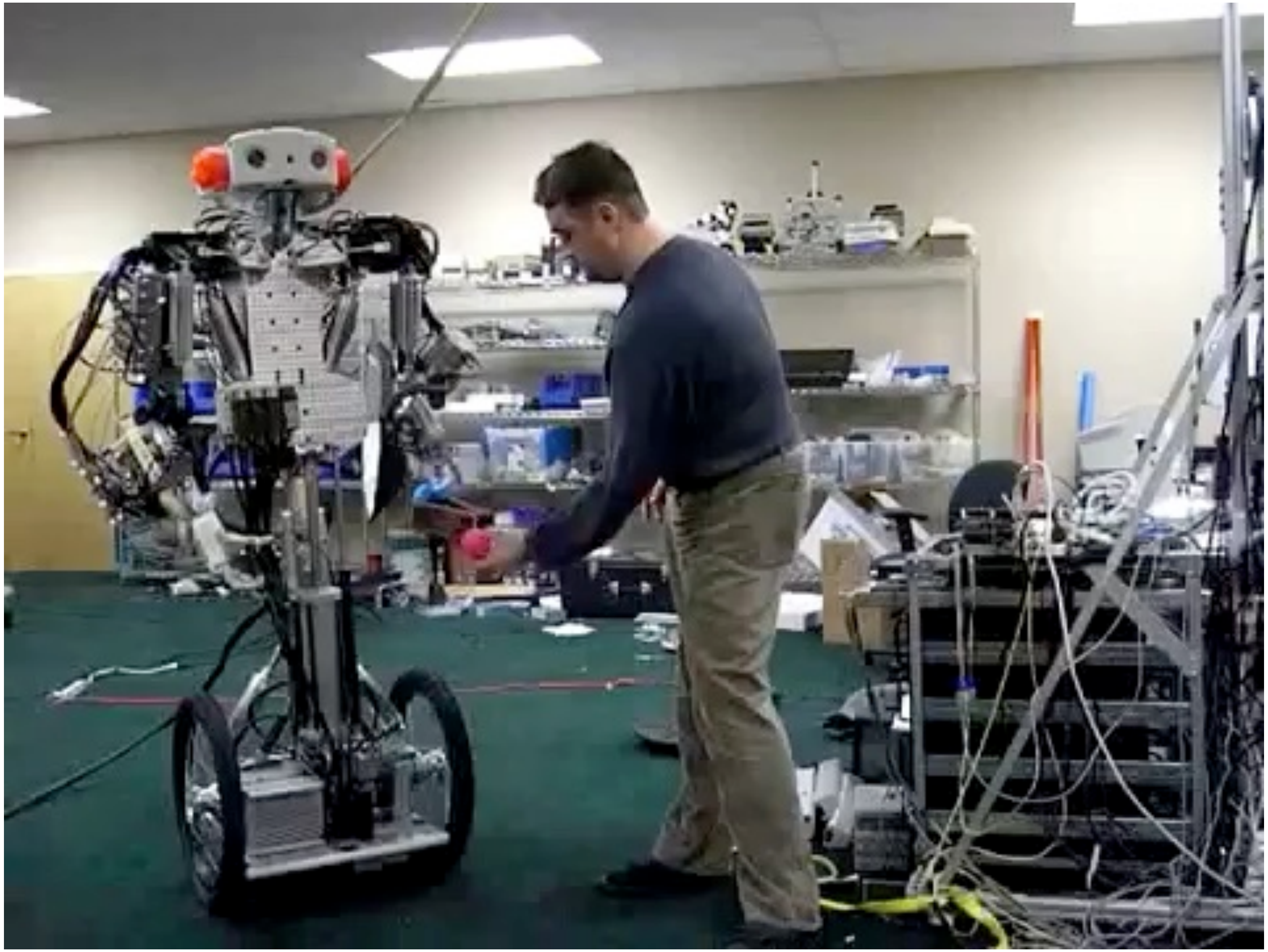
Mobile robots: legged

SpotMini, 2018

BostonDynamics: https://www.youtube.com/watch?v=aFuA50H9uek

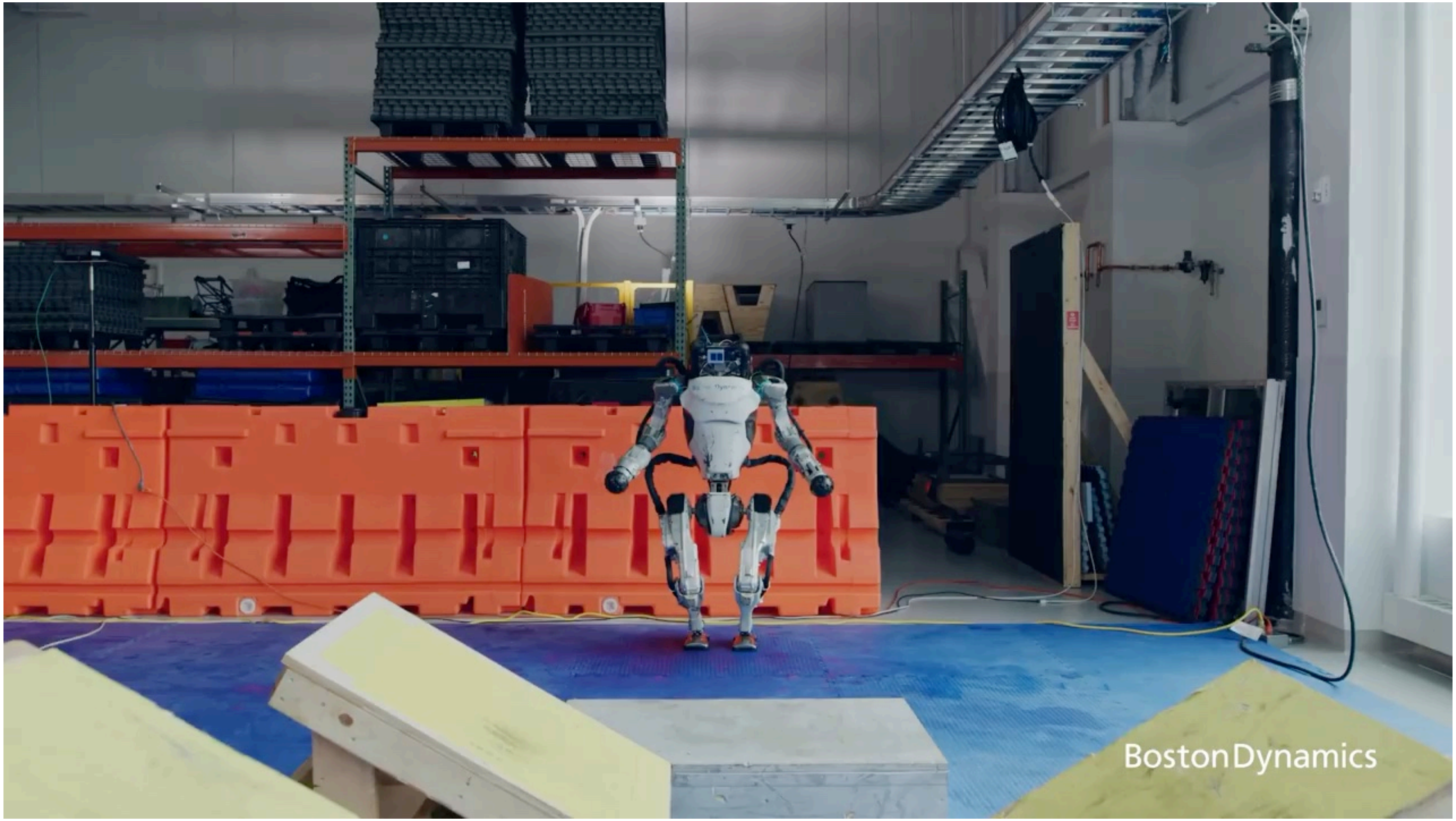
Categories of robots

- Humanoids



Monty, 2007 Anybots Inc.: https://www.youtube.com/watch?v=23kCn51FW3A

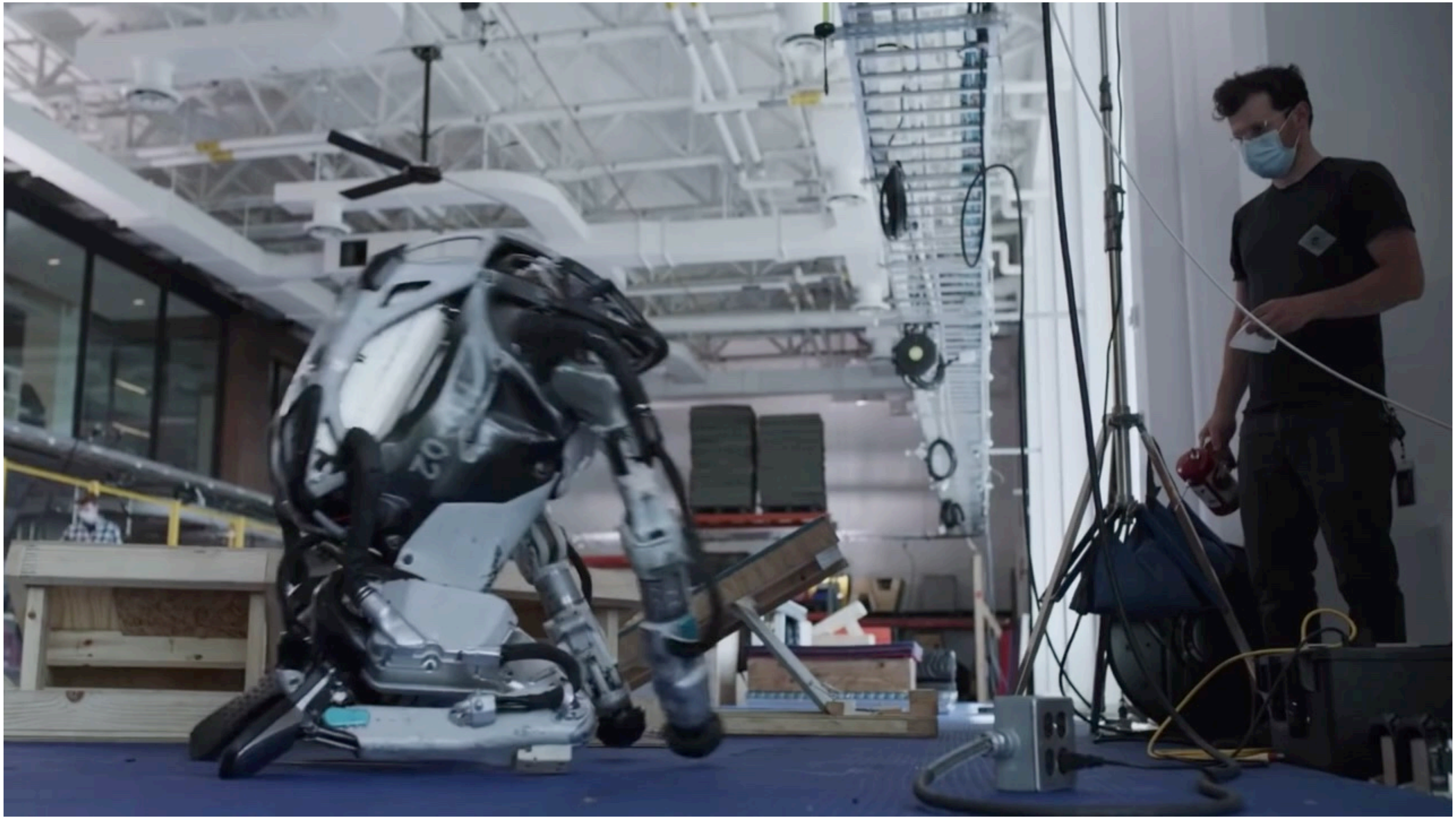
Categories of robots Humanoids



Boston Dynamics

https://www.youtube.com/watch?v=tF4DML7FIWk

Categories of robots Humanoids



Boston Dynamics

Anatomy of Robots

Robots consist of:

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

Perception

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

- 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 (a 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 a robot in its environment.

- Tactile sensors (whiskers, bumpers, etc.)
- Sonar (ultrasonic transducer)
- Laser range finder
- Radar
- (D)-GPS, A-GPS, RTK
- Motion Capture System

Imaging Sensors (Cameras)

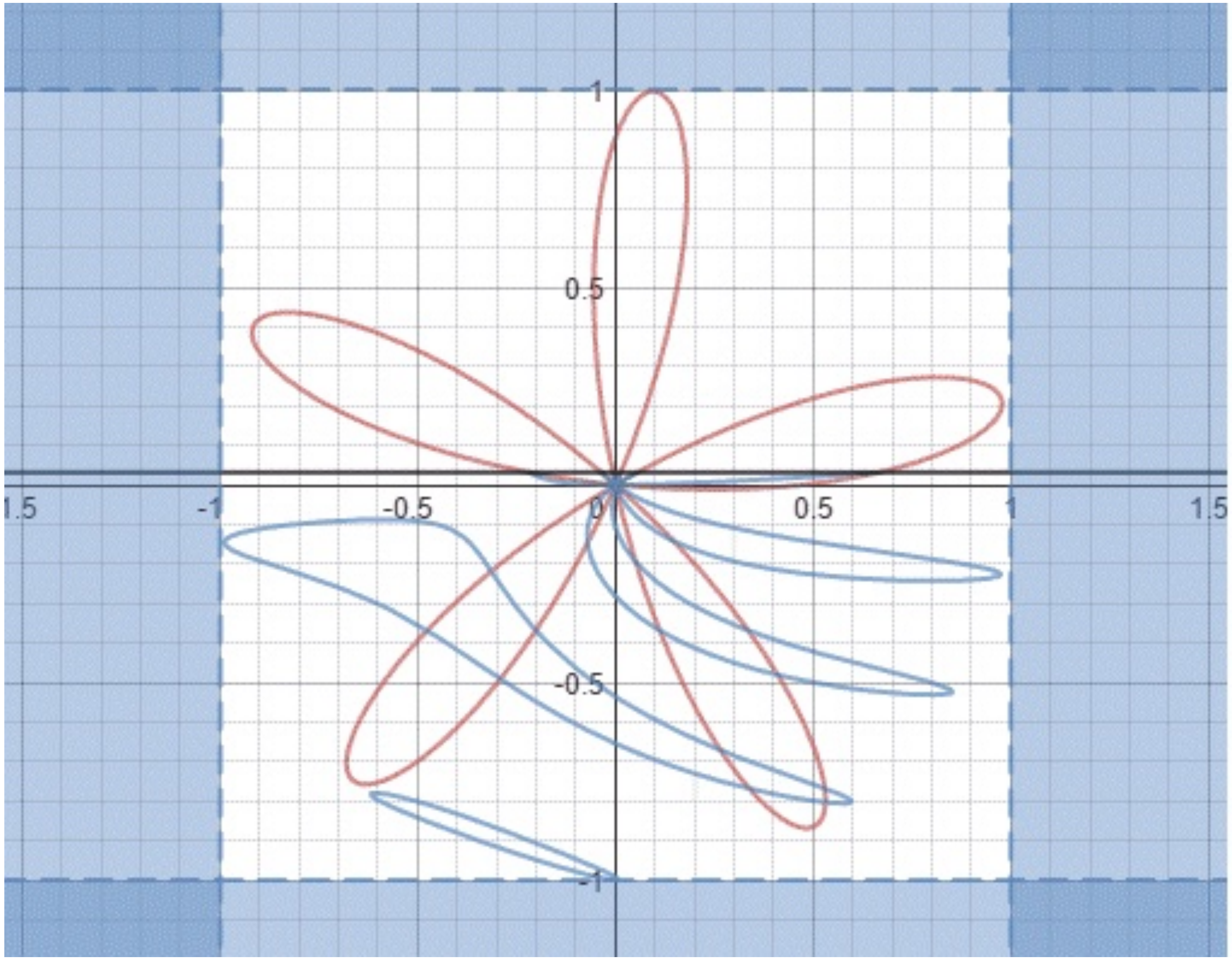
Deliver images which can be used by computer vision algorithms to sense different types of stimuli.

- Output data
  - Color
  - Black-White (Thermal)
  - Dynamic Vision Sensor (DVS)
- Configuration
  - Monocular
  - Stereo
  - Omnidirectional
  - Stereo-omnidirectional

- Type of sensor (exposure)
  - CCD
  - CMOS

CMOS problem

CMOS problem



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

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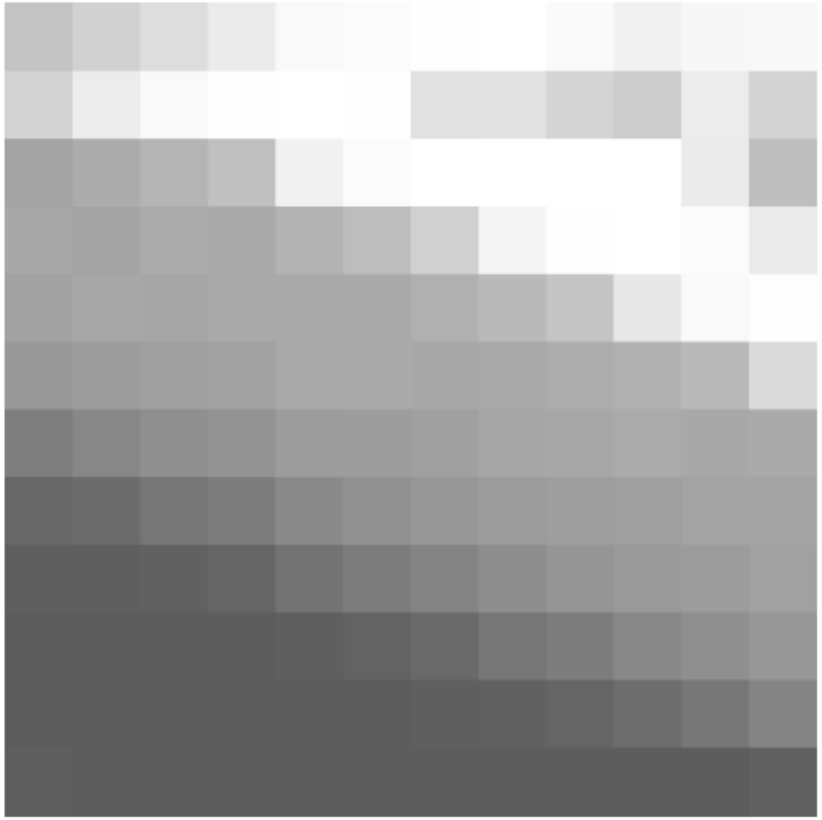
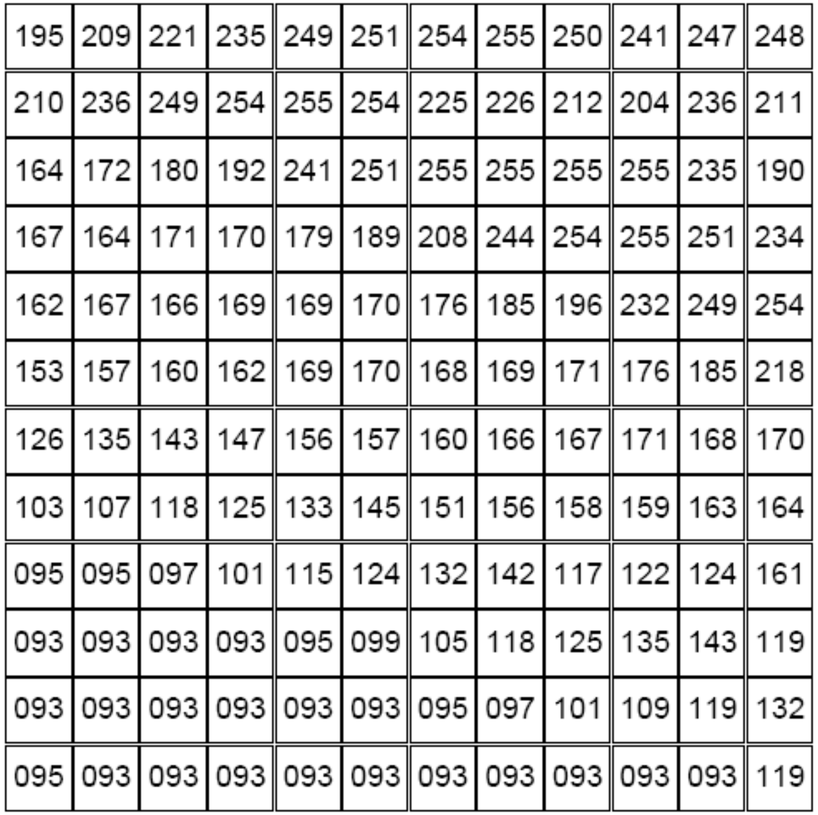
Image composition

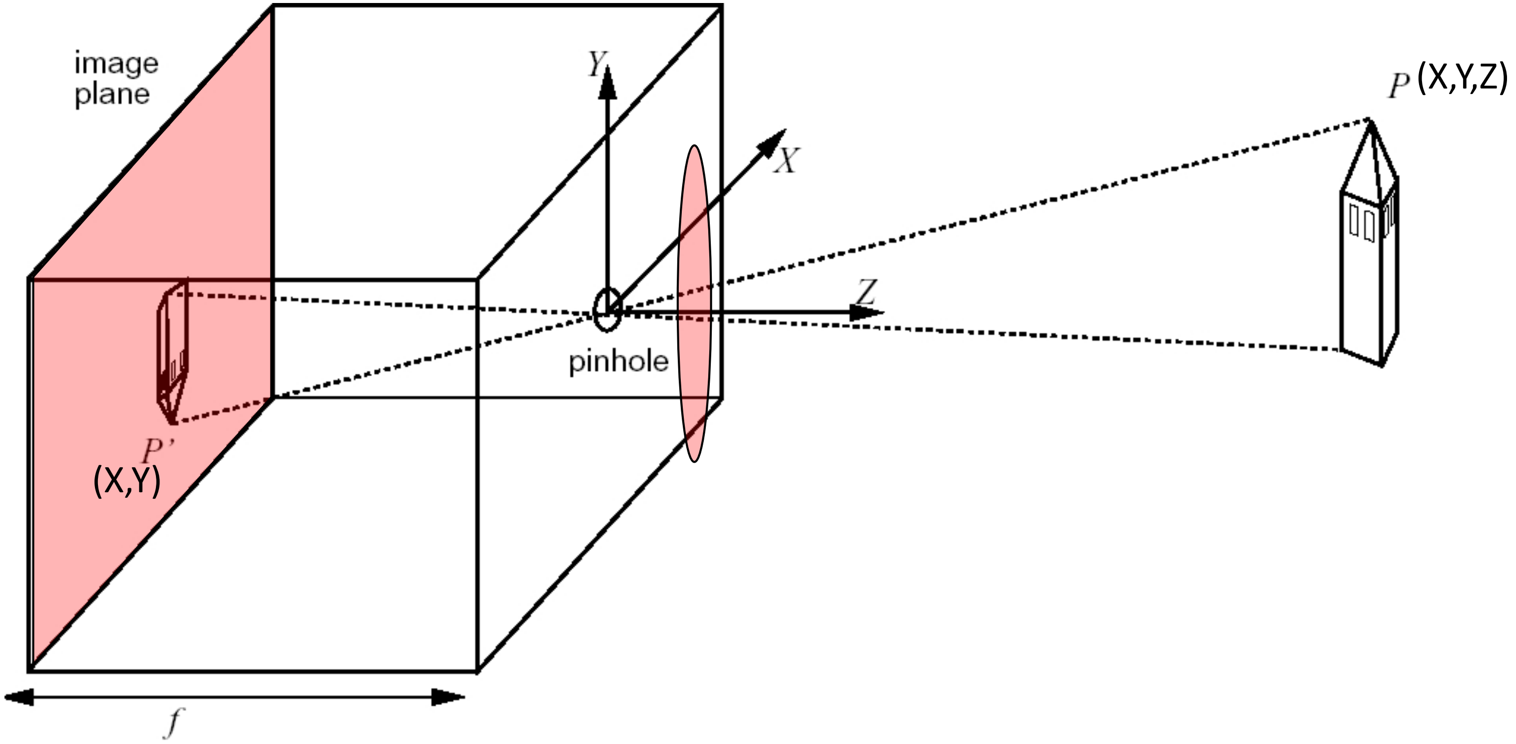




195	209	221	235	249	251	254	255	250	241	247	248
210	236	249	254	255	254	225	226	212	204	236	211
164	172	180	192	241	251	255	255	255	255	235	190
167	164	171	170	179	189	208	244	254	255	251	234
162	167	166	169	169	170	176	185	196	232	249	254
153	157	160	162	169	170	168	169	171	176	185	218
126	135	143	147	156	157	160	166	167	171	168	170
103	107	118	125	133	145	151	156	158	159	163	164
095	095	097	101	115	124	132	142	117	122	124	161
093	093	093	093	095	099	105	118	125	135	143	119
093	093	093	093	093	093	095	097	101	109	119	132
095	093	093	093	093	093	093	093	093	093	093	119

I(x, y, t) is the intensity at (x, y) at time t

Pinhole Camera Model



P is a point in the scene, with coordinates (X, Y, Z)

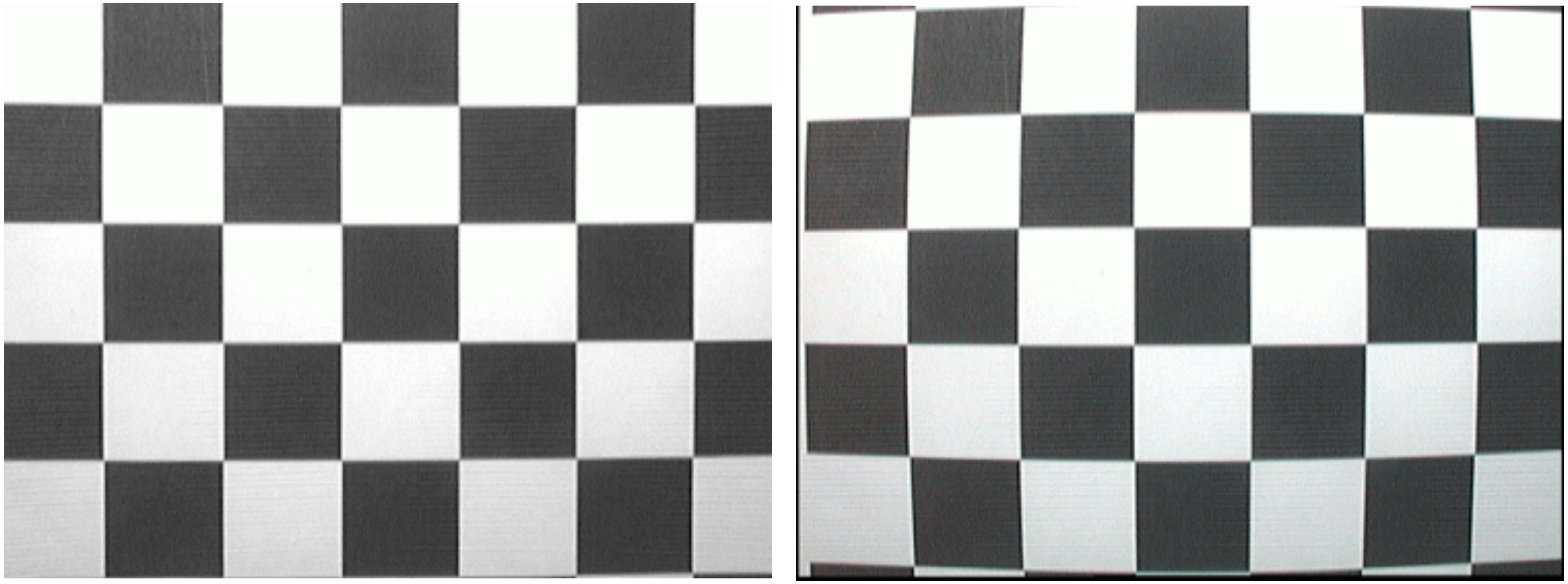
P' is its image on the image plane, with coordinates (x, y)

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

Scale/distance is indeterminate!

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.

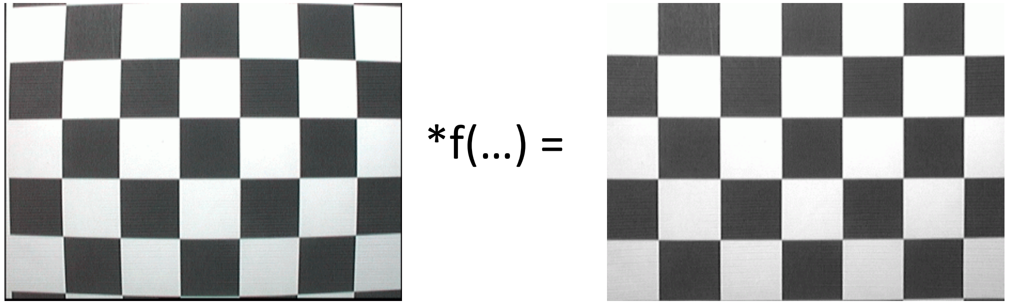
Omnidirectional Lens

Camera Calibration

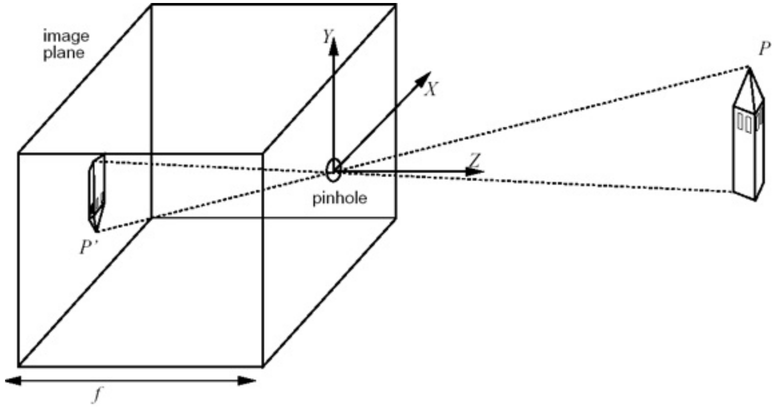
Estimate:

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

from different views of a calibration object



*f(…) =



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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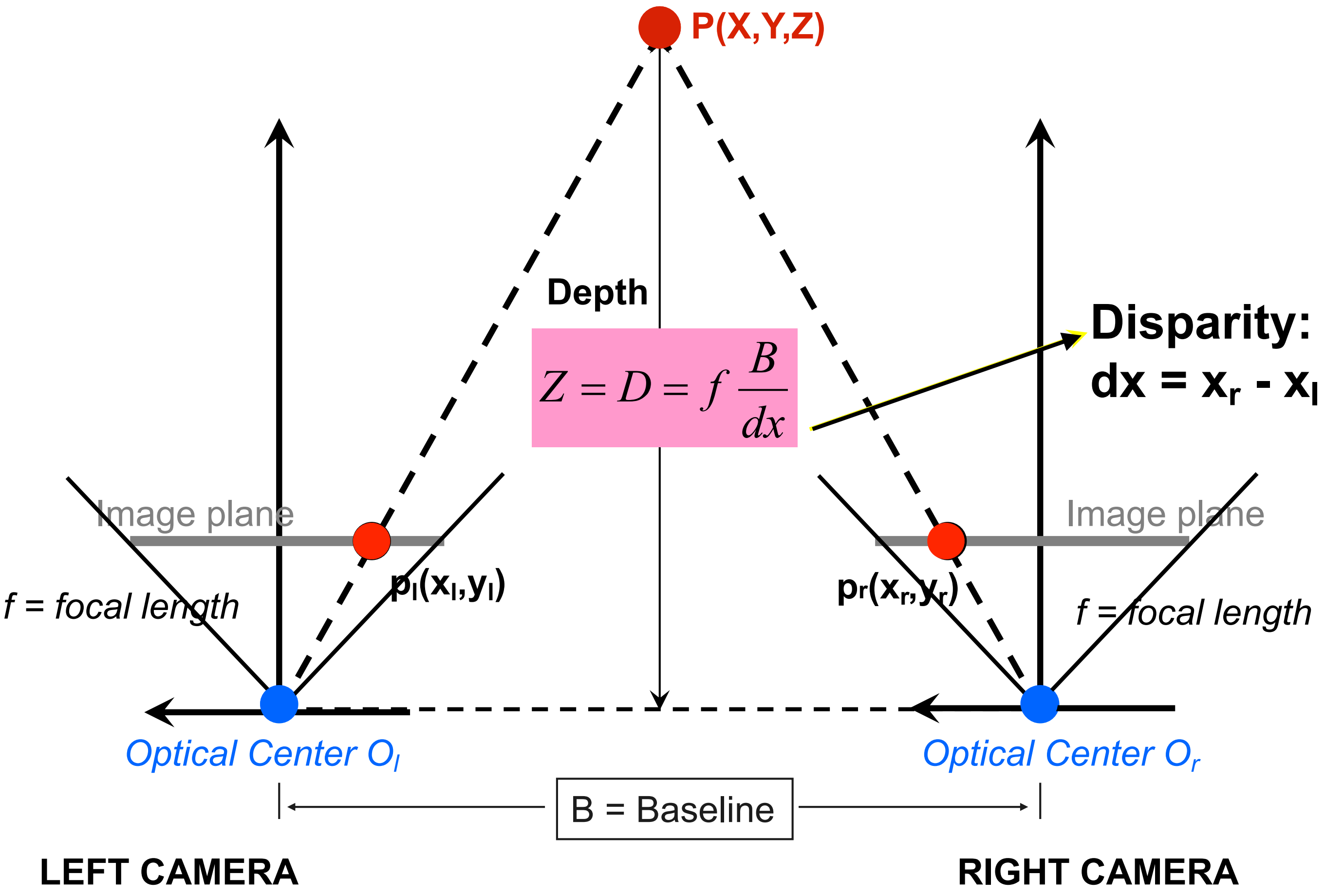
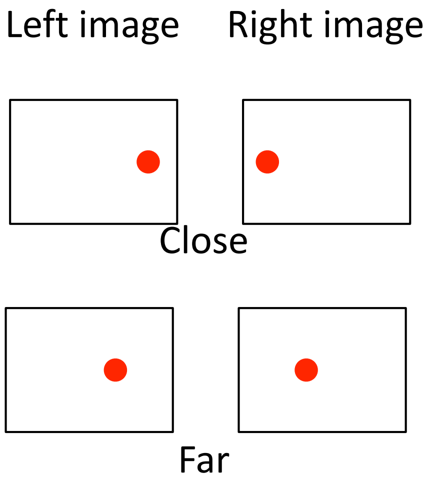
Stereo vision



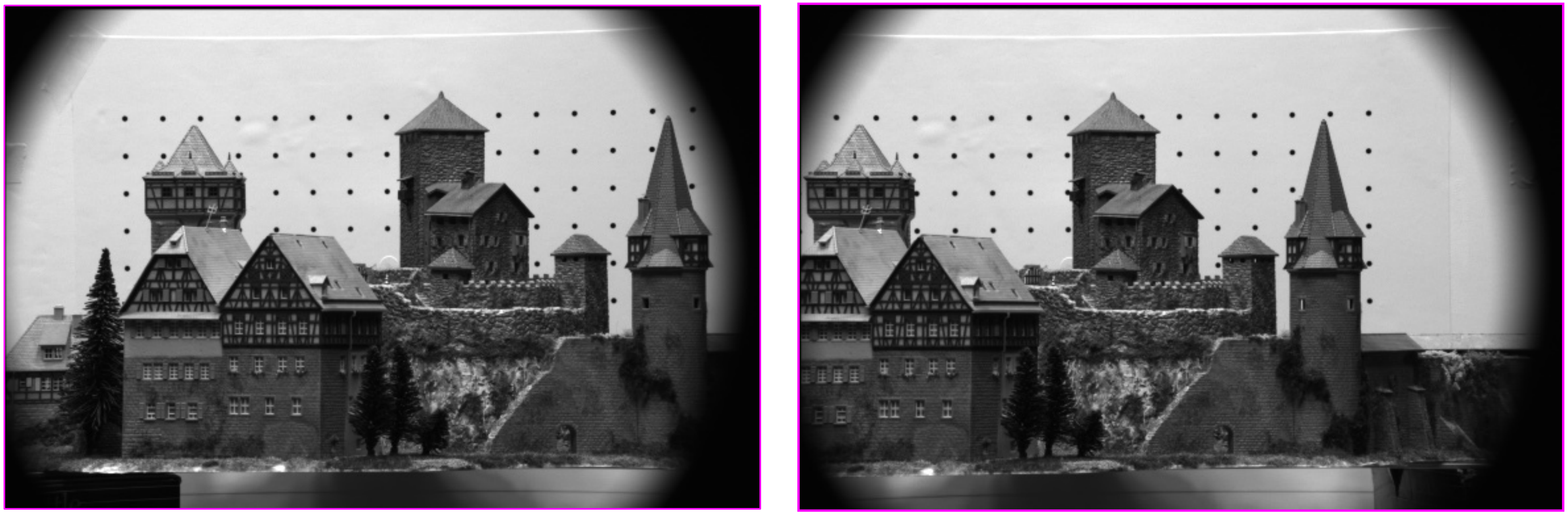
$$Z = D = f\,\frac{B}{dx}$$

Disparity:
$dx = x_r - x_l$

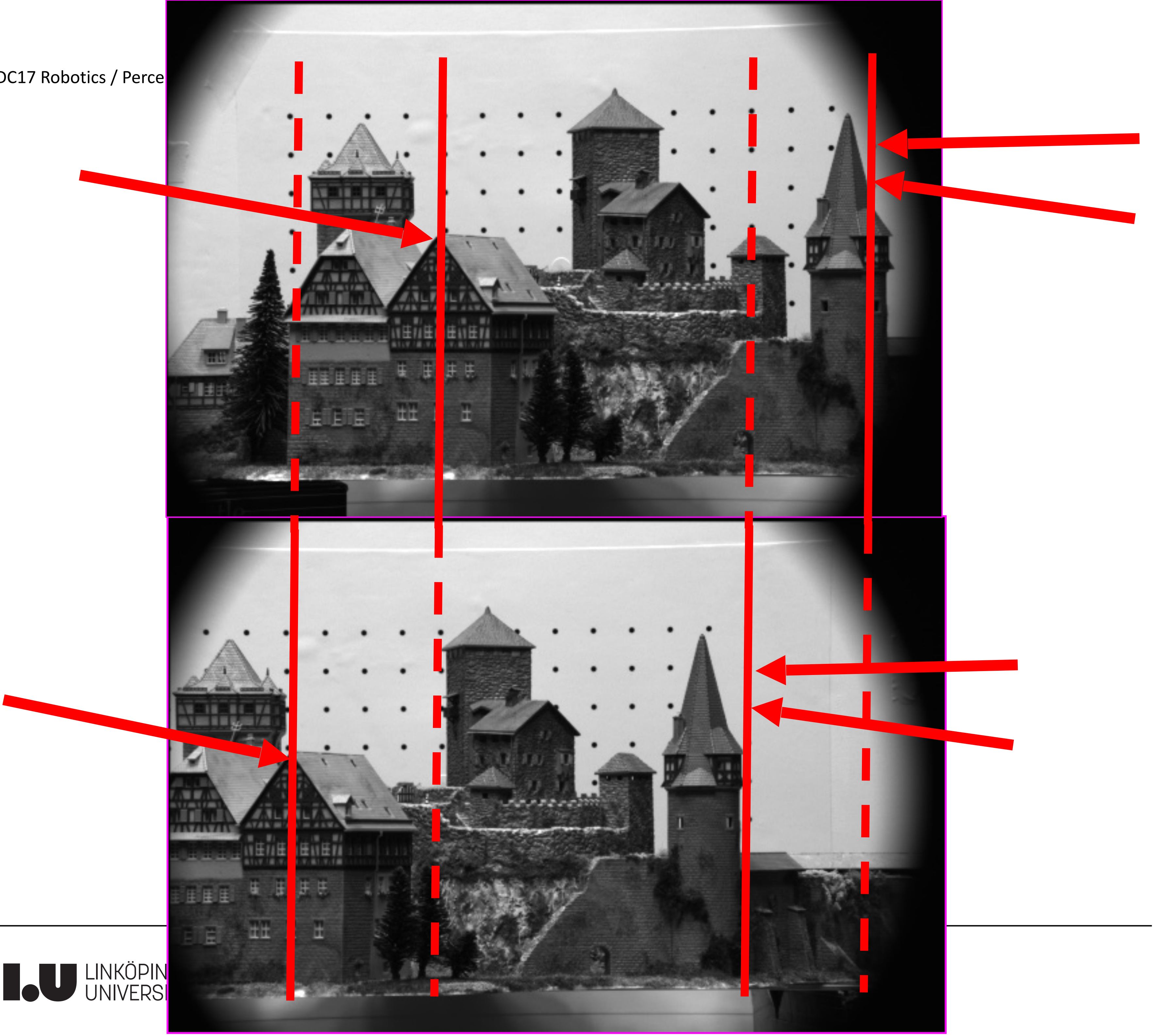


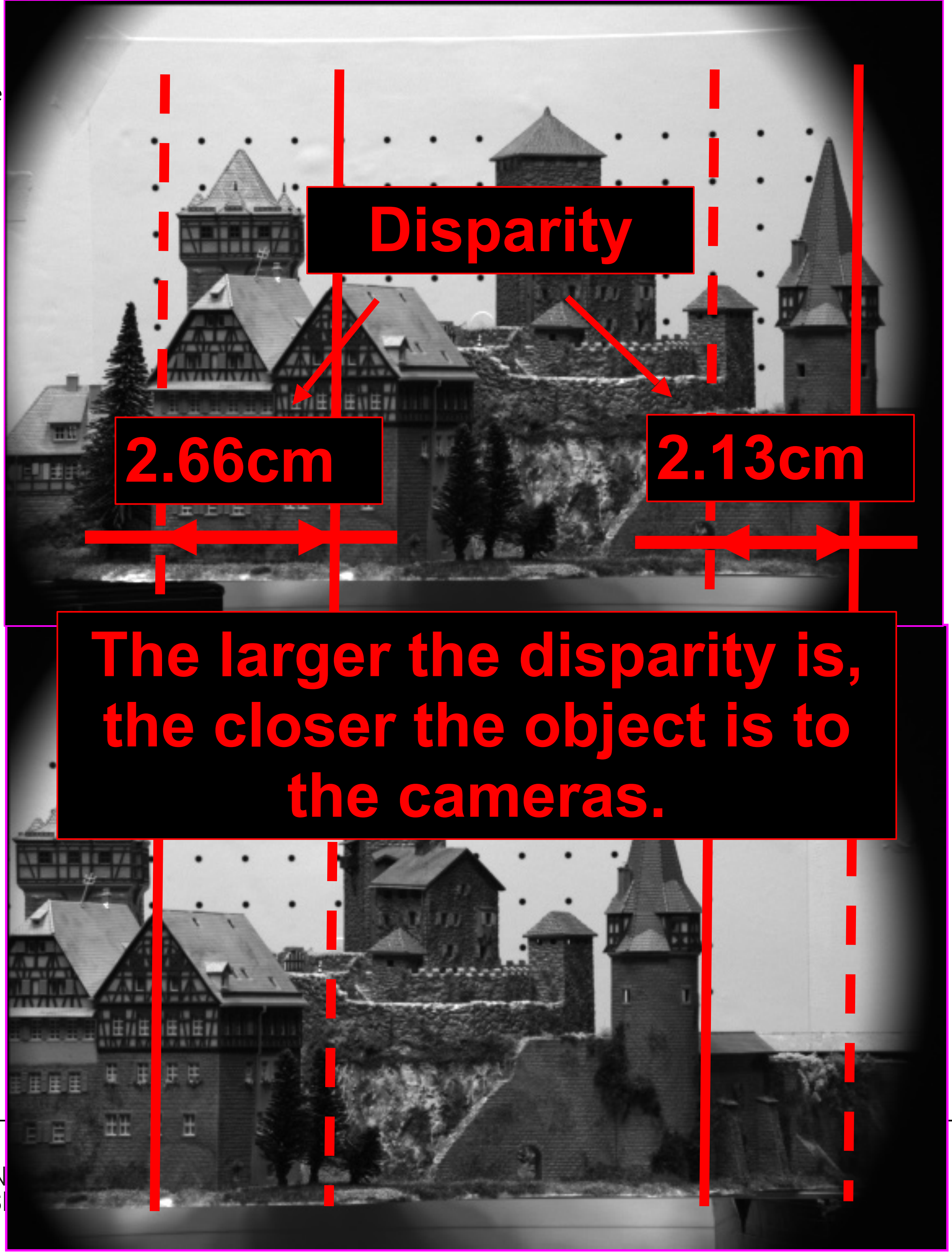
Stereo vision

A scene is photographed by two cameras: what do we gain?



CMU CIL Stereo Dataset: Castle sequence





The larger the disparity is, the closer the object is to the cameras.

Stereo processing

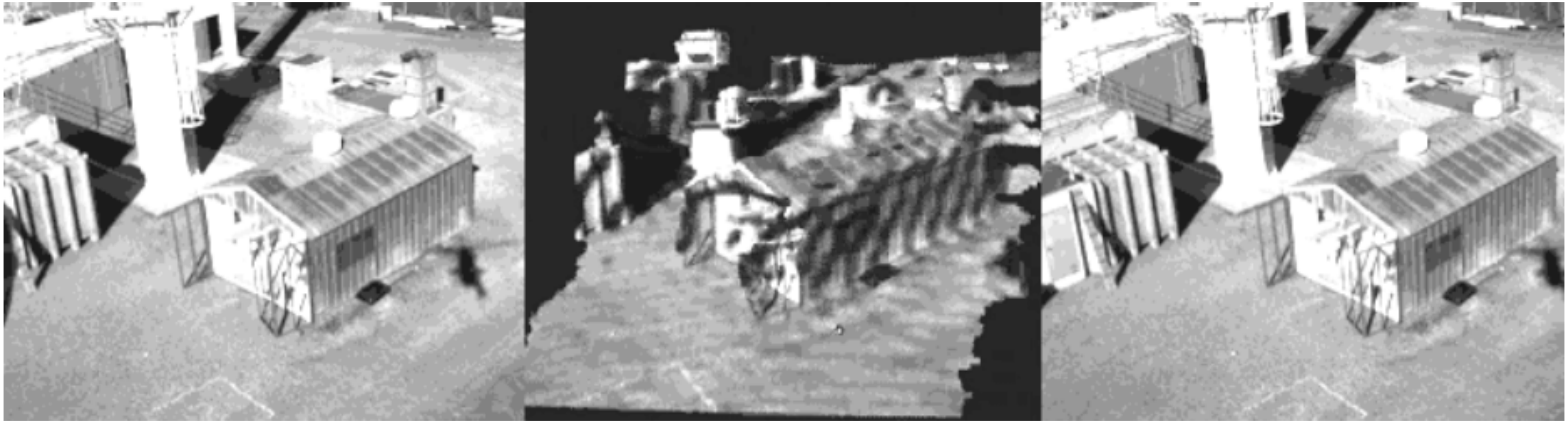
To determine depth from stereo disparity:

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 Vision for UAVs

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

Stereo Vision for UAVs



Stereo Vision for UAVs at LiU

Yamaha RMAX

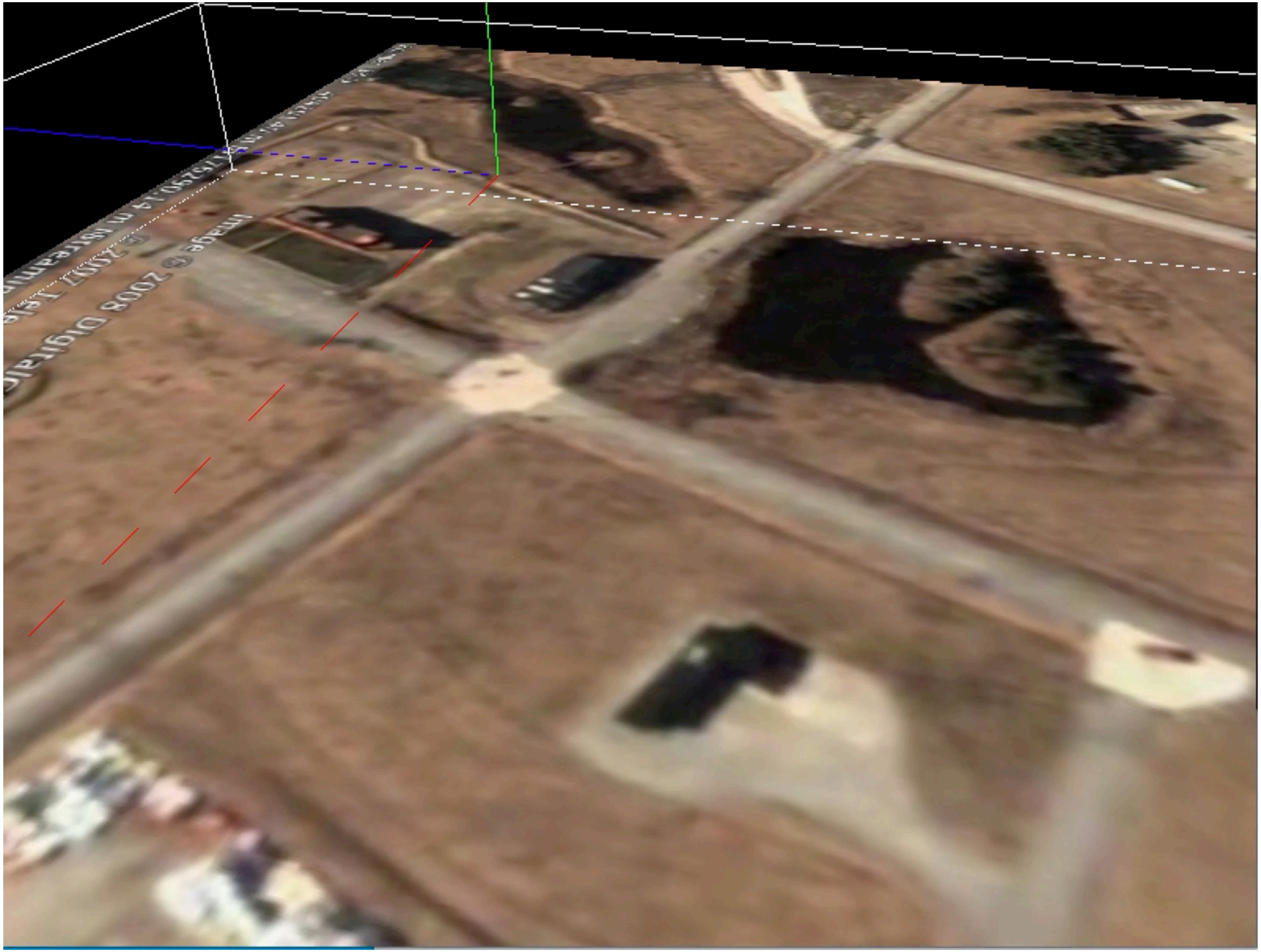


Image © 2008 DigitalGlobe
© 2007 Tele Atlas

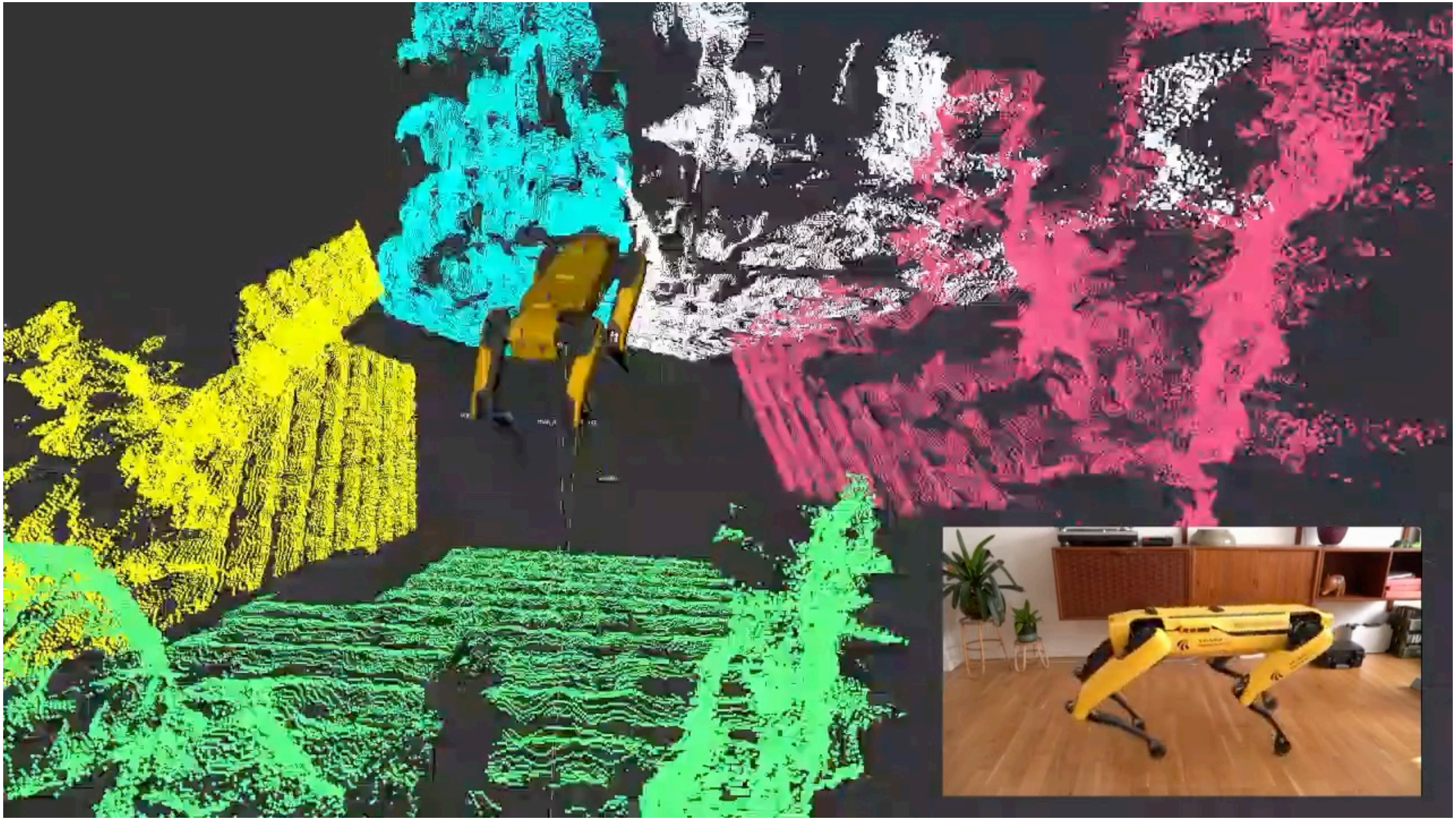
Stereo Vision on Spot

Sides

Front

Back

Stereo Vision on Spot



Source: Spot - Sensors: Depth Cameras, Mobile robots
https://www.youtube.com/watch?v=ylpzNkMyrgE

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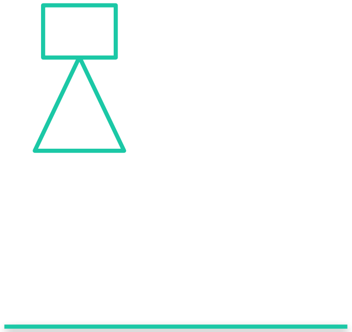
Optic Flow

Optical flow methods try to calculate the motion between two image frames which are taken at times t and t + δt at every pixel position. In practice, it is often done for features instead all of all pixels.

Optic Flow

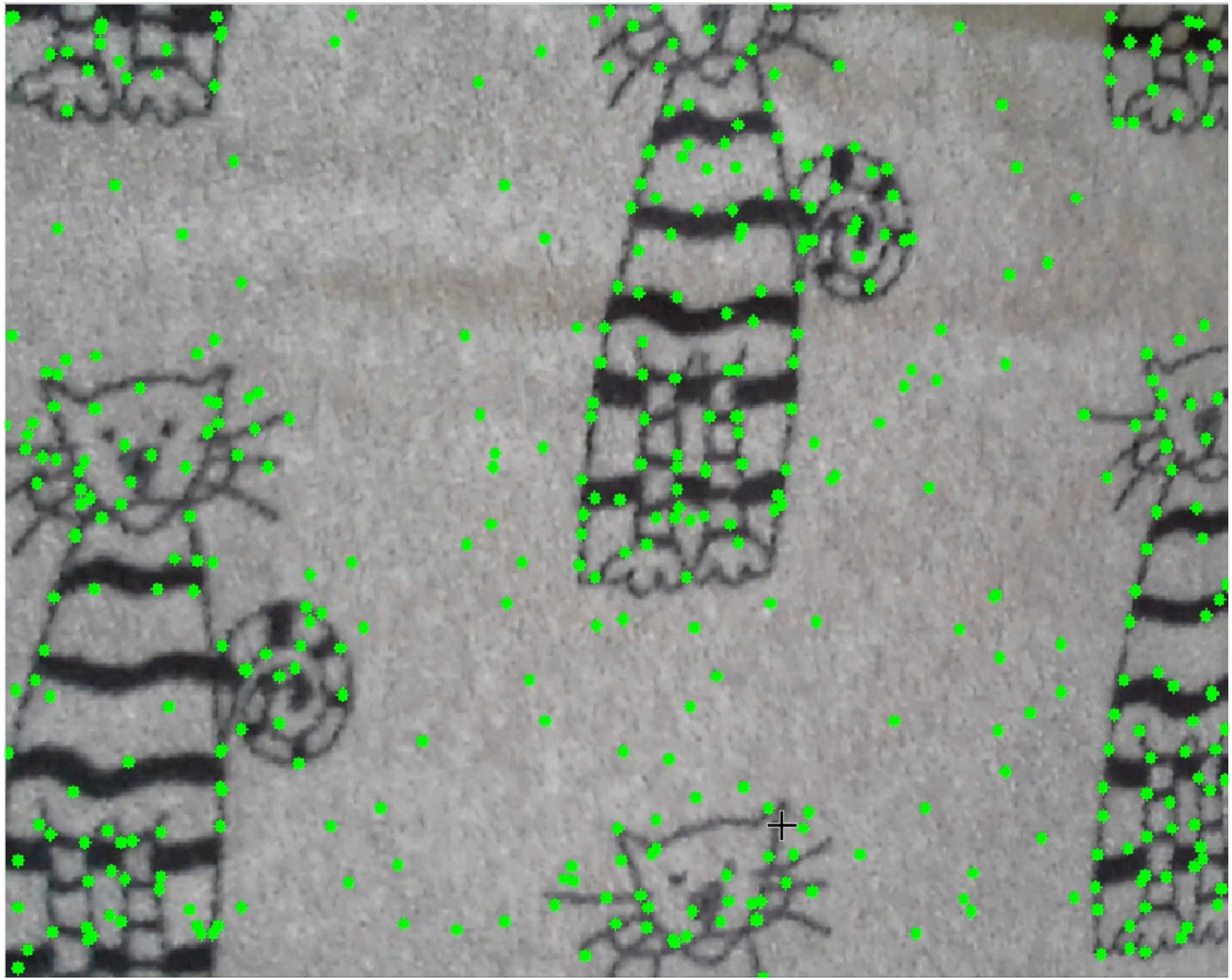

Kleenex
balsam
Superior soothing*
for the toughest cold
BalmCare
Artificial Intelligence
A Modern Approach
Fourth Edition

Optic flow we all use

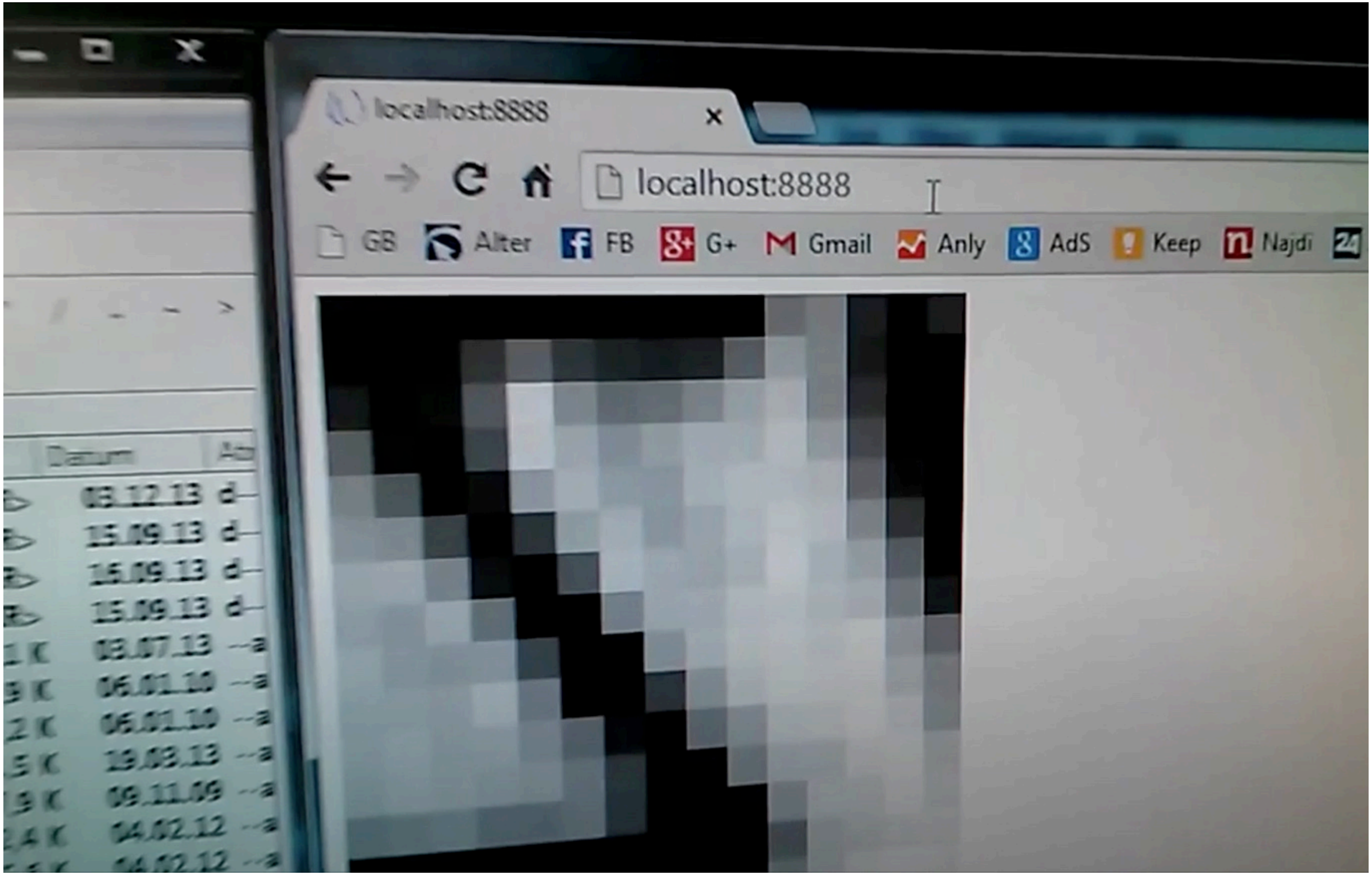


Surface

Side view



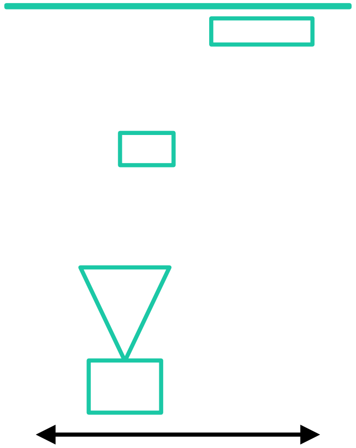
Optic flow we all use

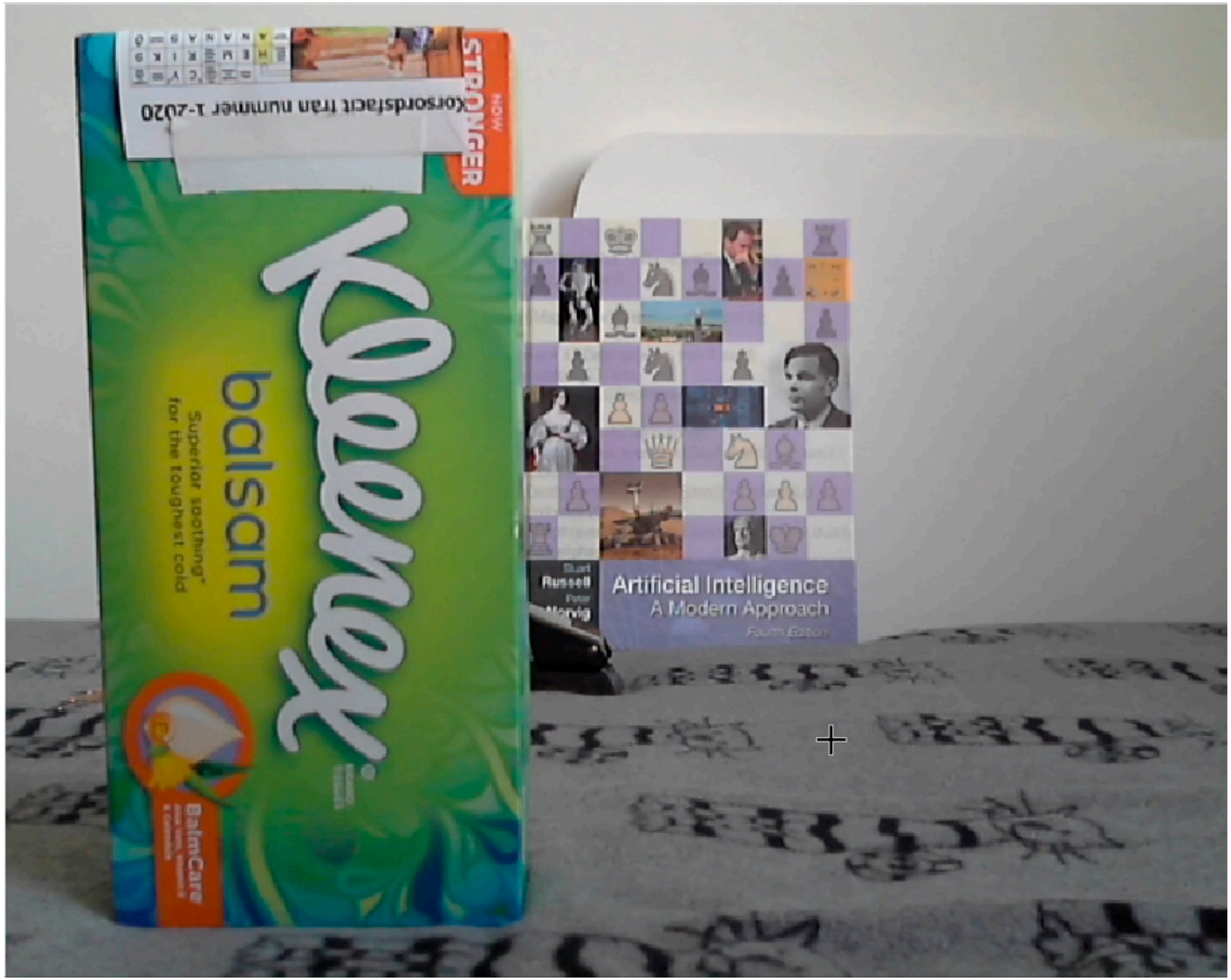


Optical Mouse as Arduino Web Camera
https://www.youtube.com/watch?v=Ix6532mrIKA

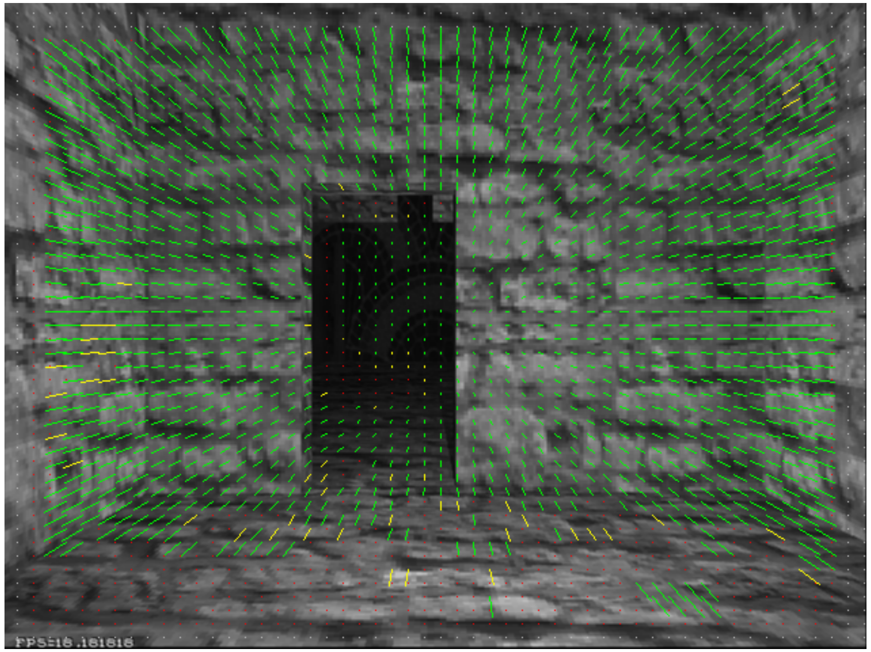
Optic Flow

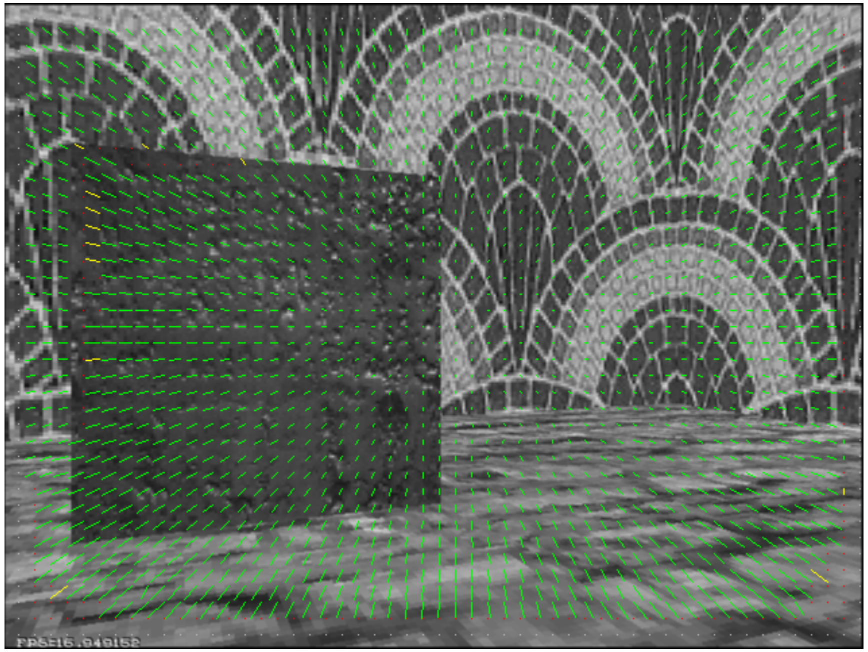
Top view



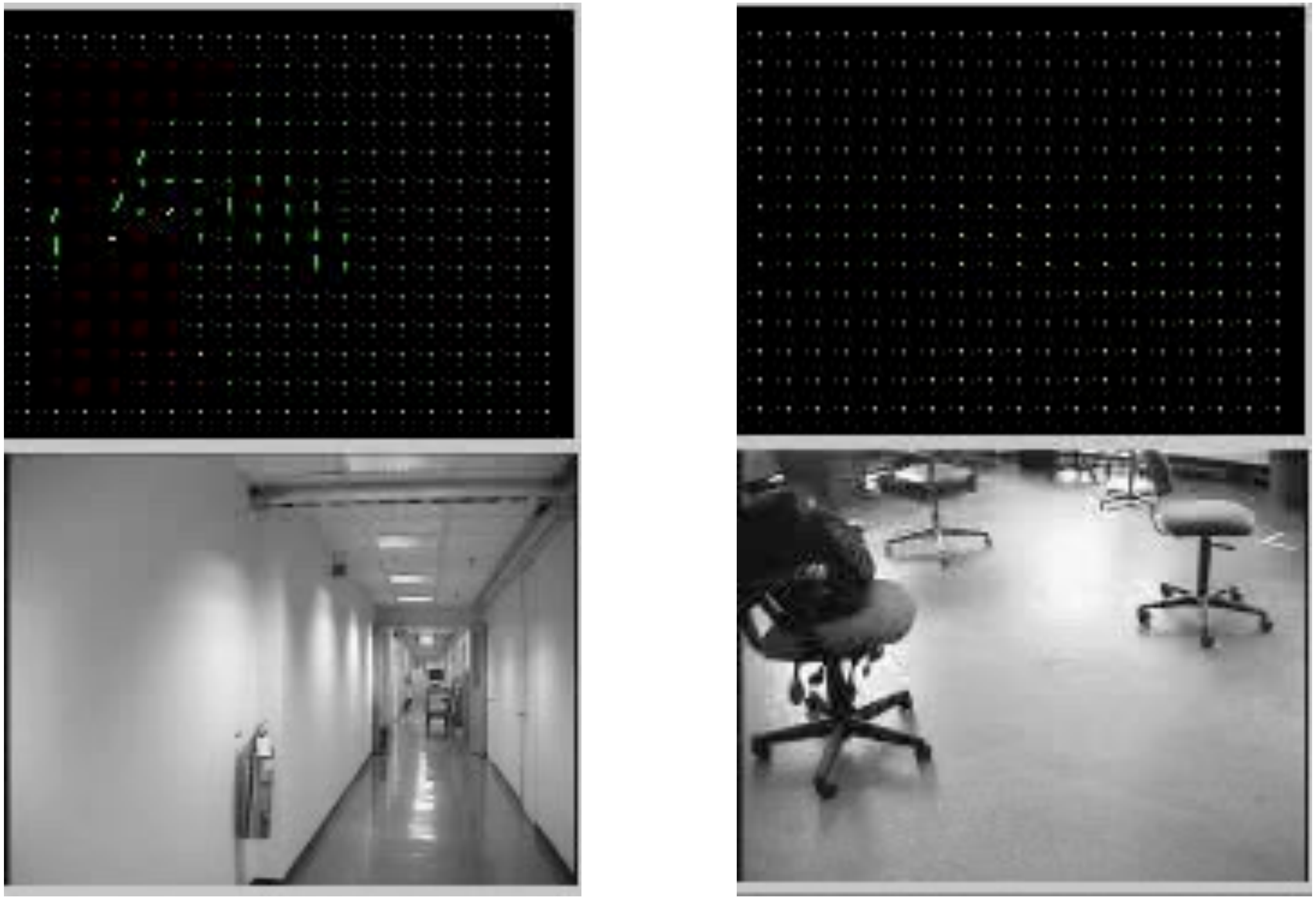


Optic Flow





Optic Flow

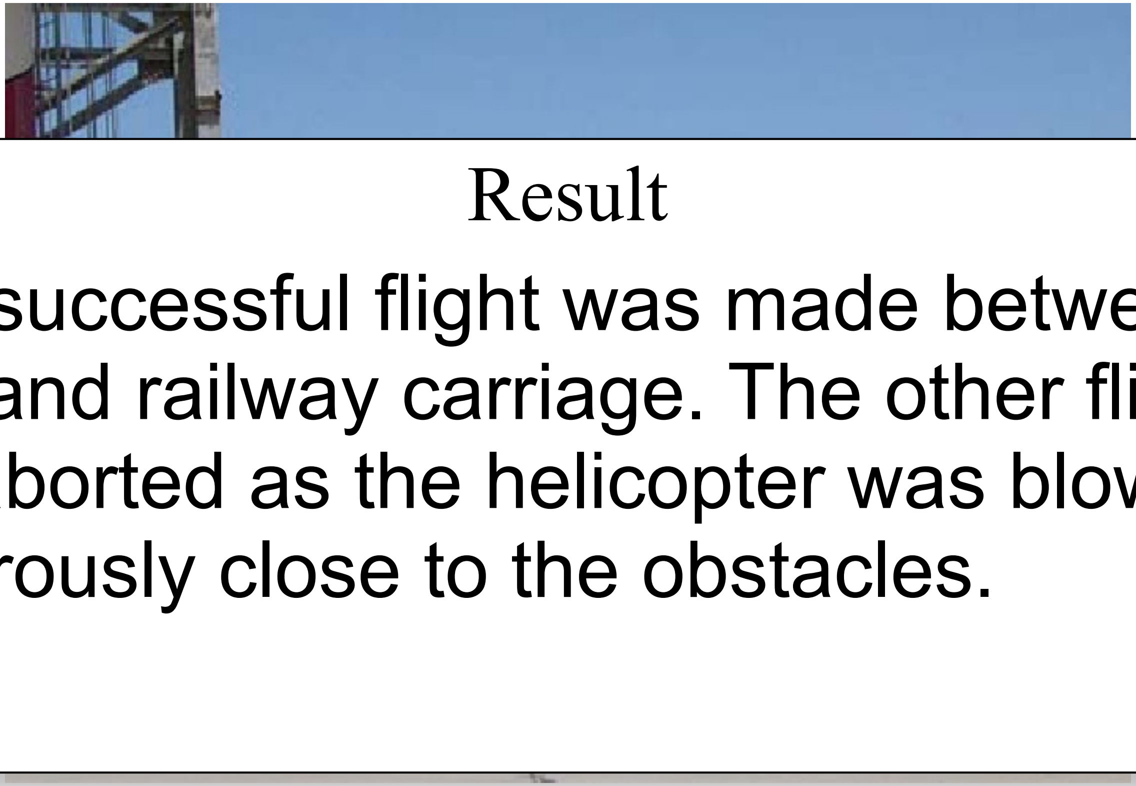


Obstacle Avoidance Example

- 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

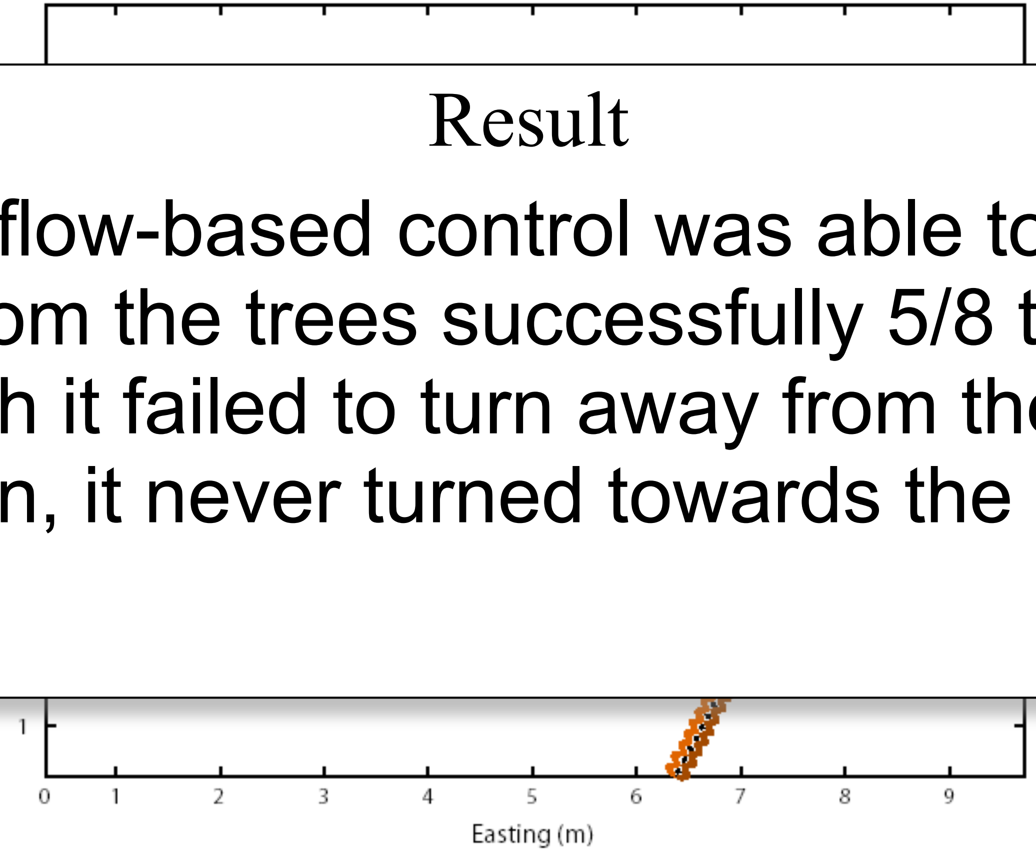


Result

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

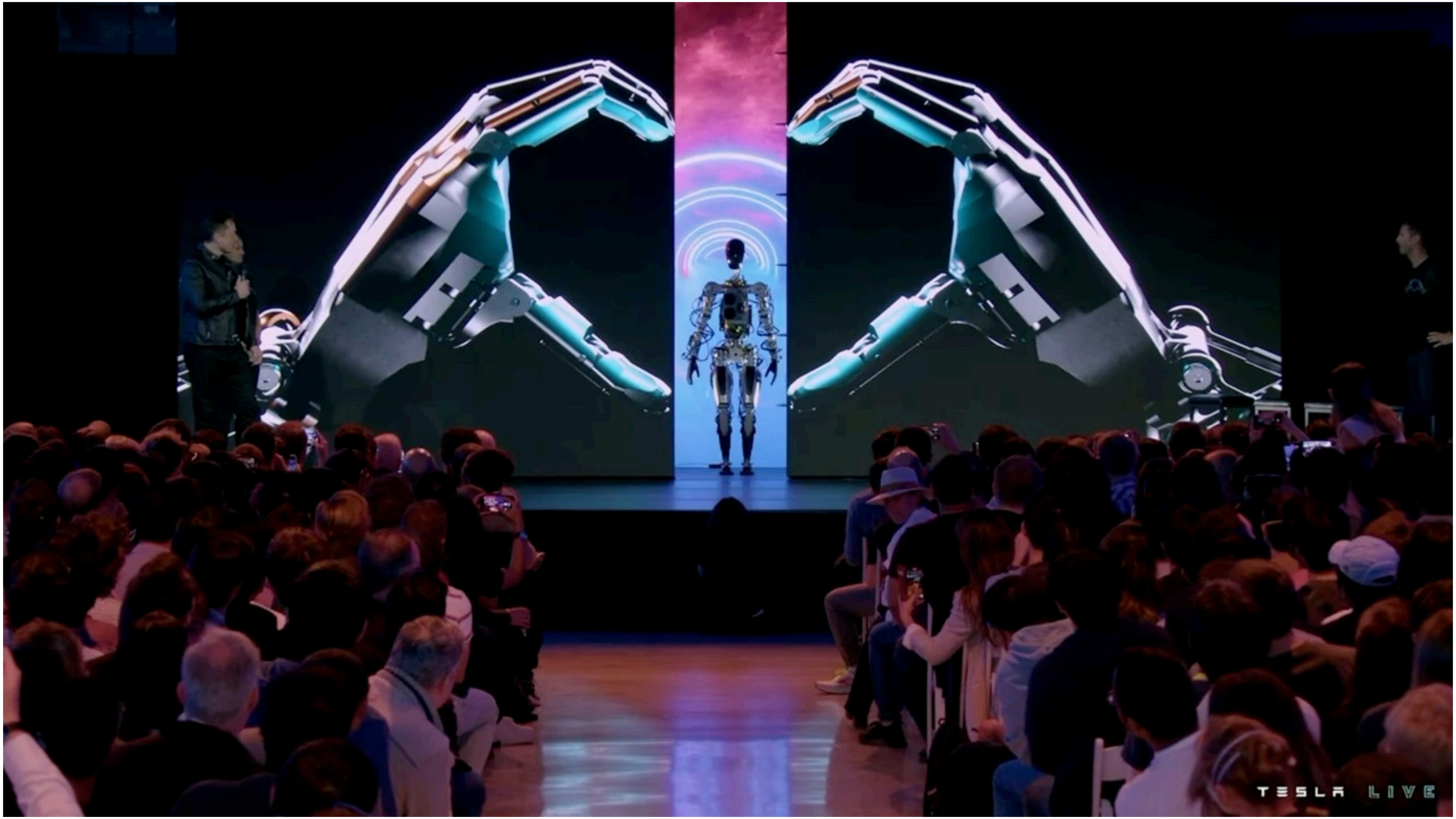


Result

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.

Tesla AI Day 2022 - Optimus



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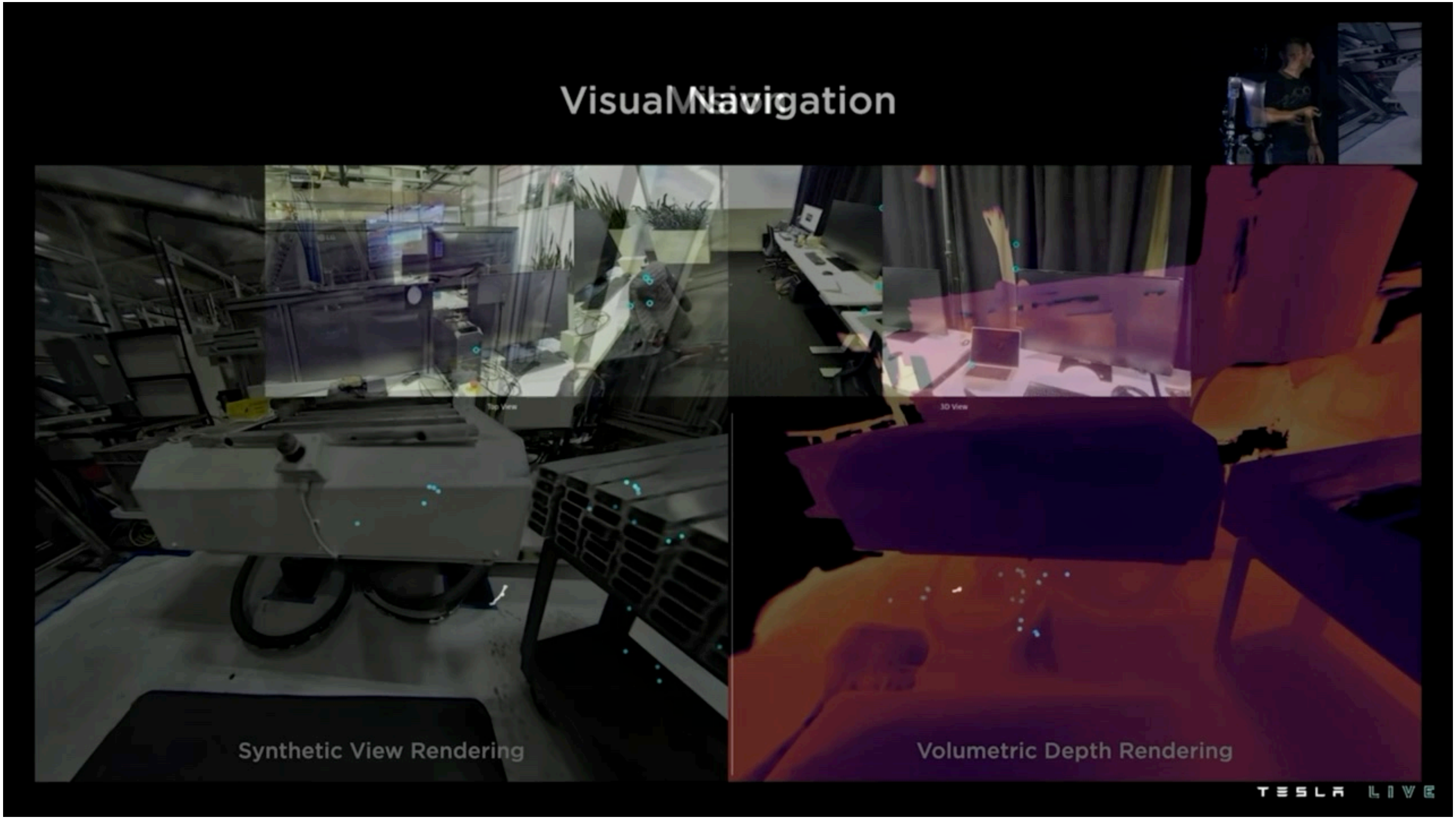

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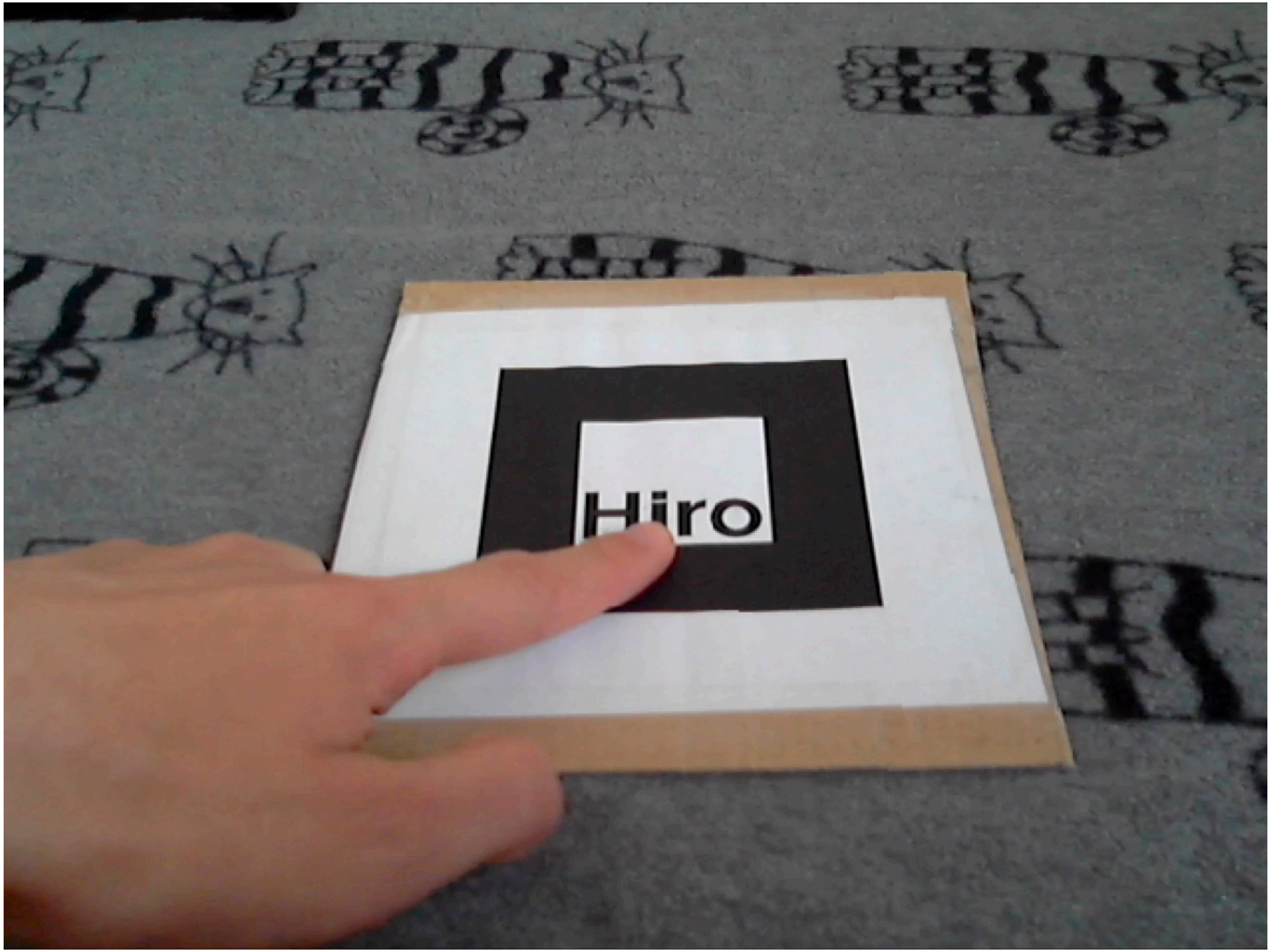
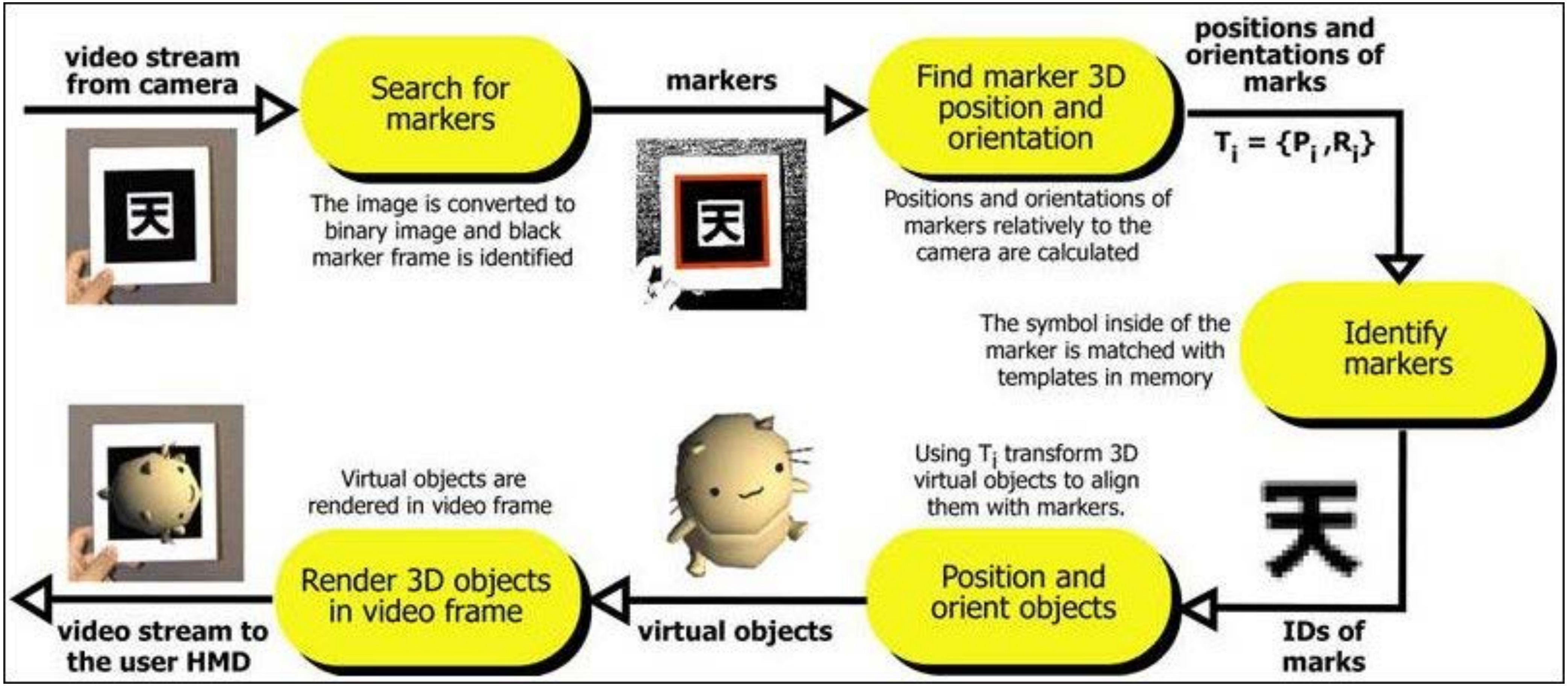
Pose Estimation

- 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.

Pose Estimation



ARToolkit


video stream from camera
Search for markers
The image is converted to binary image and black marker frame is identified
markers
Find marker 3D position and orientation
Positions and orientations of markers relatively to the camera are calculated
positions and orientations of marks
$T_i = \{P_i, R_i\}$
Identify markers
The symbol inside of the marker is matched with templates in memory
IDs of marks
Position and orient objects
Using T_i transform 3D virtual objects to align them with markers.
virtual objects
Render 3D objects in video frame
Virtual objects are rendered in video frame
video stream to the user HMD

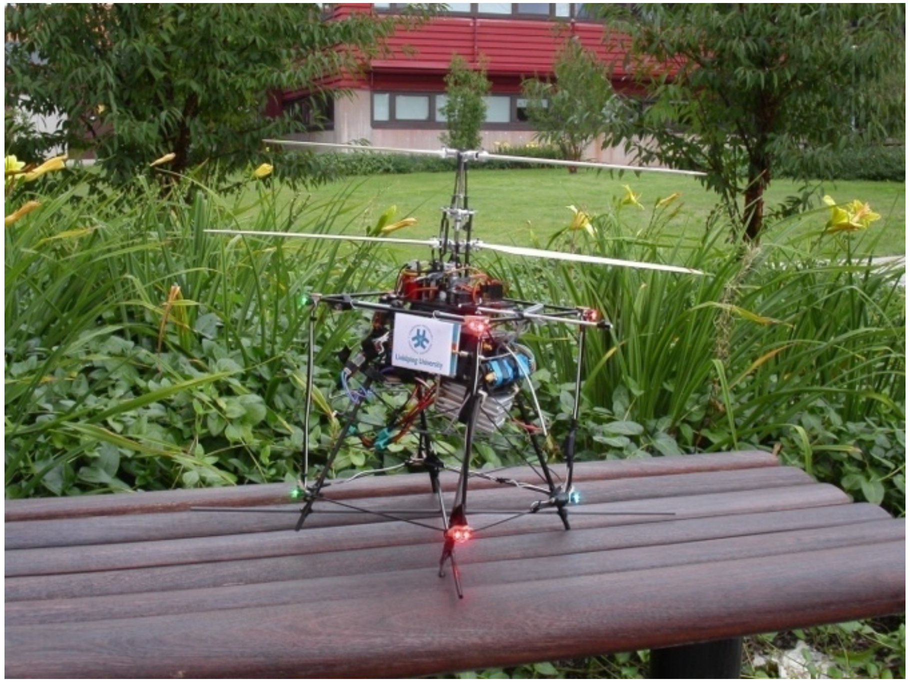
Pose Estimation

Pose Estimation for Indoor Flying Robots

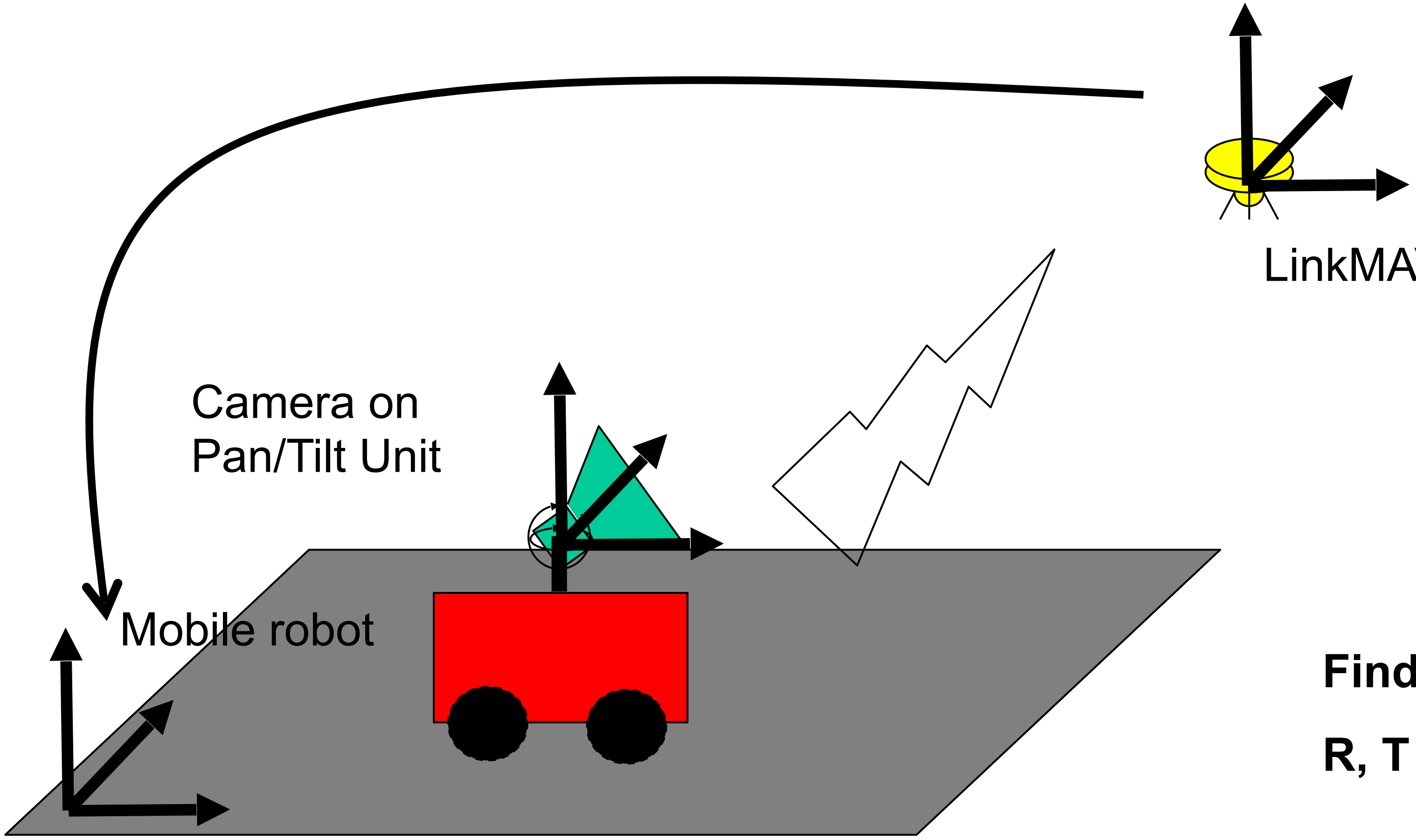
Motivation:

- 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.

LinkMAV, Pioneer 3-AT



Ground robot



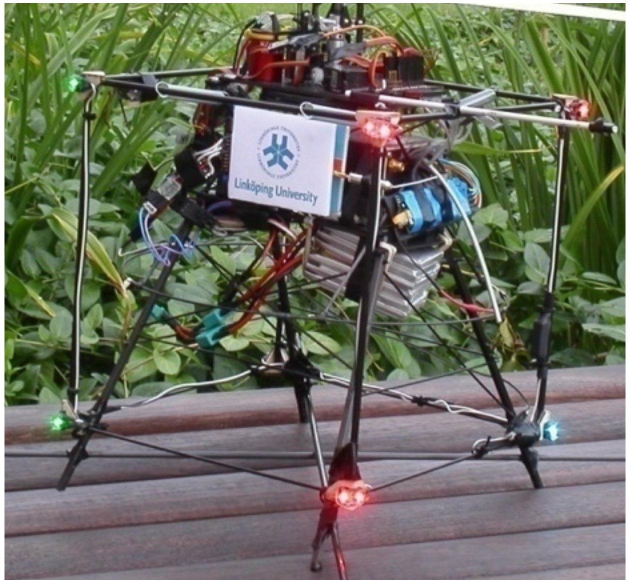
Find:

R, T

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



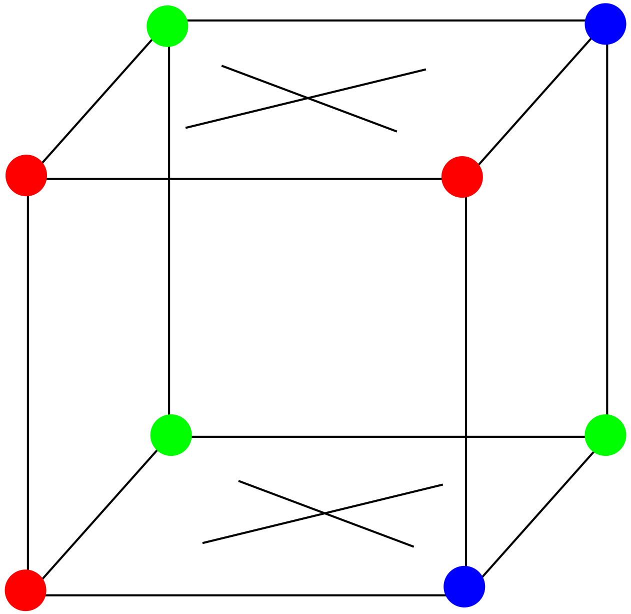
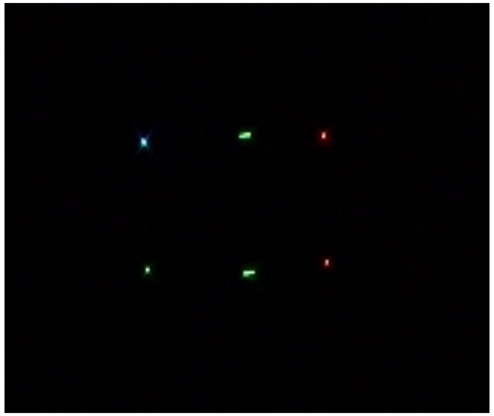


Image processing

- Video camera operates with closed shutter for easy and fast diode identification.
- Four identified diodes from one face of the cube go through the “Robust Pose Estimation from a Planar Target” 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.

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

Spot using markers

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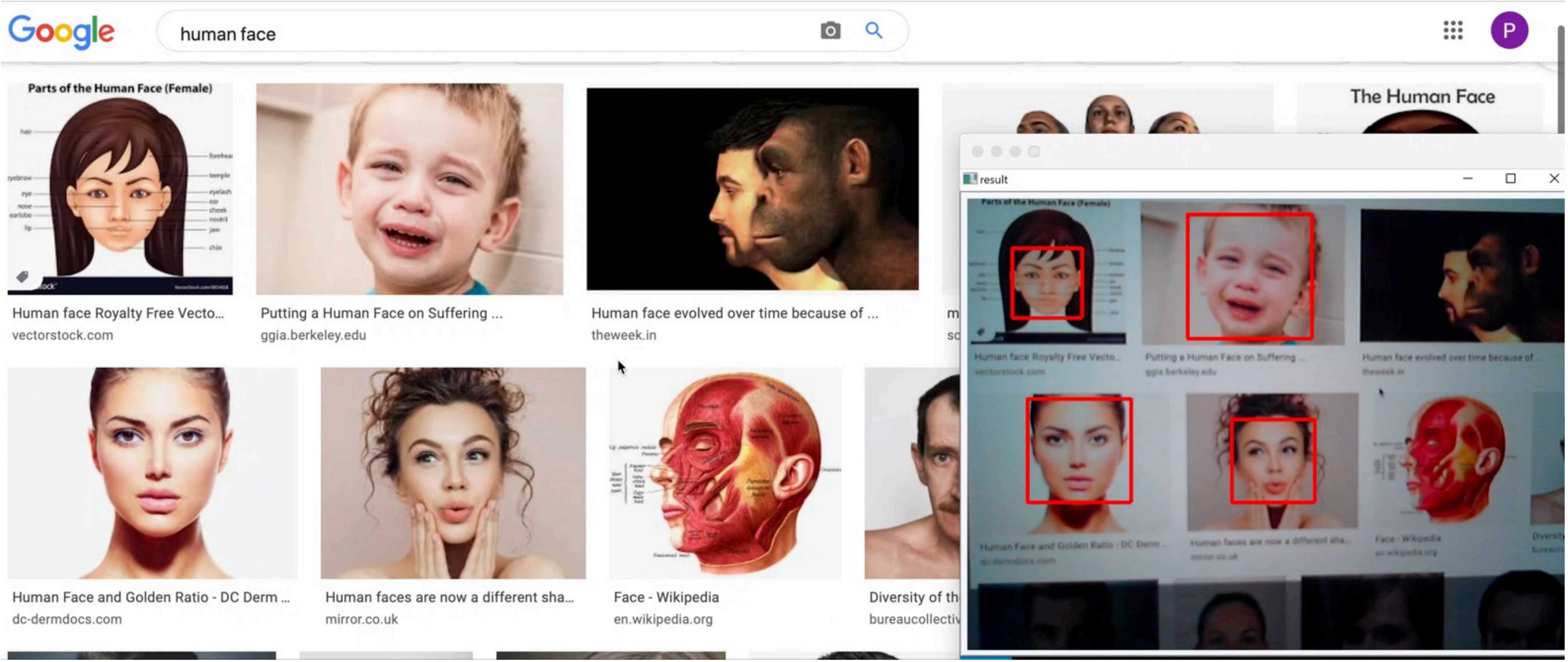
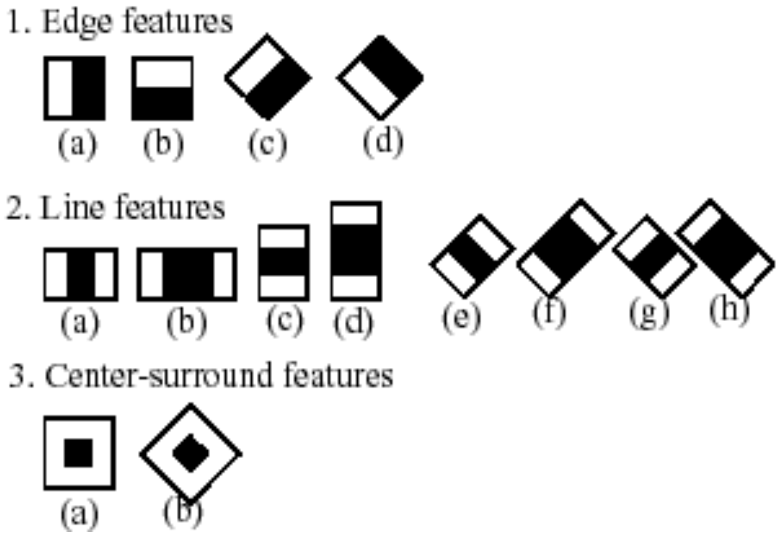
Object detection

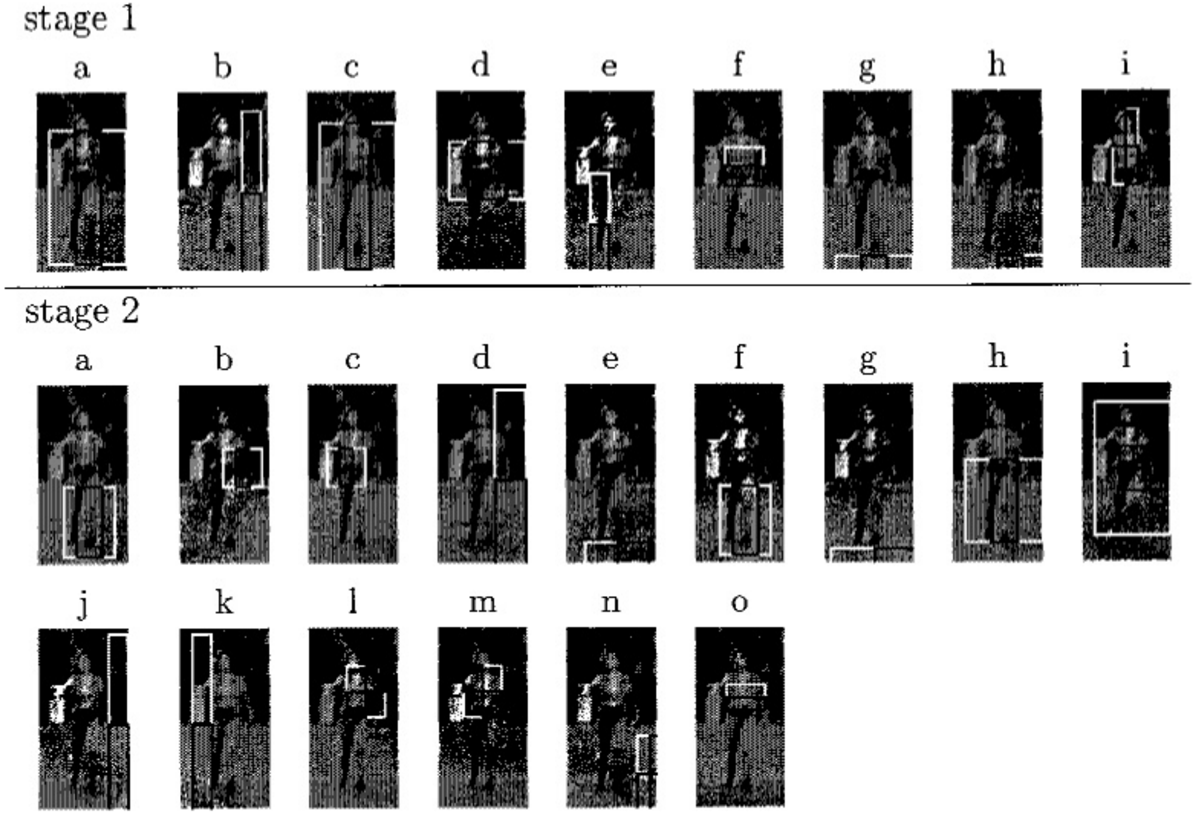


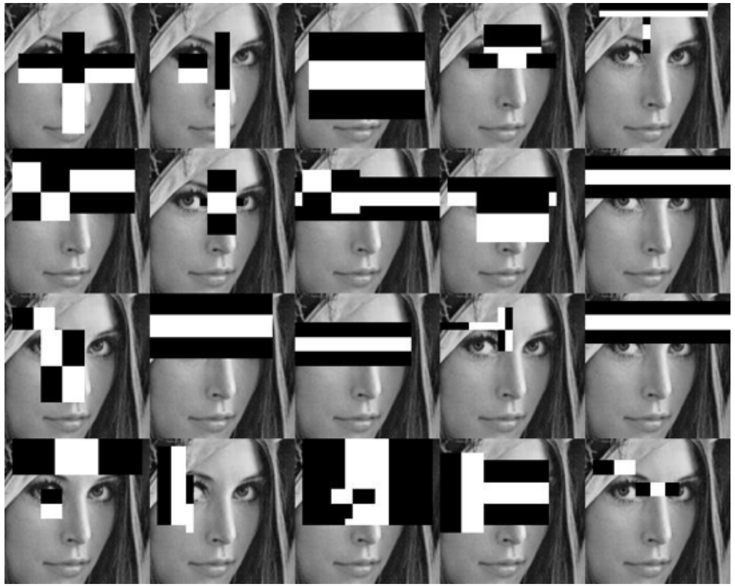
Object recognition

- Cascade of boosted classifiers working with Haar-like features



Object recognition





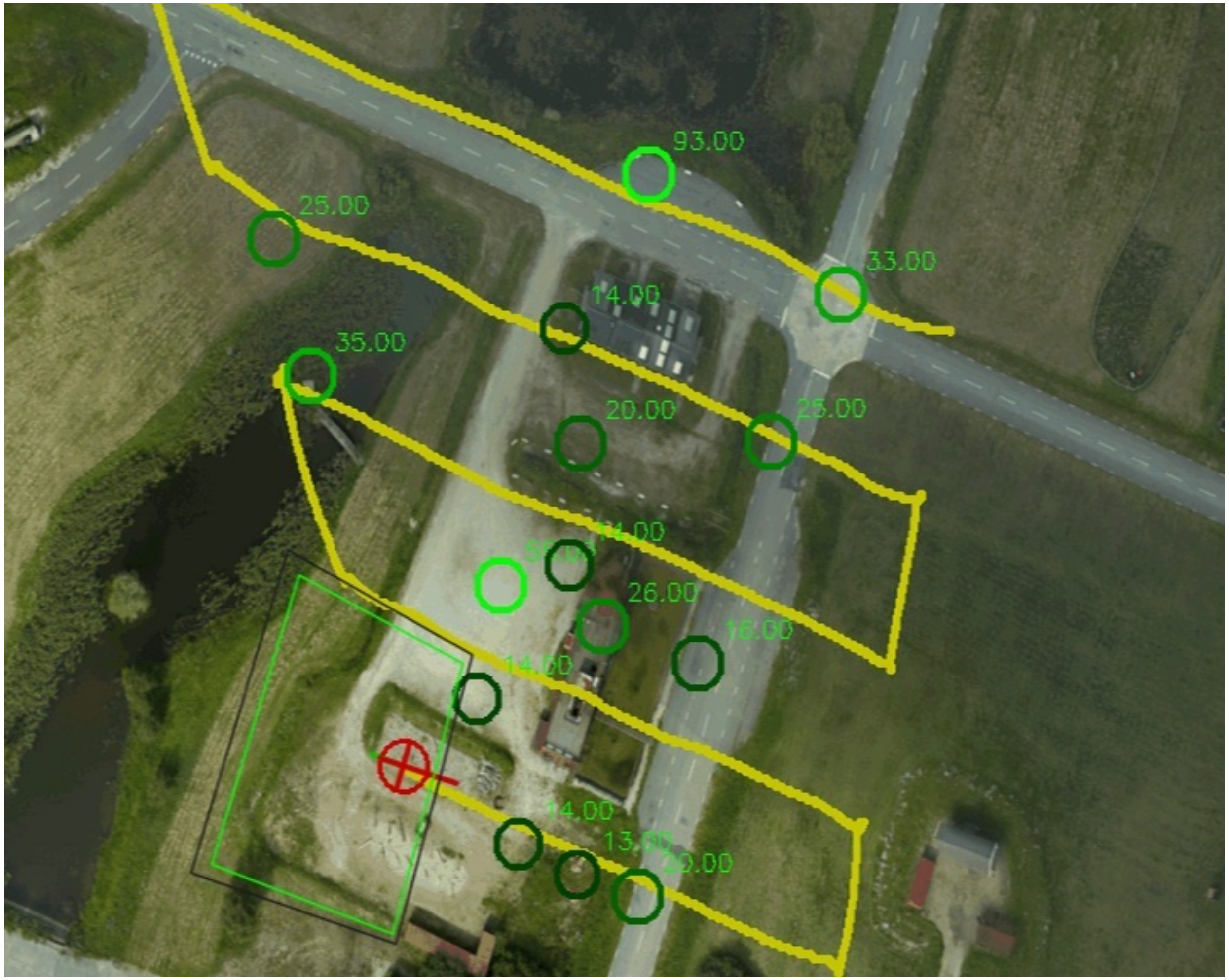
Human body detection with UAVs

THE UAV IS EQUIPPED WITH COLOR AND THERMAL CAMERAS

Human body detection with UAVs

Human body detection with UAVs

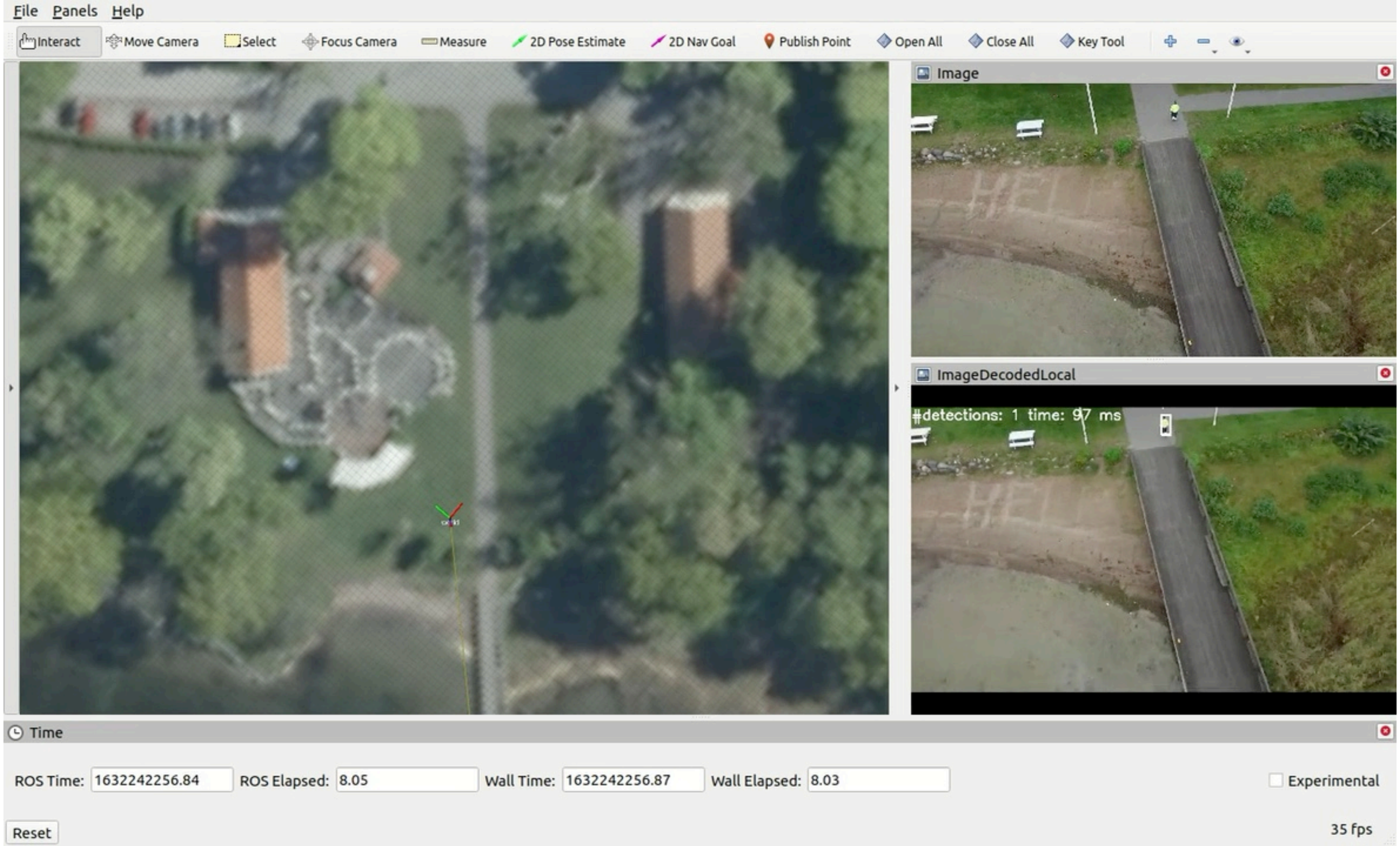
Human body detection with UAVs



Human body detection with UAVs

DJI Matrice 100

Human body detection with UAVs



#detections: 1 time: 97 ms

ROS Time: 1632242256.84 ROS Elapsed: 8.05 Wall Time: 1632242256.87 Wall Elapsed: 8.03 ☐ Experimental

35 fps

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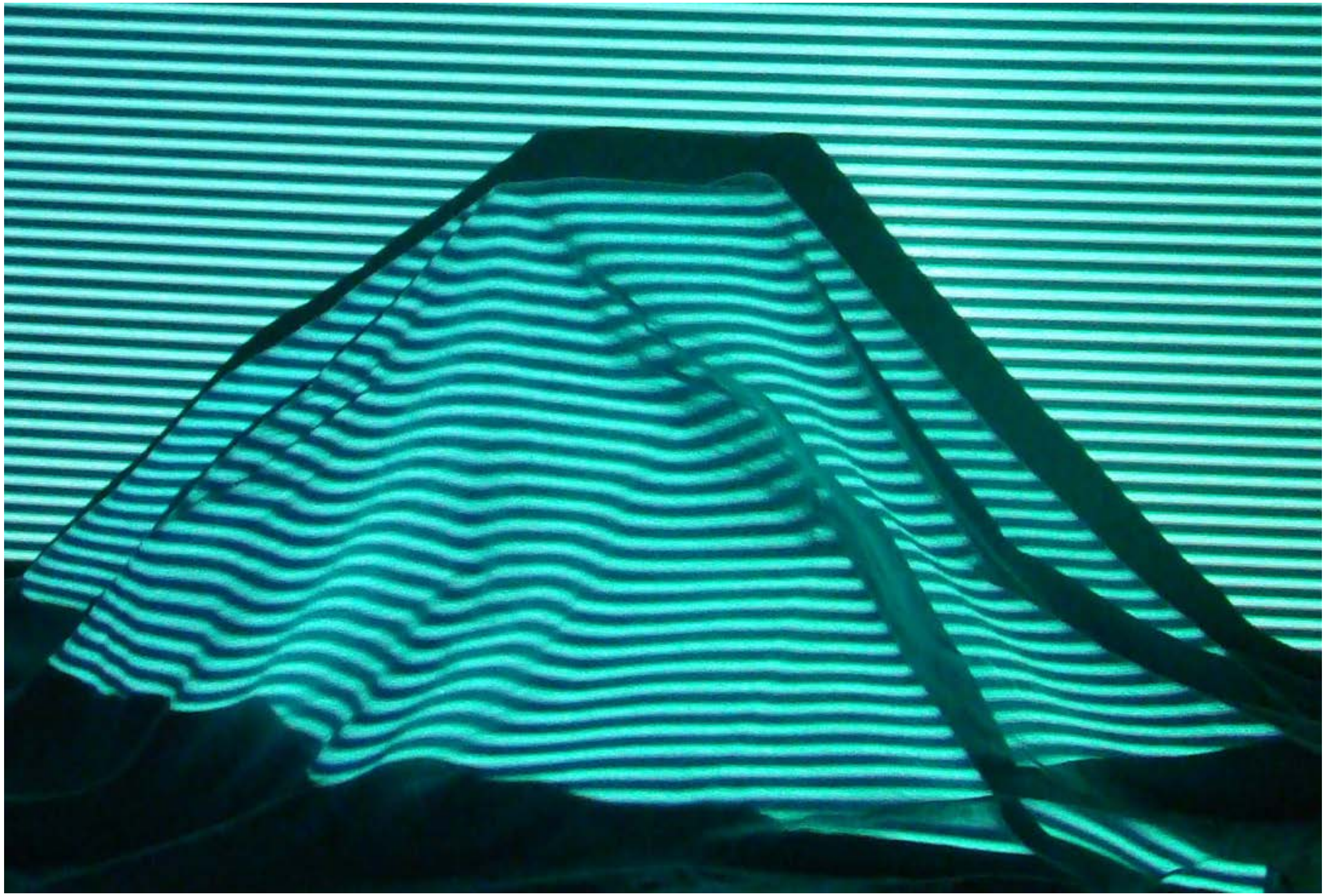
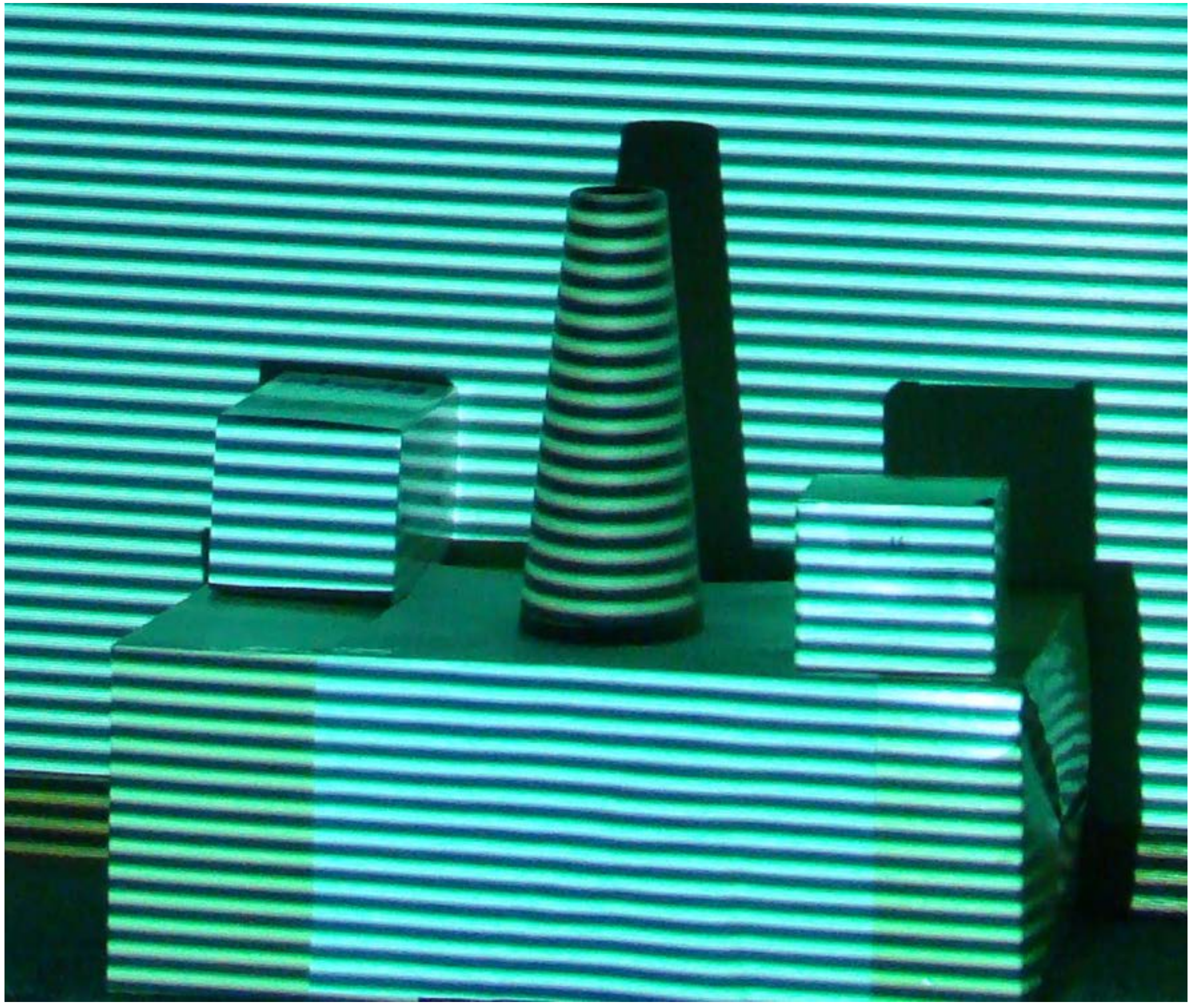
- **Kinect: Structured Light**
- Laser Range Finder

Structured Light

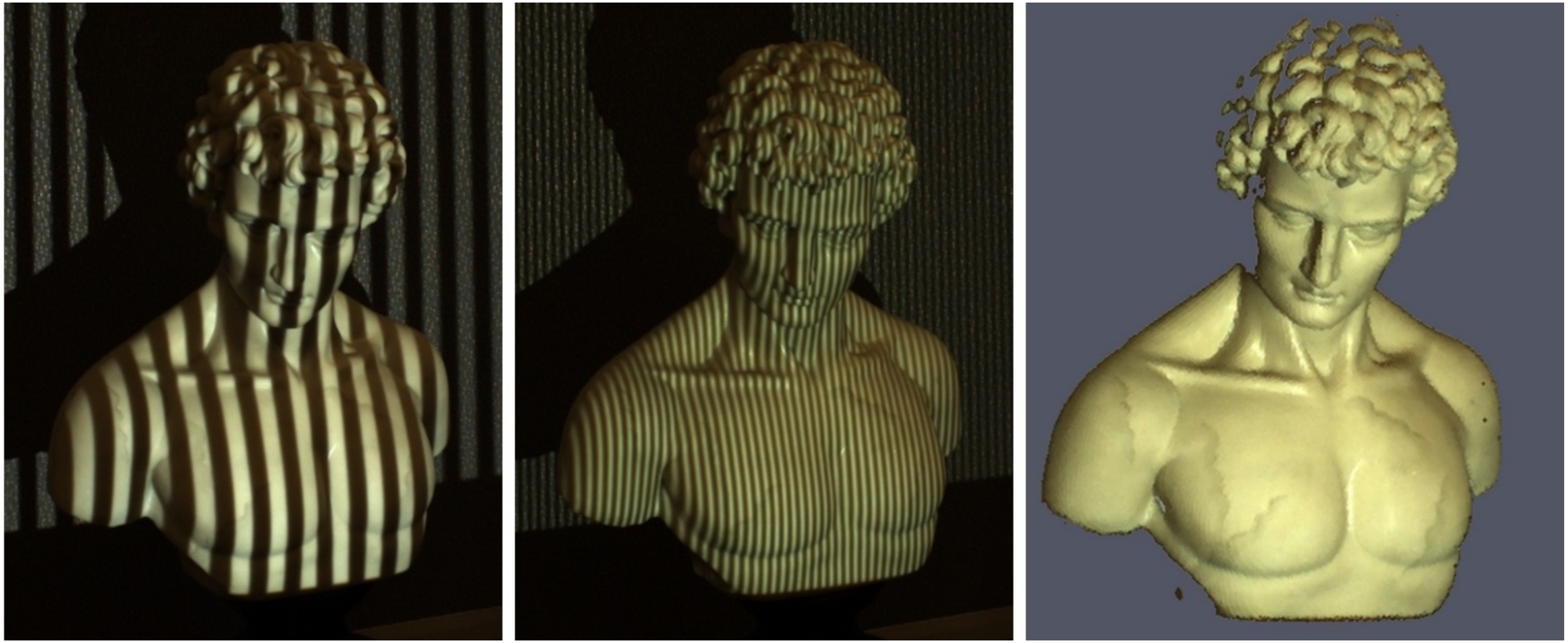
Structured Light



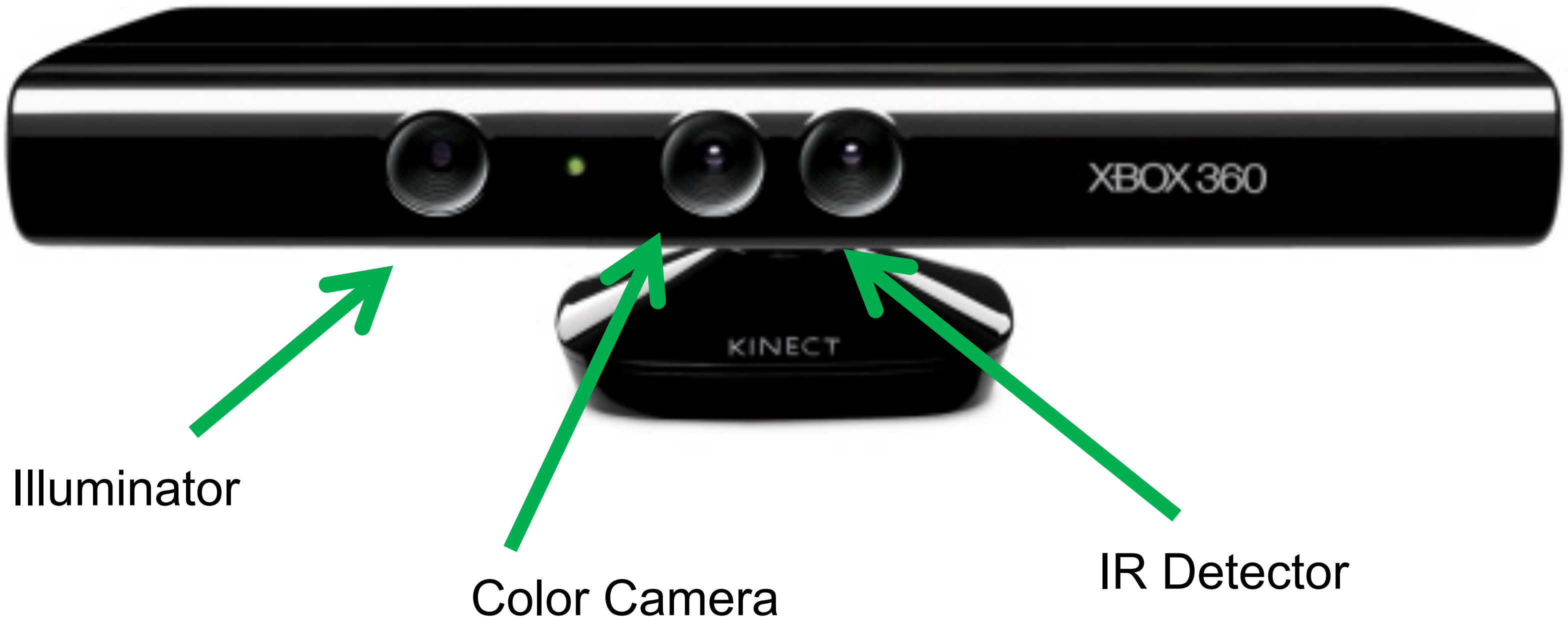
Structured Light



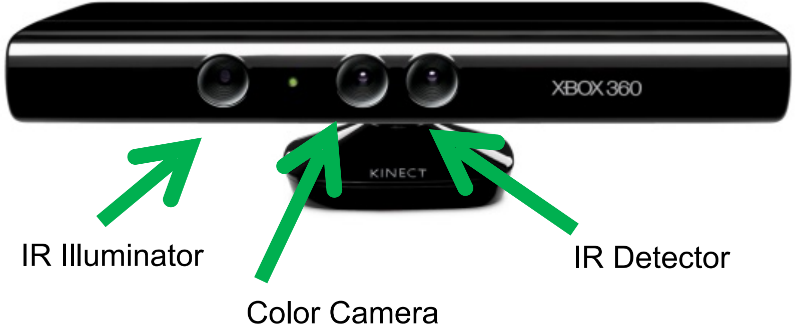
Structured Light

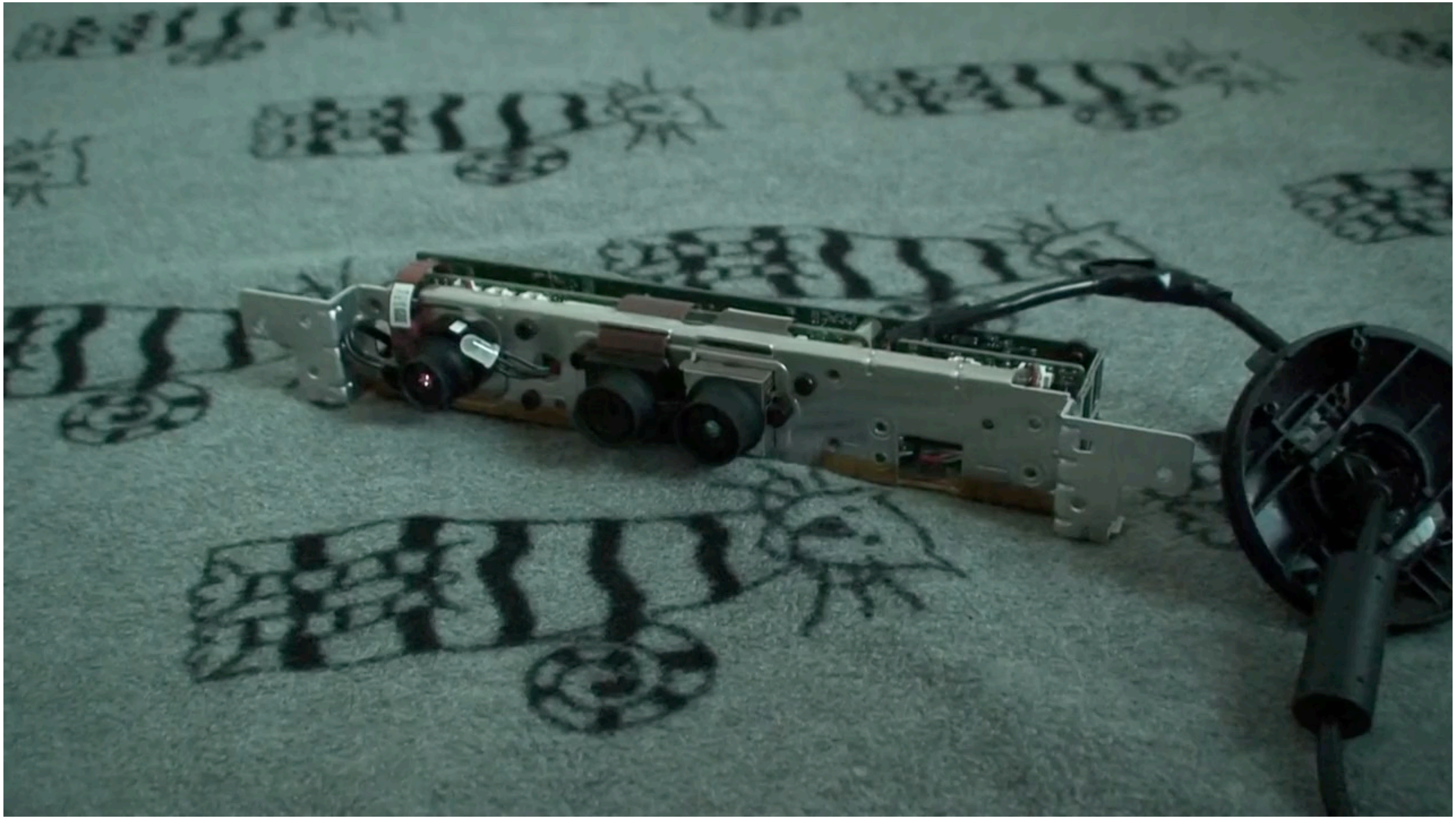


Kinect



Kinect

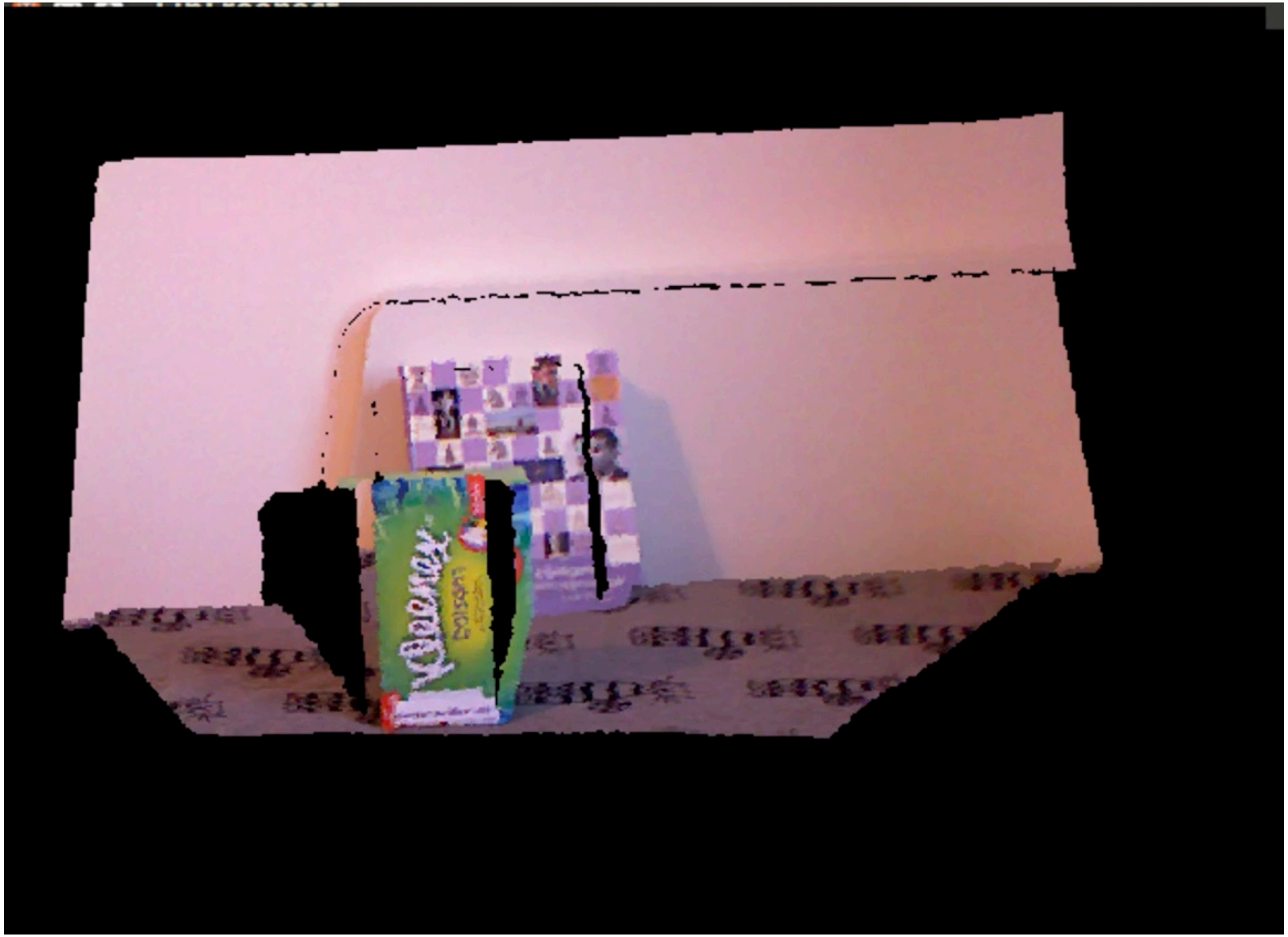




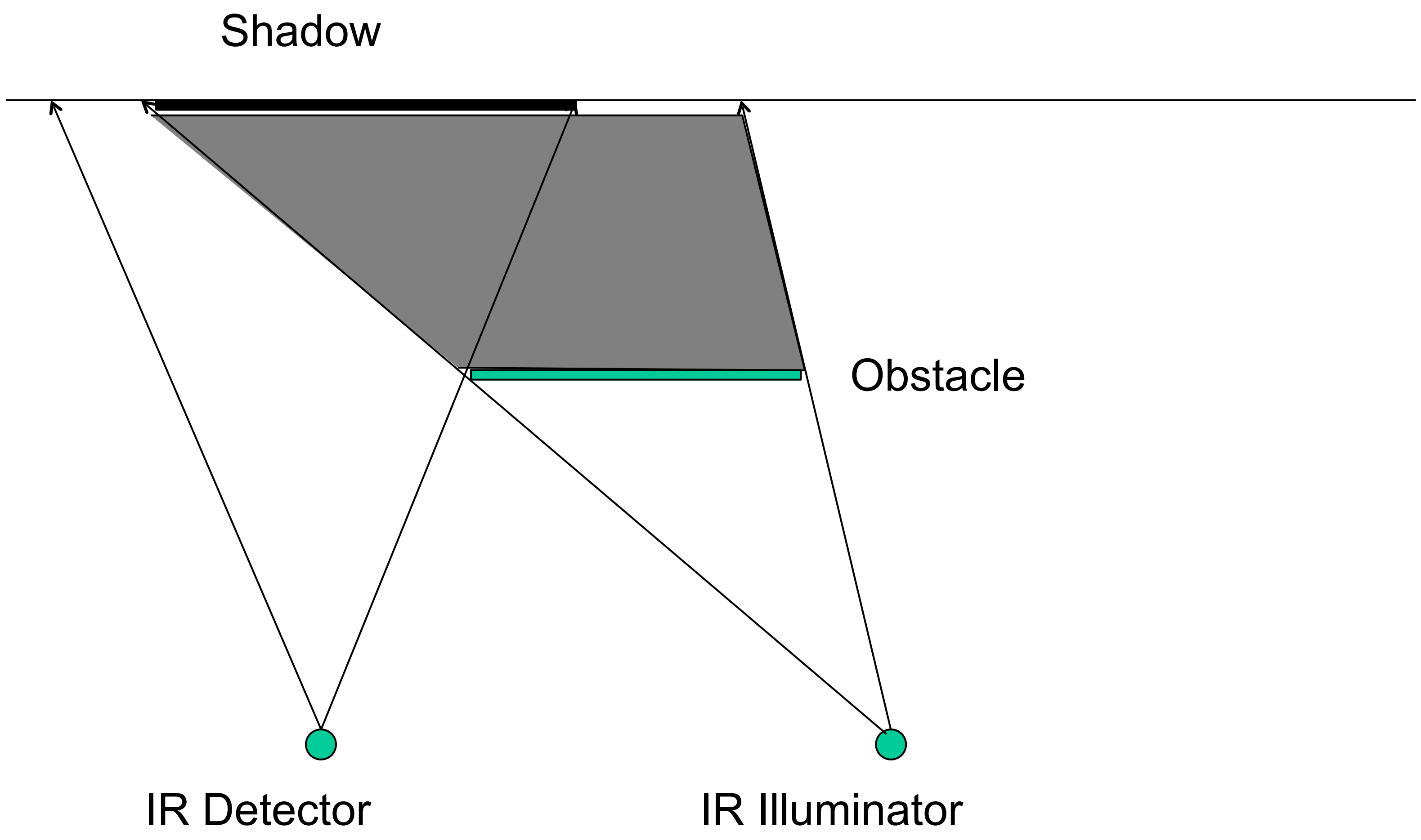
Kinect

Structured Light

Structured Light

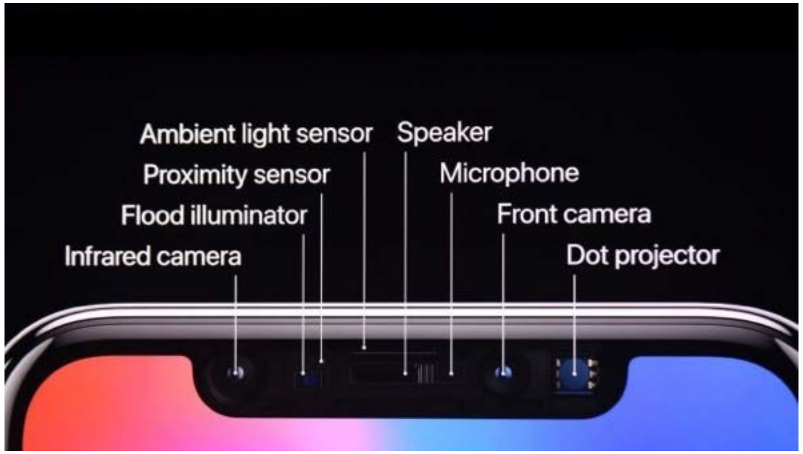


Shadows



Shadows

Application - FaceID



The Verge, Apple

Application - LiDAR

The Verge, Apple

Application - LiDAR - AR

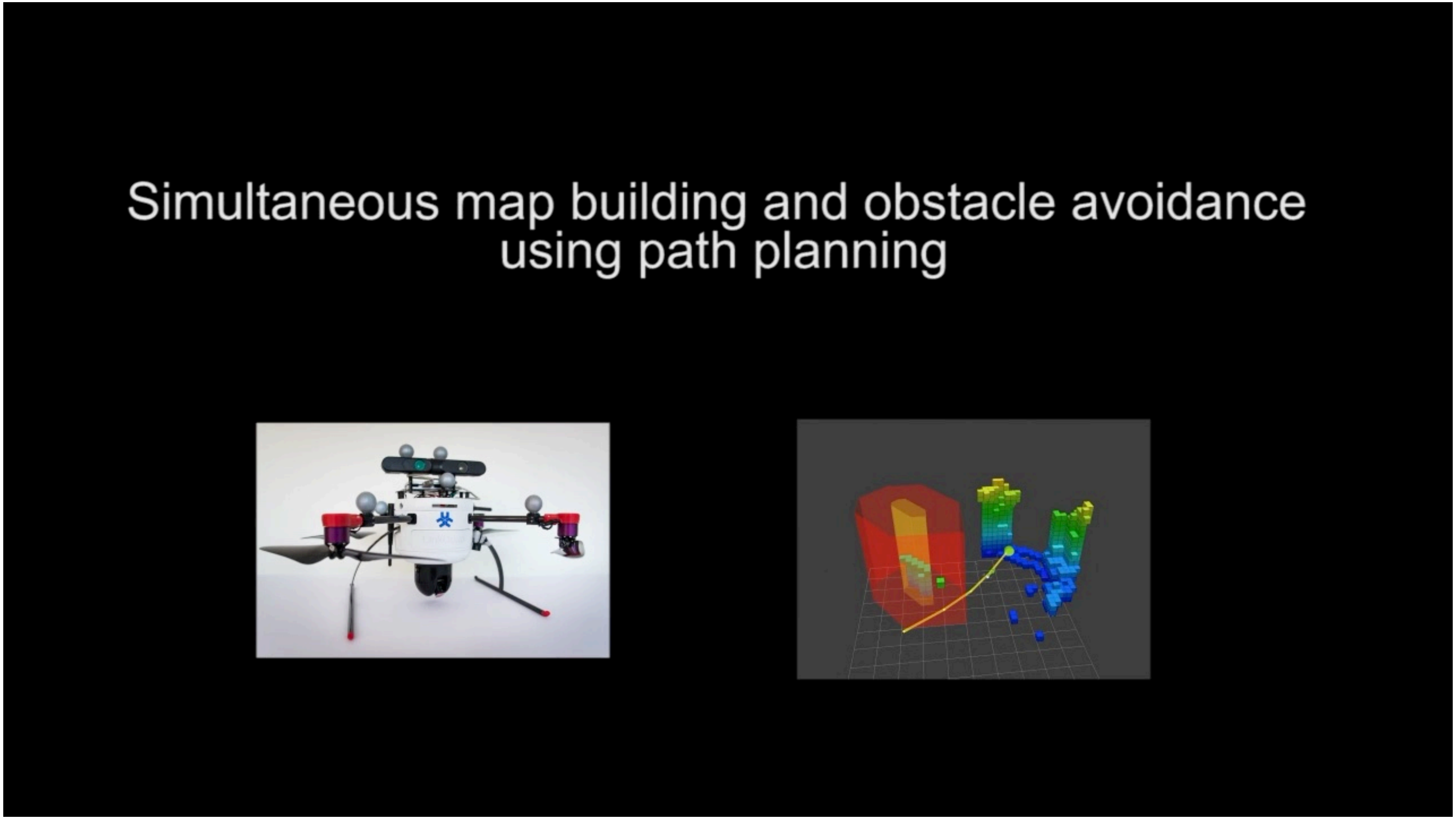
Lamp

○

Top view

IKEA Place app

Kinect and UAVs



Simultaneous map building and obstacle avoidance using path planning

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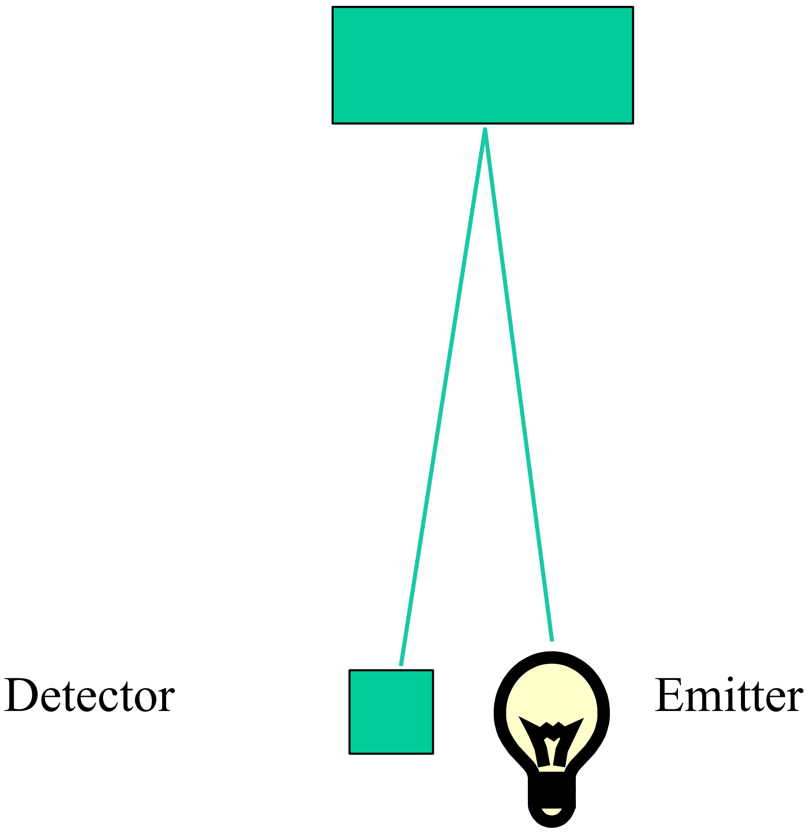
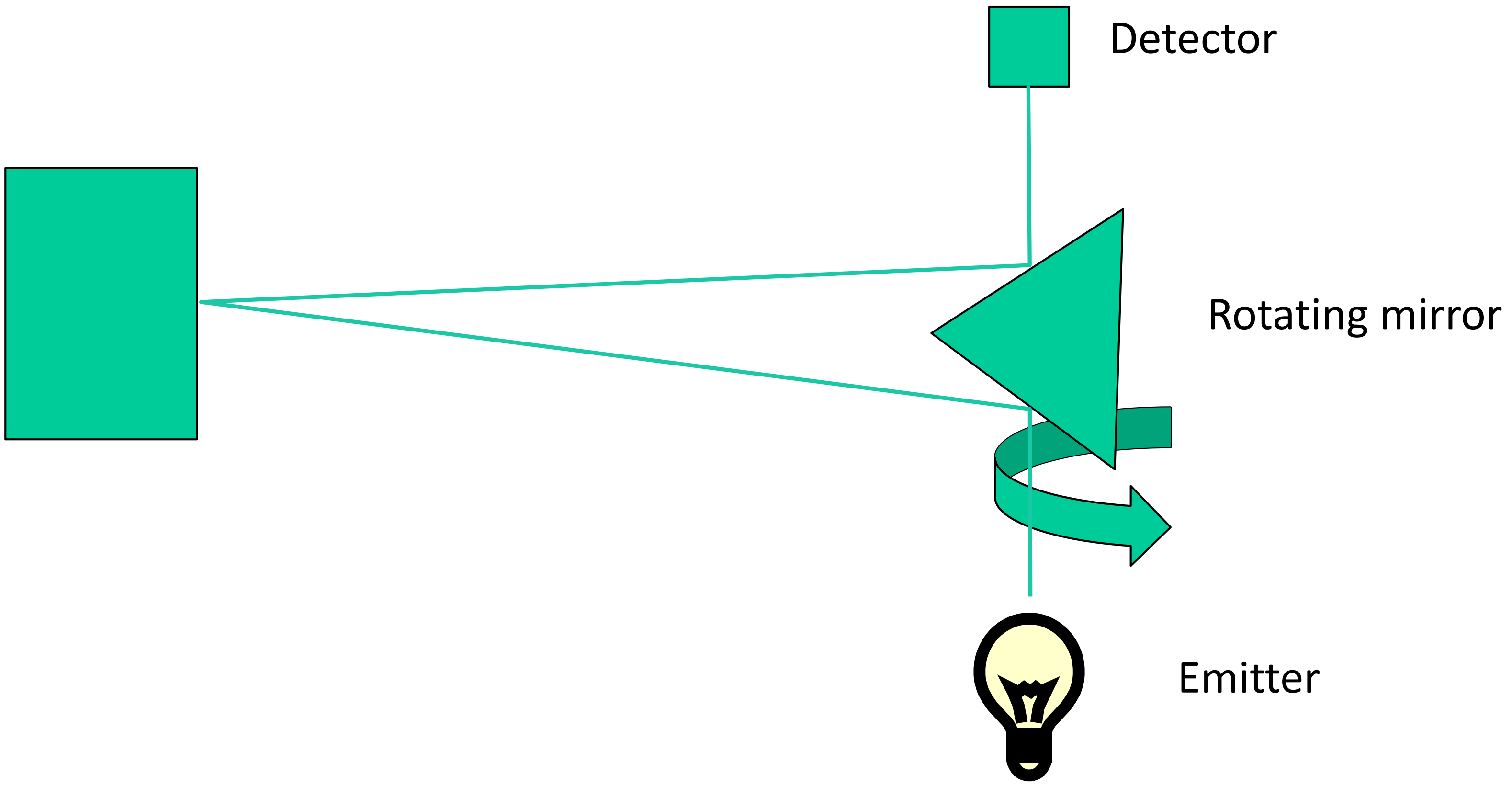
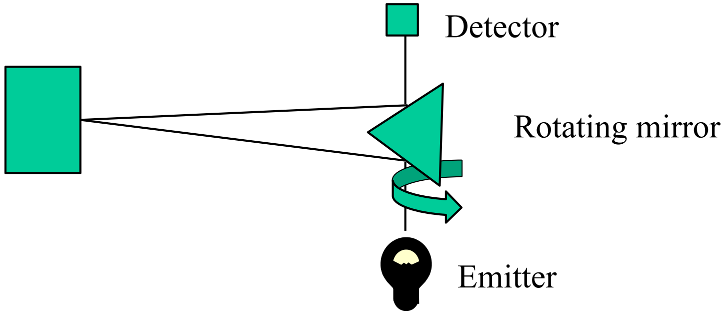
- **Laser Range Finder**

Laser Range Finder – 1D

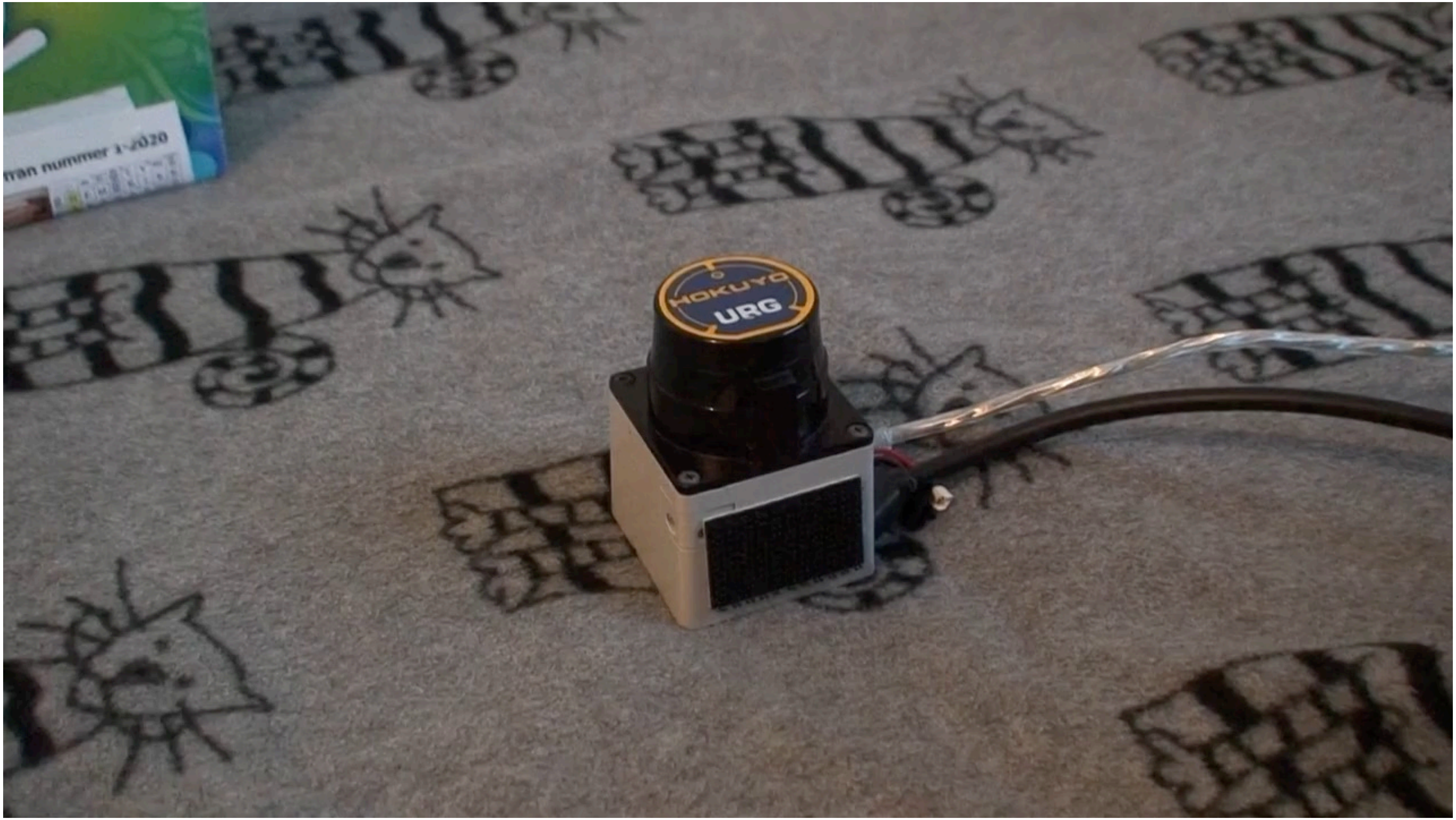


Laser Range Finder - Sweeping

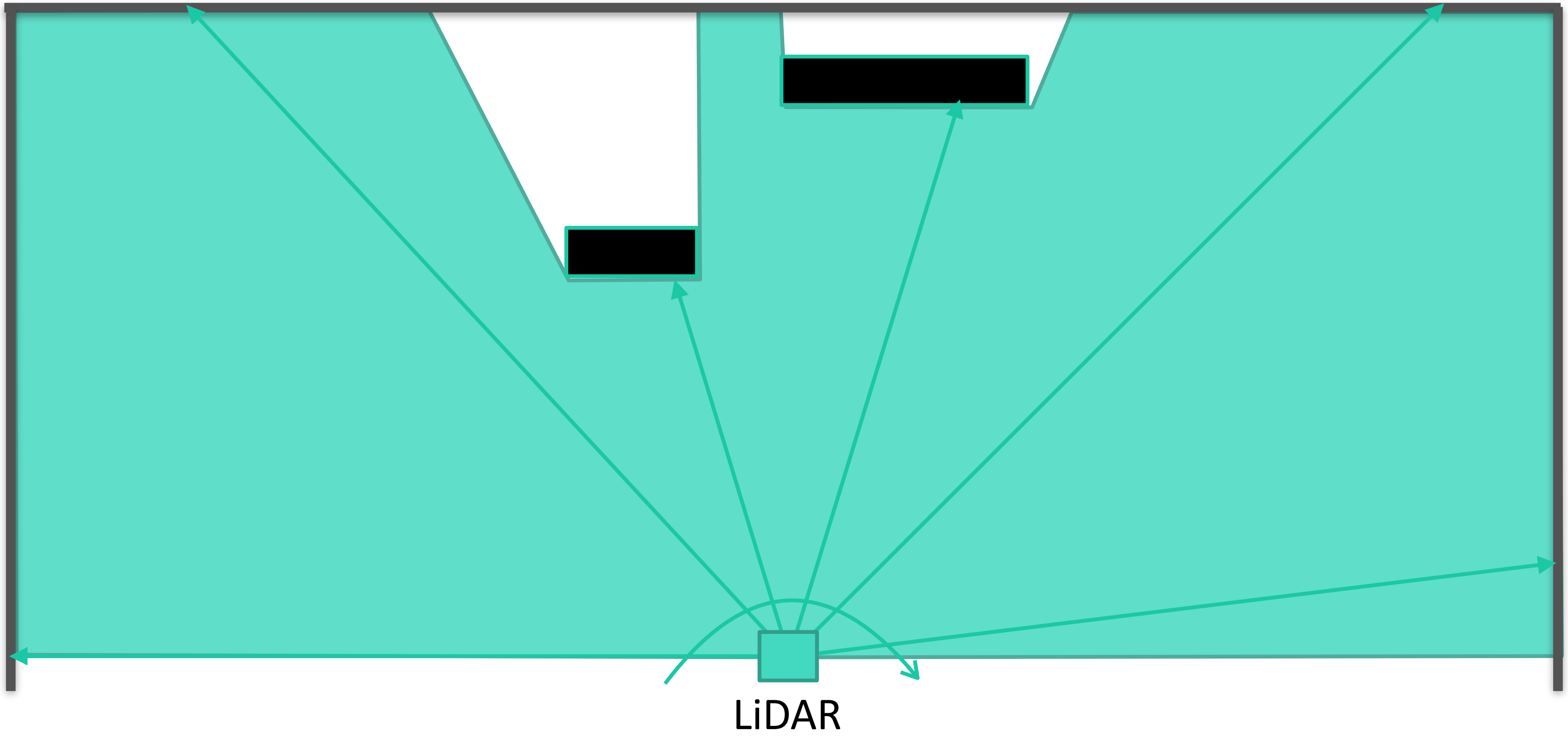




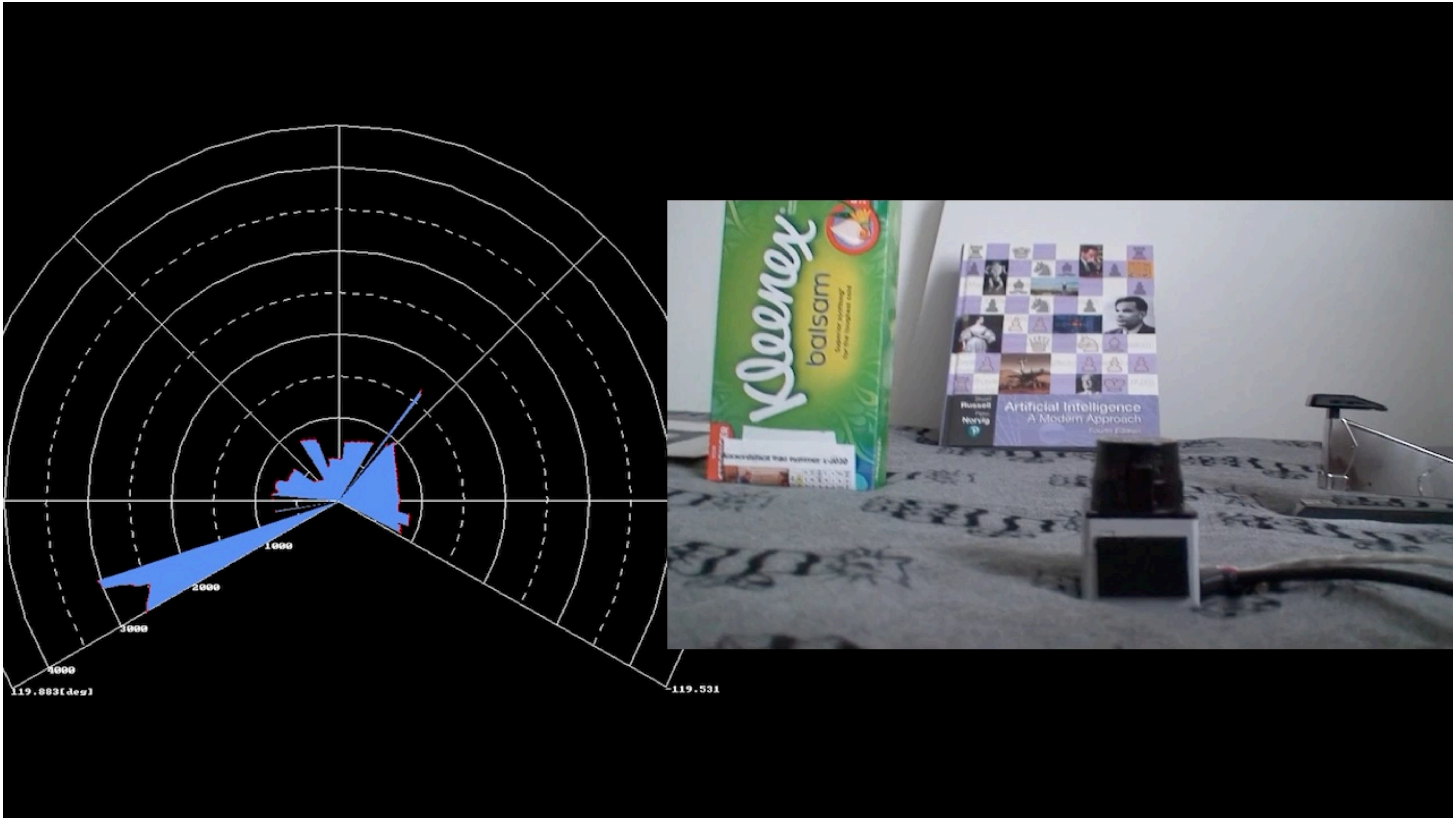
Hokuyo URG-04LX



Laser Range Finder - Sweeping



Top view


1000
2000
3000
4000
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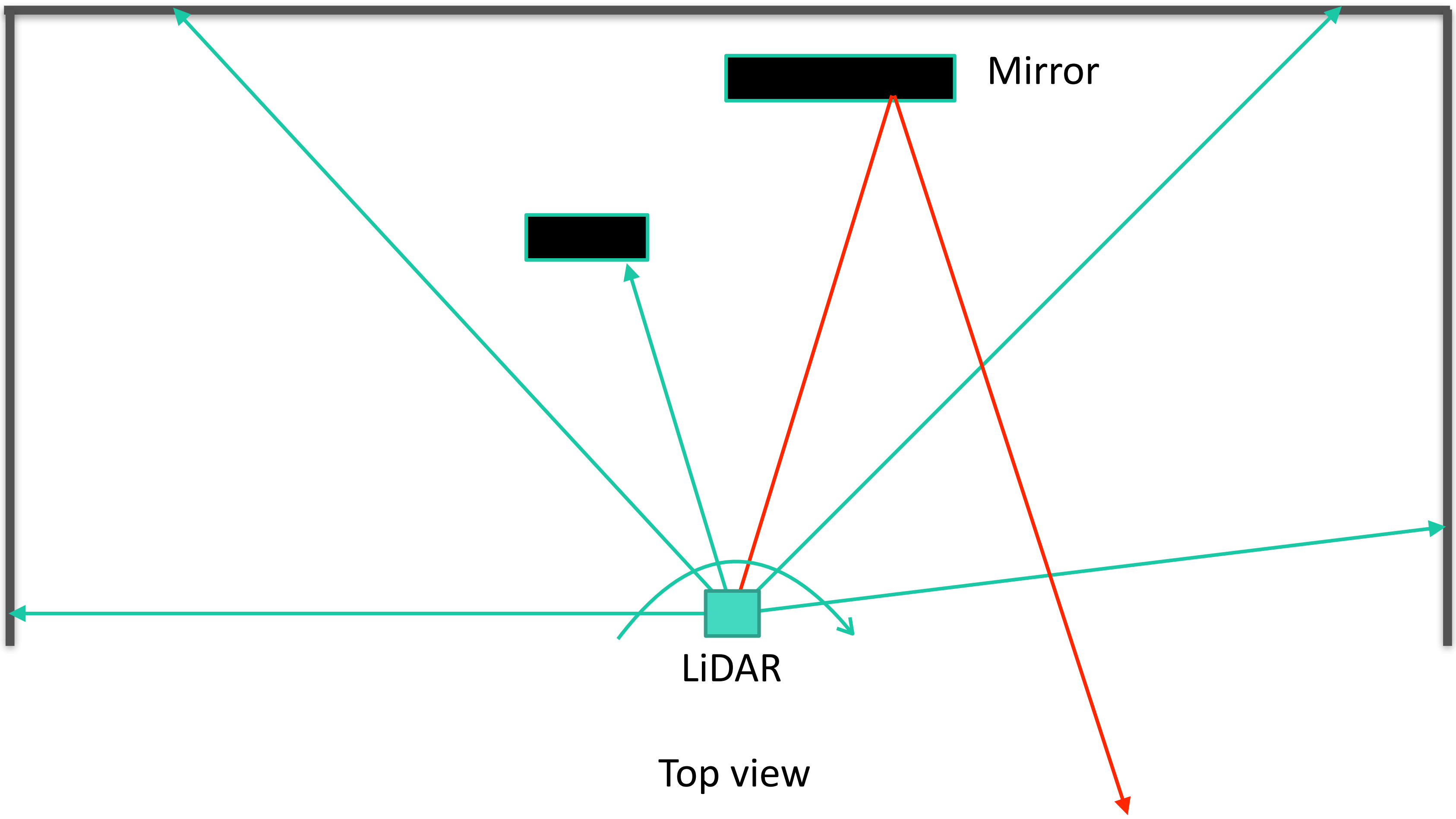
Kleenex
balsam
Russell
Norvig
Artificial Intelligence
A Modern Approach

Laser Range Finder



Top view

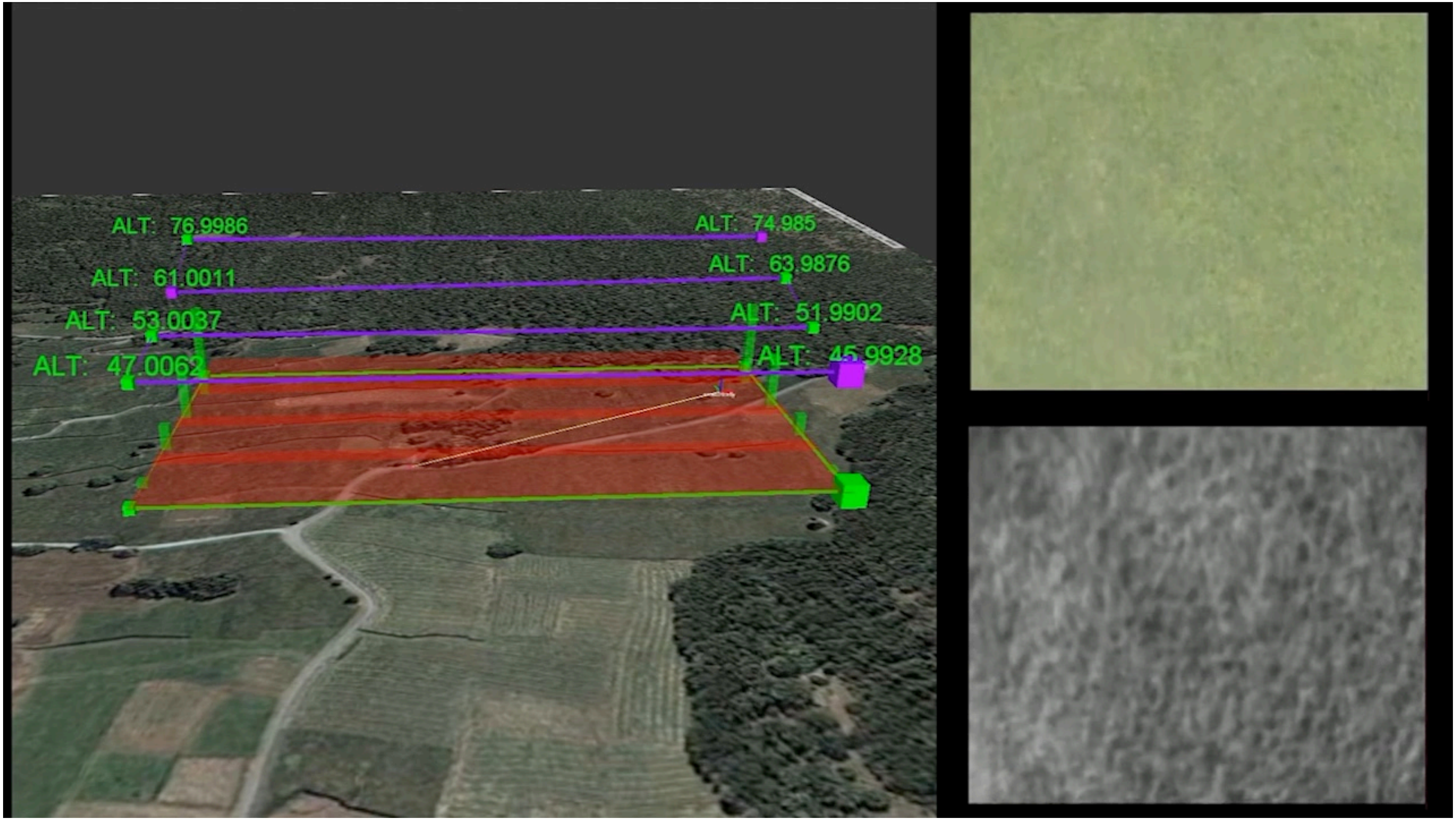
3D Laser Scanner On a UAV

Yamaha RMAX

Sick LMS 291

DJI Matrice 600 Pro

Velodyne Puck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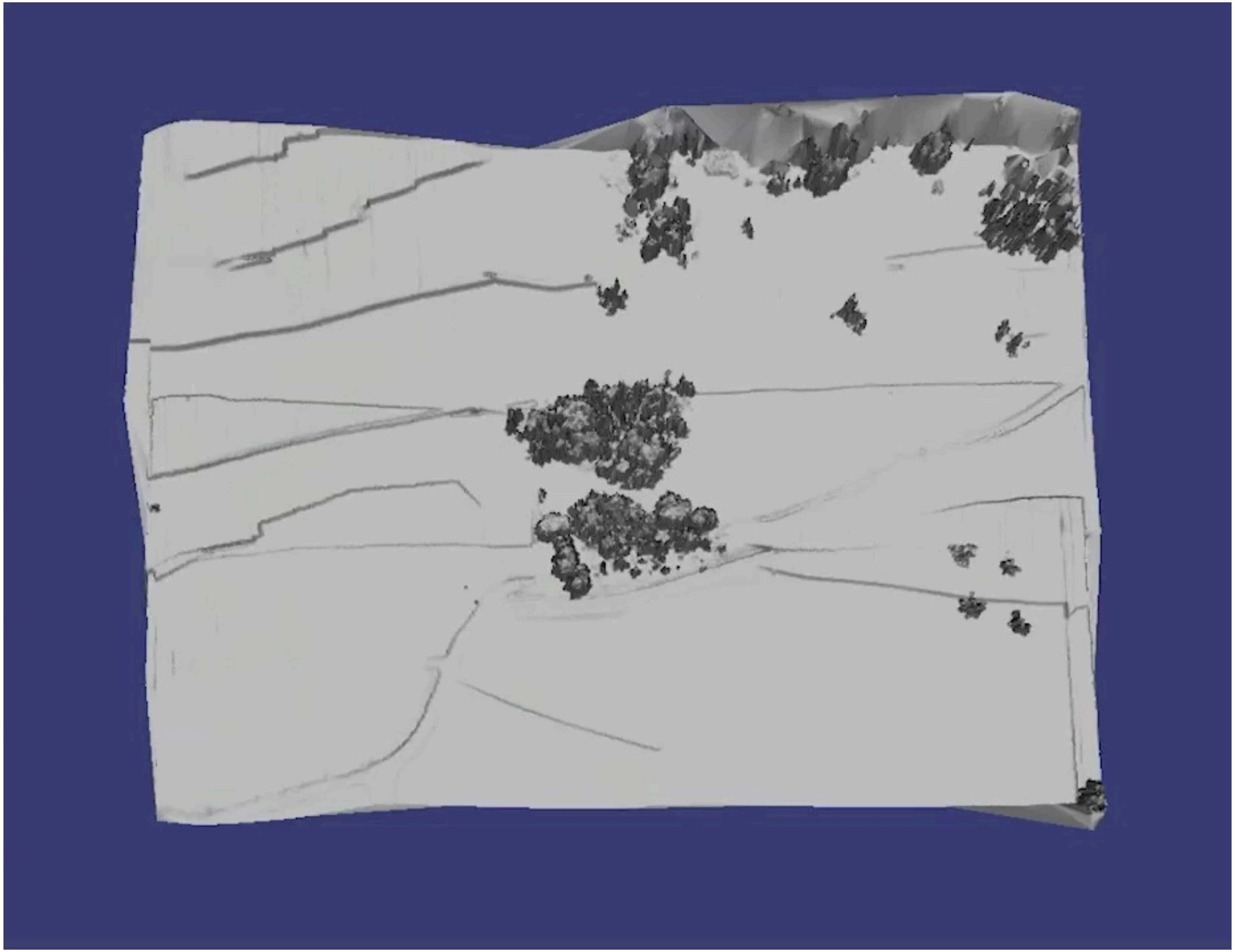

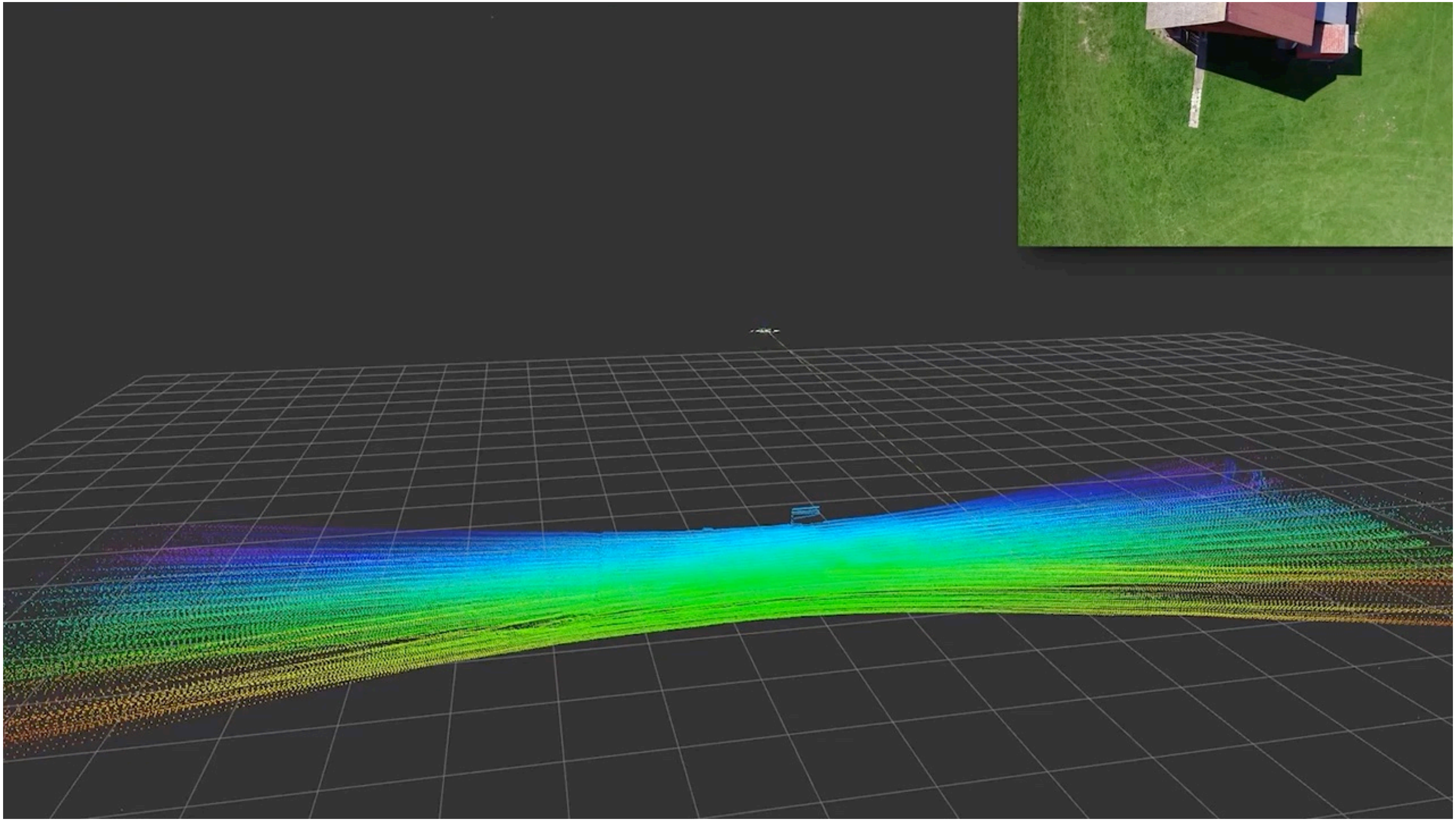

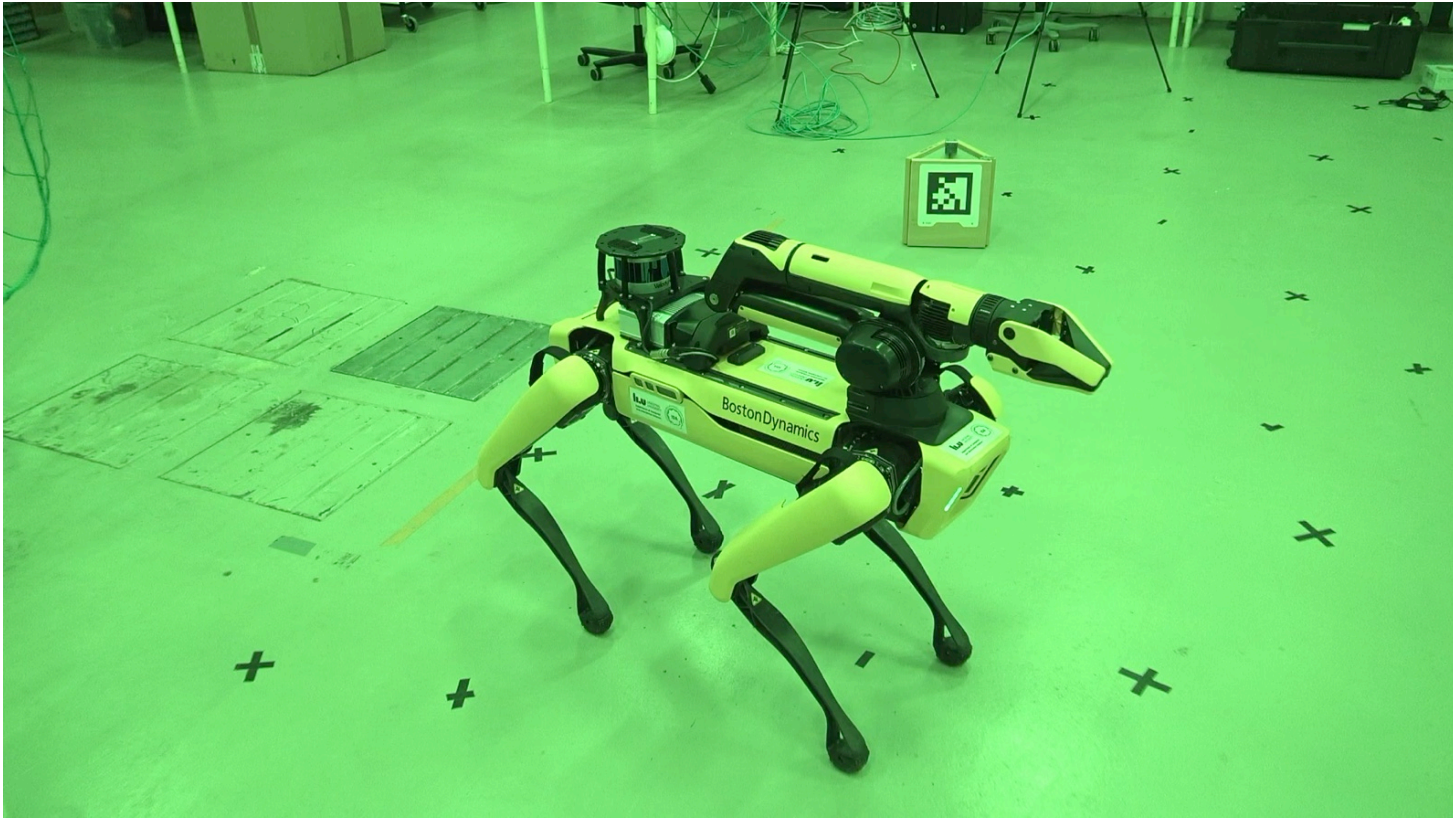
BostonDynamics

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- **Next lecture: Localisation, planning, other hardware...**