MEMS mirror for LiDAR and Laser Display

By

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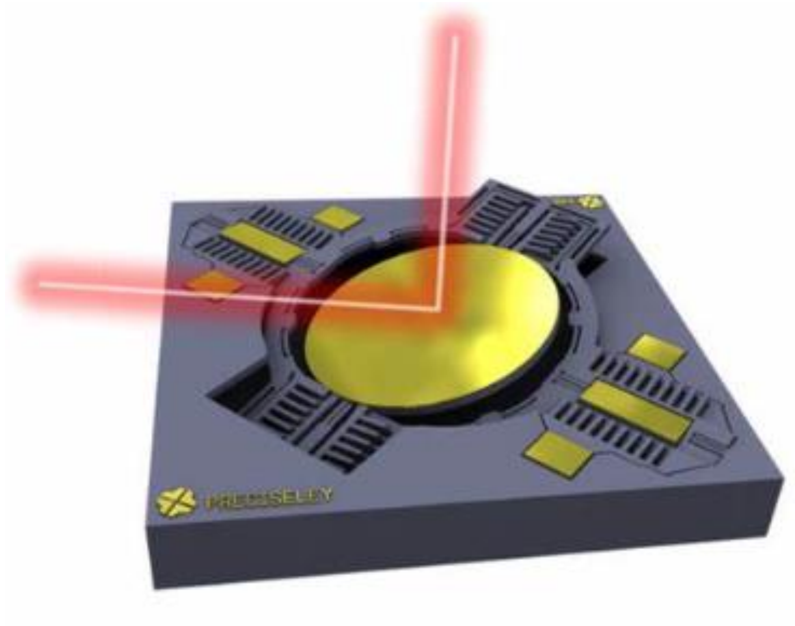
MEMS Mirror

What is a MEMS Mirror?

- Micro-Electro-Mechanical Systems (MEMS)
    - MEMS mirror is an actuator that steers optical beams.



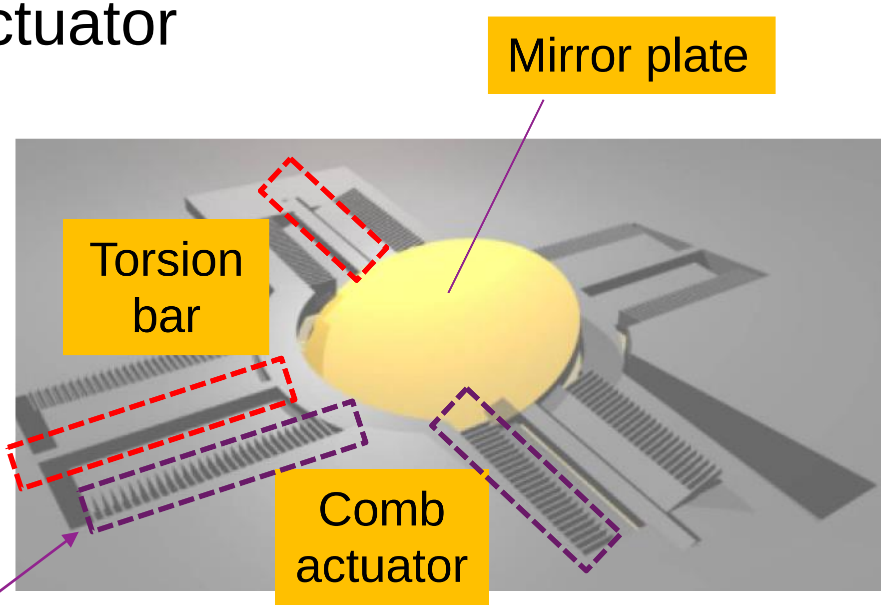
✓ In recent years, MEMS mirror has gained popularity for use as micro scanners in commercial products like,

- Laser projector
- LiDAR camera
- AR/VR glass

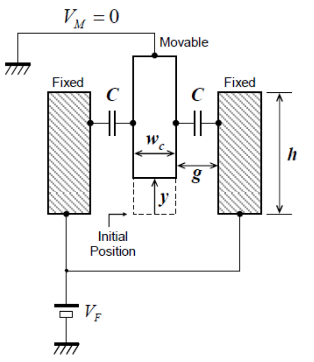
MEMS Mirror

Key components of MEMS Mirror

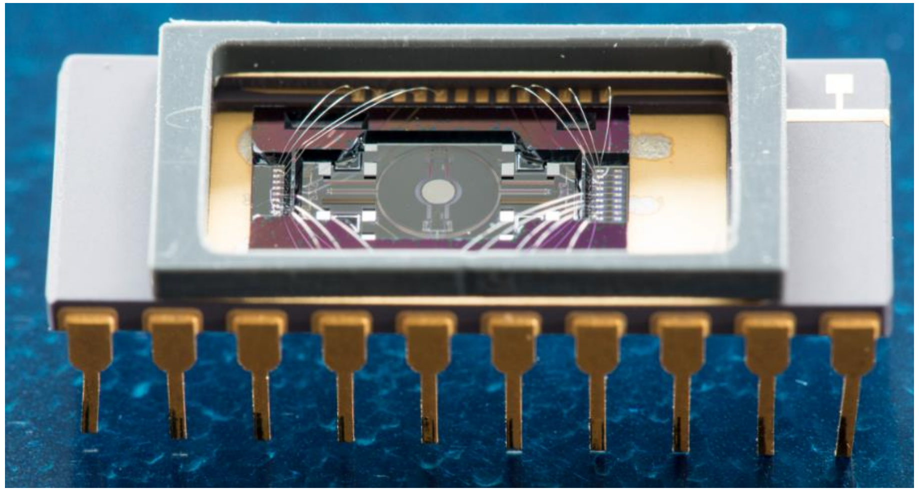
- Reflecting surface
- Torsion bar
- Actuator



Electrostatic actuated MEMS Mirror for 2D scanning



➢ Electrostatic actuation:
A capacitive force generated after applying voltage between two plates.

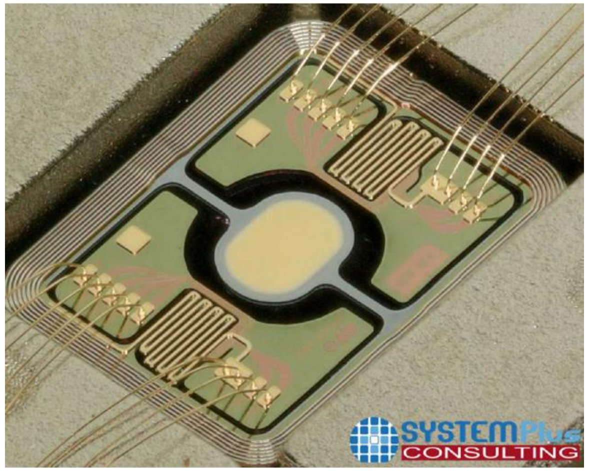


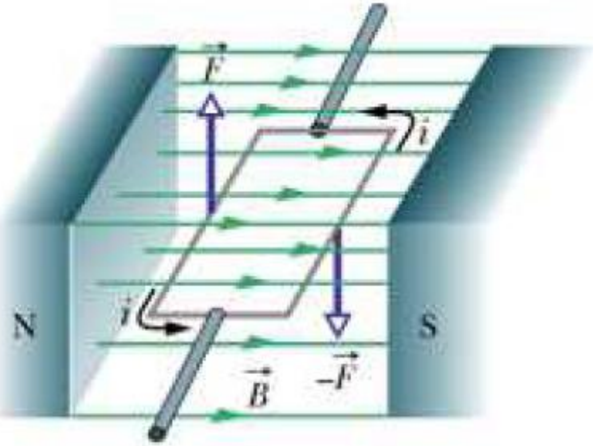
Fabricated MEMS Mirror chip (~mm)

Working Principle of MEMS Mirror

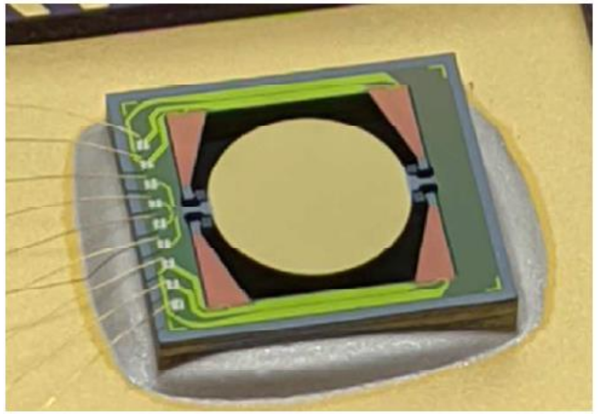
Actuation Mechanism

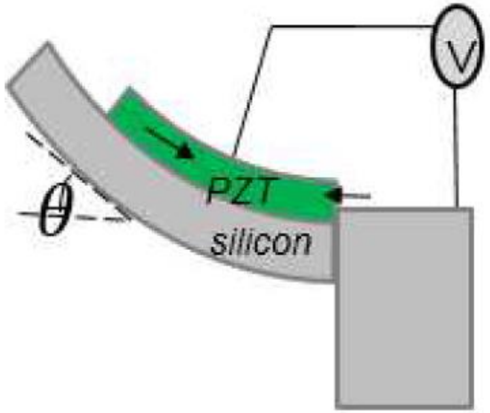
□ electromagnetic





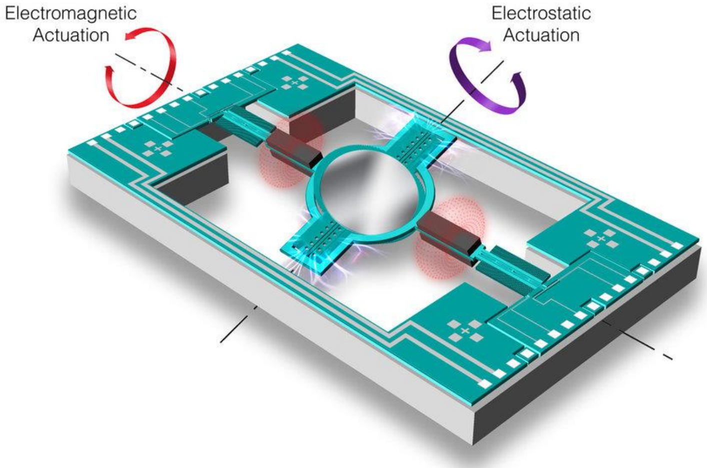
□ piezoelectric





➢ Comparison between different actuation

Category	Electrostatic	Electromagnetic	Piezoelectric
Preferred Type	Comb drive	Moving coil	PZT film
Simple Fabrication	✓✓✓	✓✓✓	✓✓
Large Displacement	✓✓	✓✓✓	✓
High Force	✓	✓✓	✓✓✓
Low Power	✓✓	✓	✓✓✓
Low Voltage	✓	✓✓✓	✓✓
Compactness	✓✓✓	✓	✓✓✓
Linearity	✓	✓✓✓	✓✓



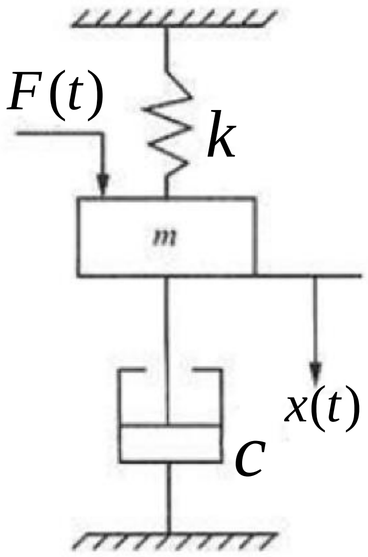
Combination of different actuation

MCK Model for Vibration Analysis

- a mass-spring-damping system

m: mass
k: spring
c: damping

Input: mechanical force
Output: displacement



- Static equation

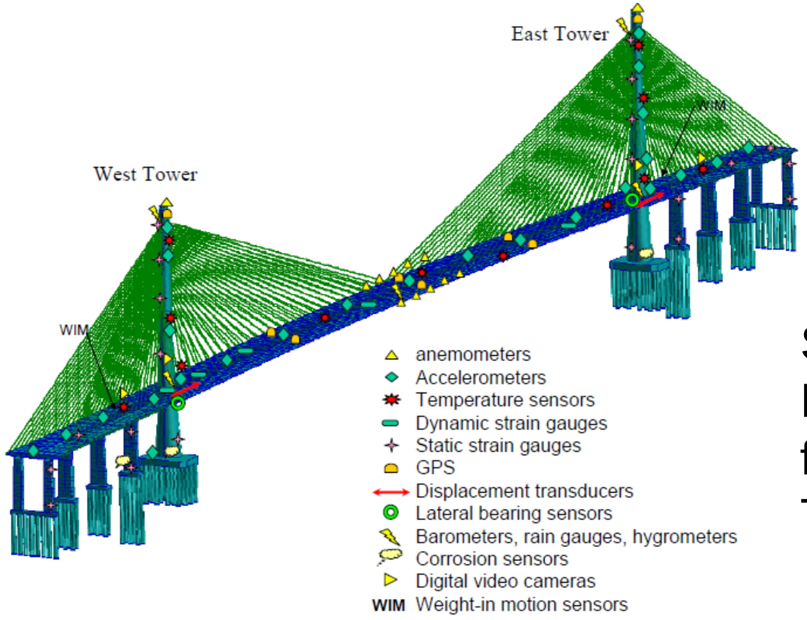
$$kx = F$$

- dynamic equation

$$m\frac{d^2x}{dt^2} + c\frac{dx}{dt} + kx = F(t)$$

MCK model is widely used in vibration engineering!!!

The Tacoma Bridge collapsed due to high winds on November 7, 1940.

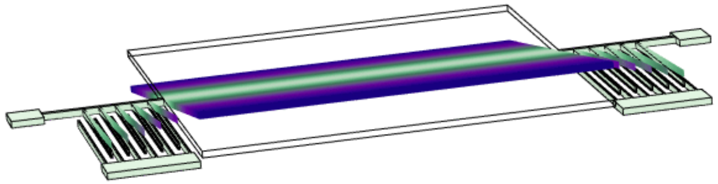


Structural Health Monitoring System for Hong Kong's Tsing-Ma Bridge

Modelling of MEMS Mirror

➢ MCK model for the motion of MEMS Mirror

Input: electrical force
Output: rotation angle

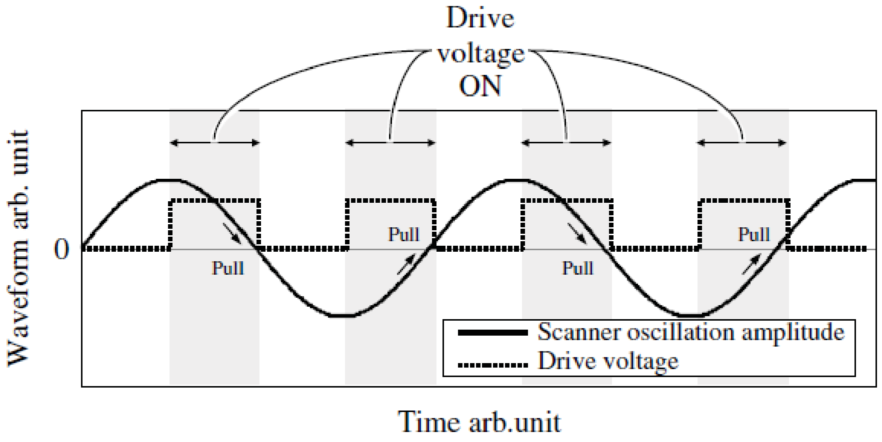


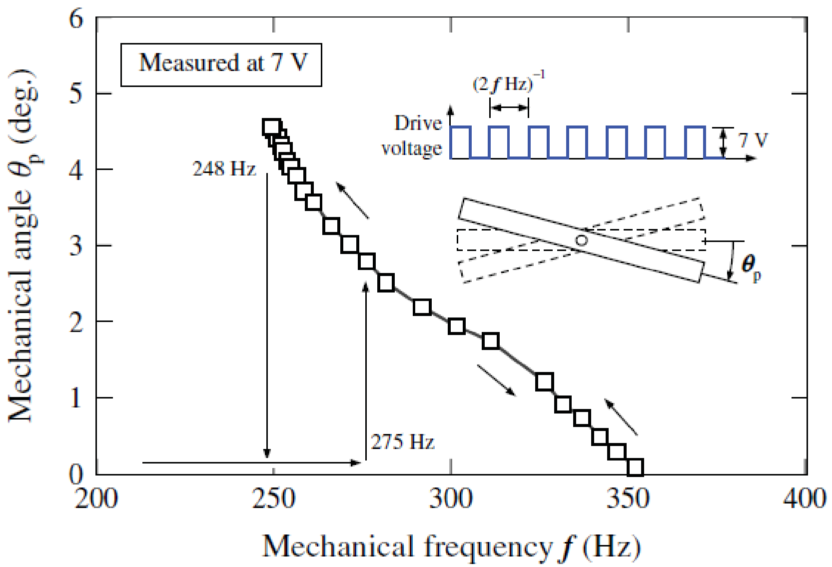
- Static equation (under DC voltage)

$$k\theta = F_e$$

- Dynamic equation (under AC voltage)

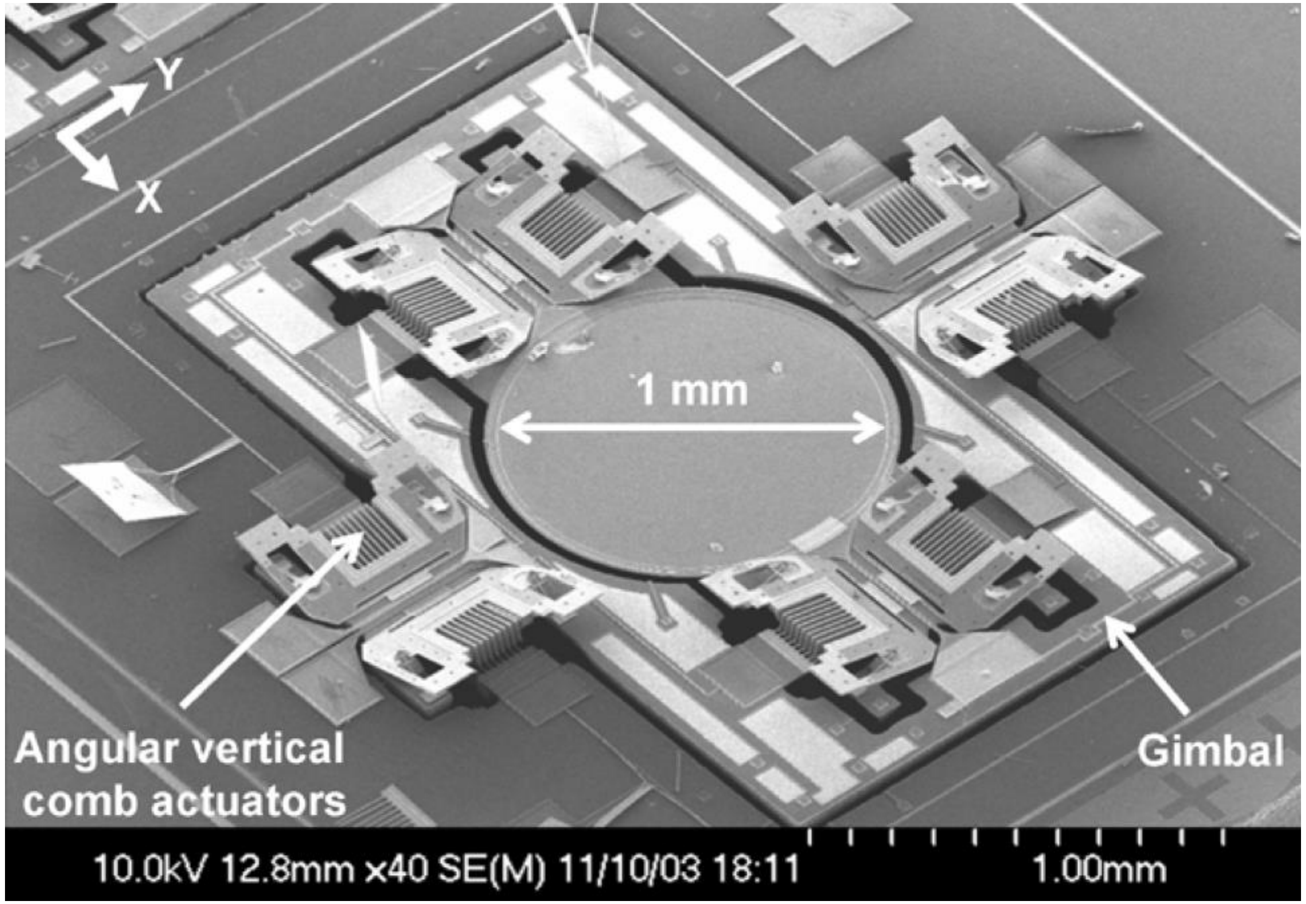
$$m\frac{d^2\theta}{dt^2} + c\frac{d\theta}{dt} + k\theta = F_e(t)$$

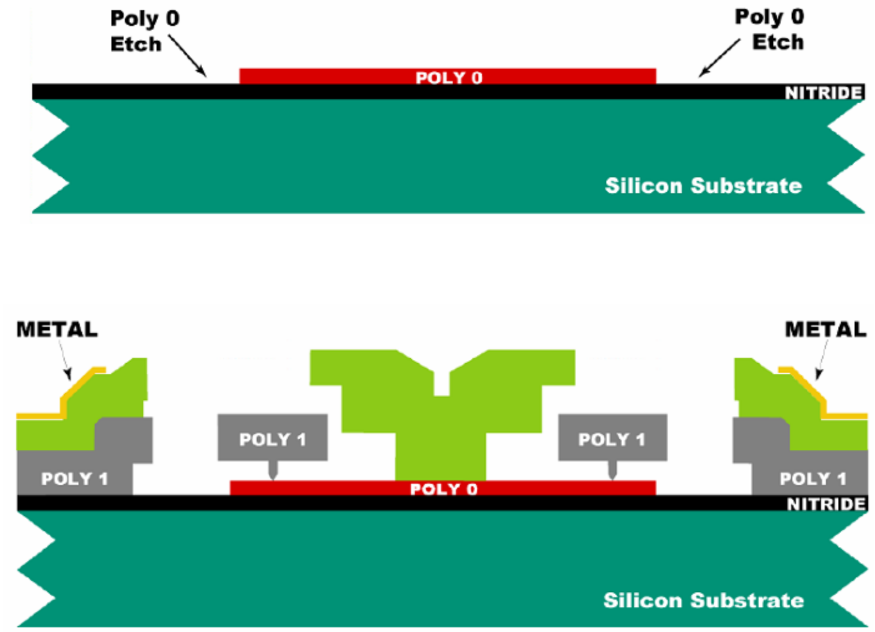




Fabrication of MEMS Mirror

surface-/bulk- micromachining process



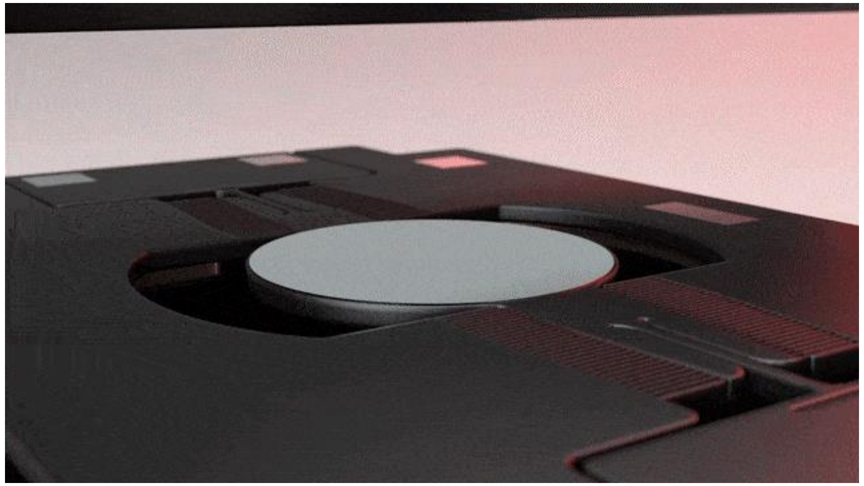


from *PolyMUMPs.Inc*

Common MEMS Mirror Criteria

- Performance
  - **Field of View (FoV)**
  - Scanning frequency
  - **Resolution**
  - Bandwidth
  - Figure of Merit
  - Lifespan
  - Optical aperture
  - Power consumption

- Specifications
  - **Cost**
  - Mirror surface flatness
  - Shock survivability
  - Size and Weight



MEMS Mirror based Laser Beam Scanning Technology

LiDAR

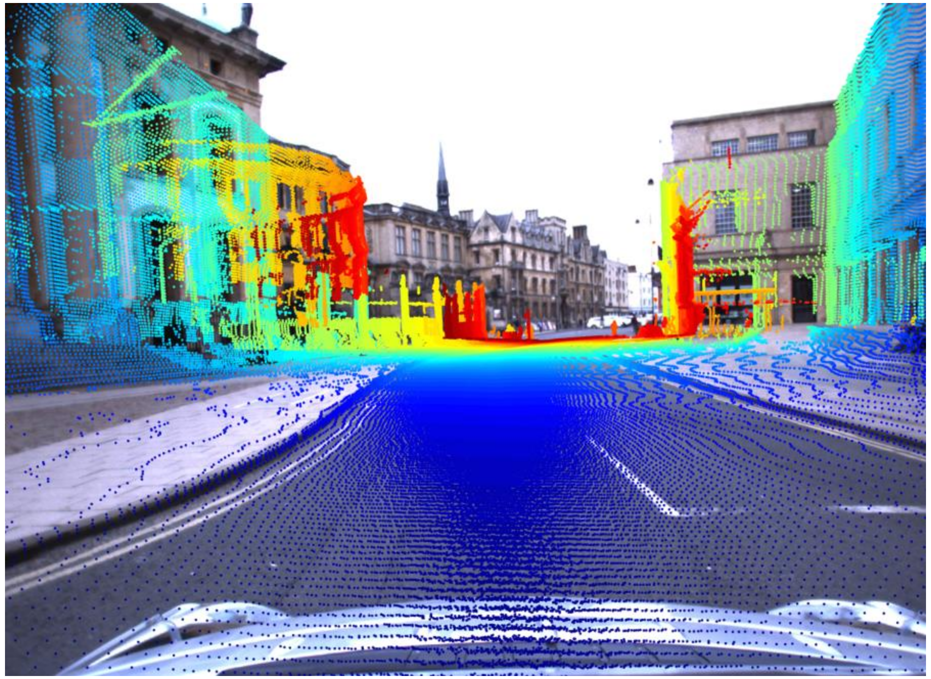
What's LiDAR?

- Light Detection and Ranging (LiDAR) is a 3D depth sensor which can provide high-density point clouds image with accurate 3D information.

✓ LiDAR is widely used in

- Consumer vehicles
- Logistics
- Industrial Drones

Intel® RealSense™ D405



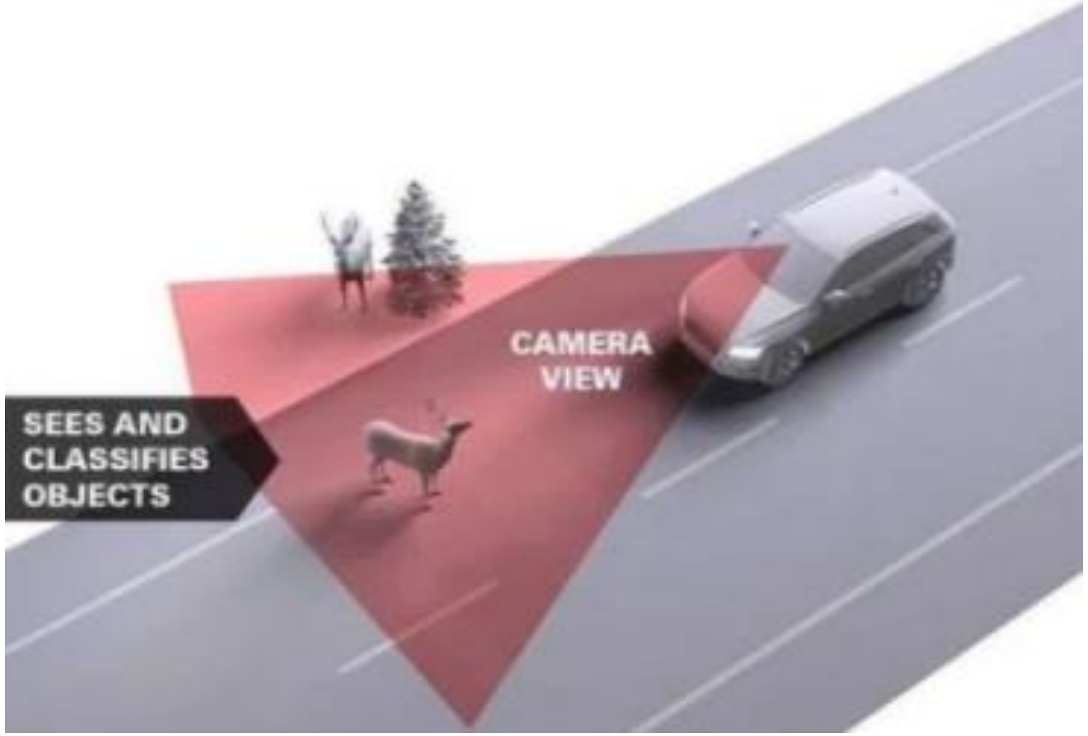
Point cloud image for autonomous driving

Exterior Sensor Technologies for Vehicles

➢Difference between Camera & Radar & LiDAR

Camera

- Camera records video interpreted by computer vision algorithms.



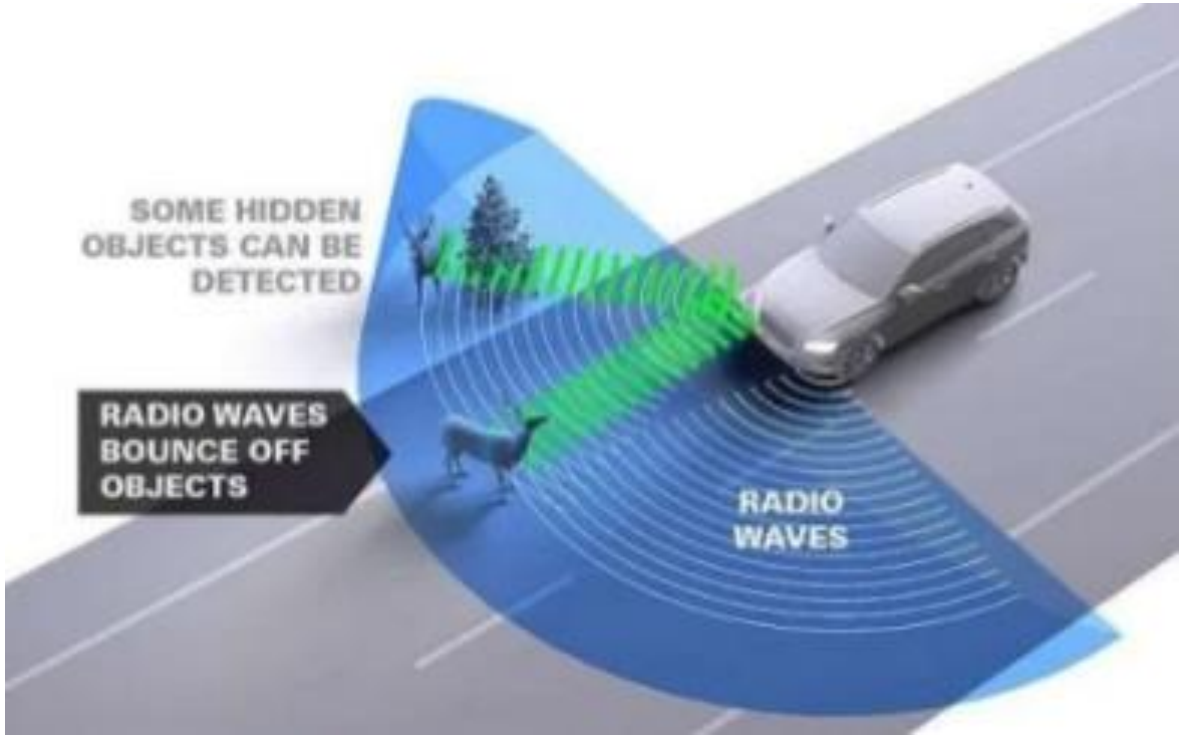
- **Pros:** Can distinguish and classify objects, such as signs, lane markings, traffic lights. May also be able to classify more complex objects such as animals and pedestrians

- **Cons:** Can only see what camera can see, challenges in low light or bright sun light

Exterior Sensor Technologies for Vehicles

Radar

- Car transmits radio waves and interprets the back reflection from objects.



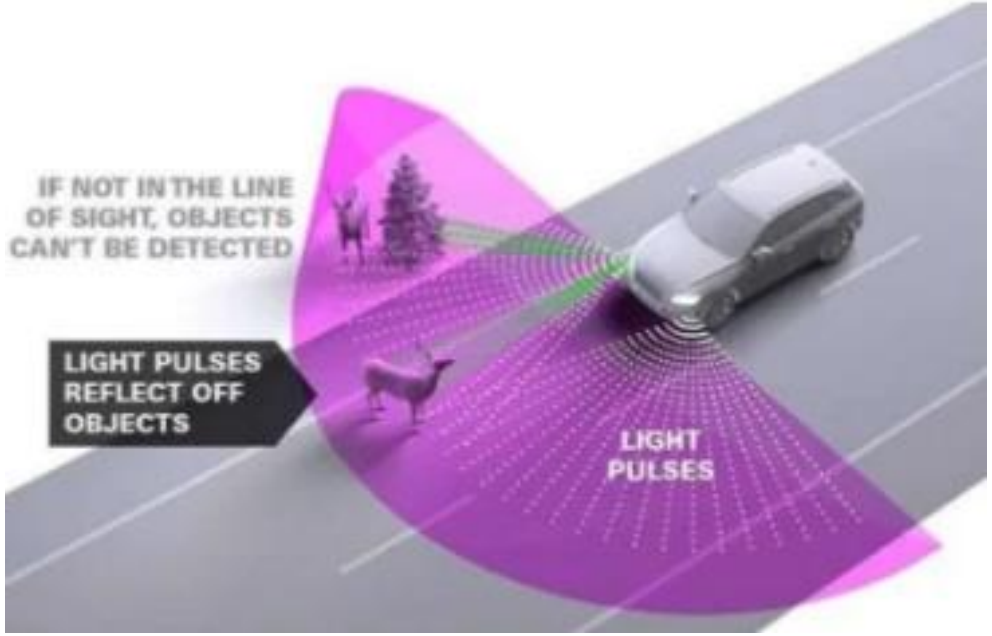
- **Pros:** Can detect large objects and can easily calculate speed and distance. Works in all weather and lighting conditions, day or light.

- **Cons:** Cannot distinguish color or differentiate between objects. All same size objects look the same.

Exterior Sensor Technologies for Vehicles

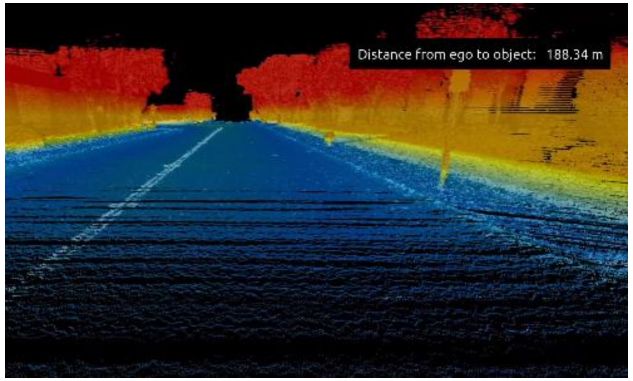
LiDAR

- Car transmits light pulses and interprets the back reflection from objects



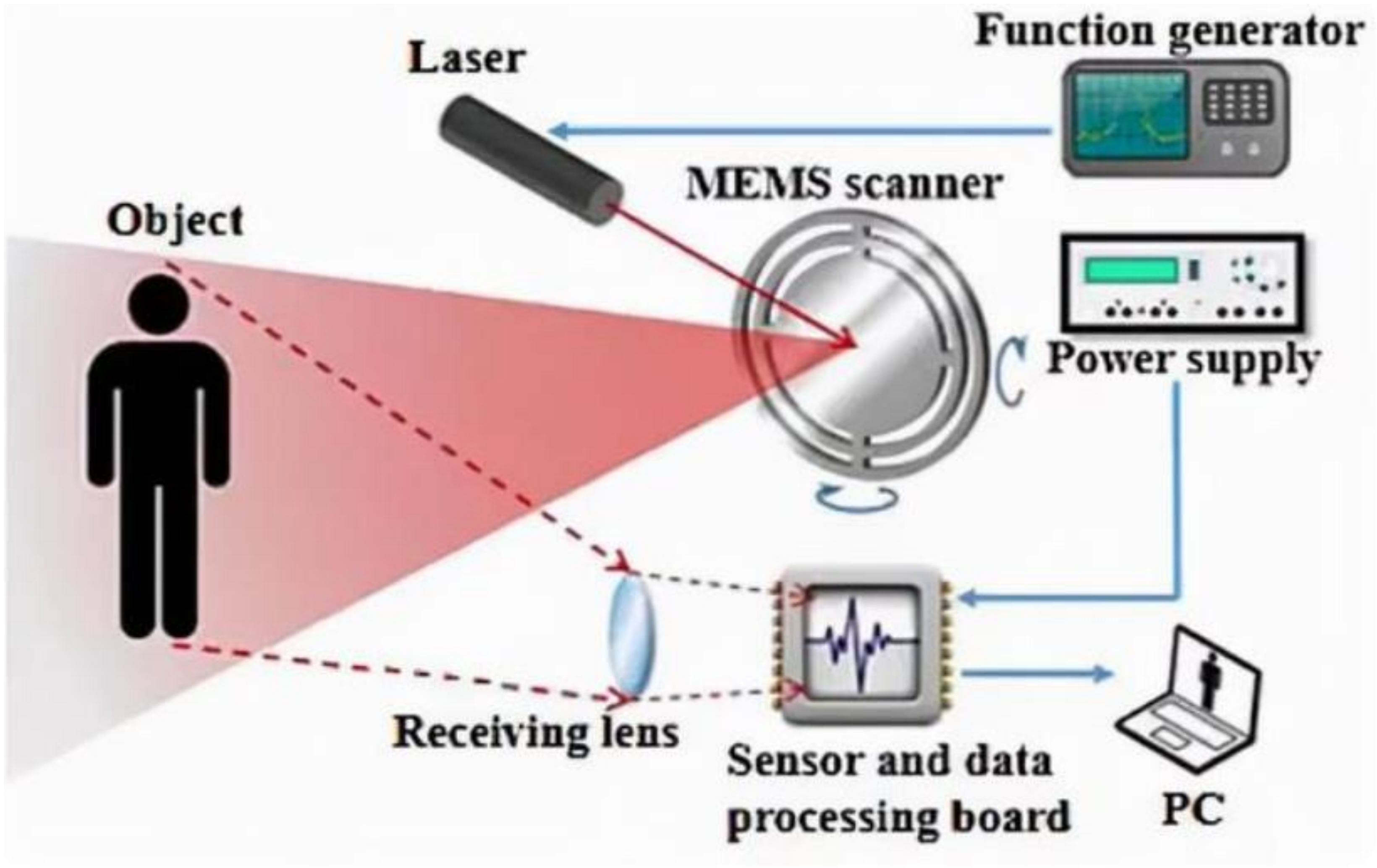
- **Pros:** Can detect specific objects and calculate distance. Can detect lines and edges of the road. Works during day and in the dark at night

- **Cons:** In inclement weather, the light can reflect from rain, snow, or fog, reducing the effectiveness and detection range.



Exterior Sensor Technologies for Vehicles

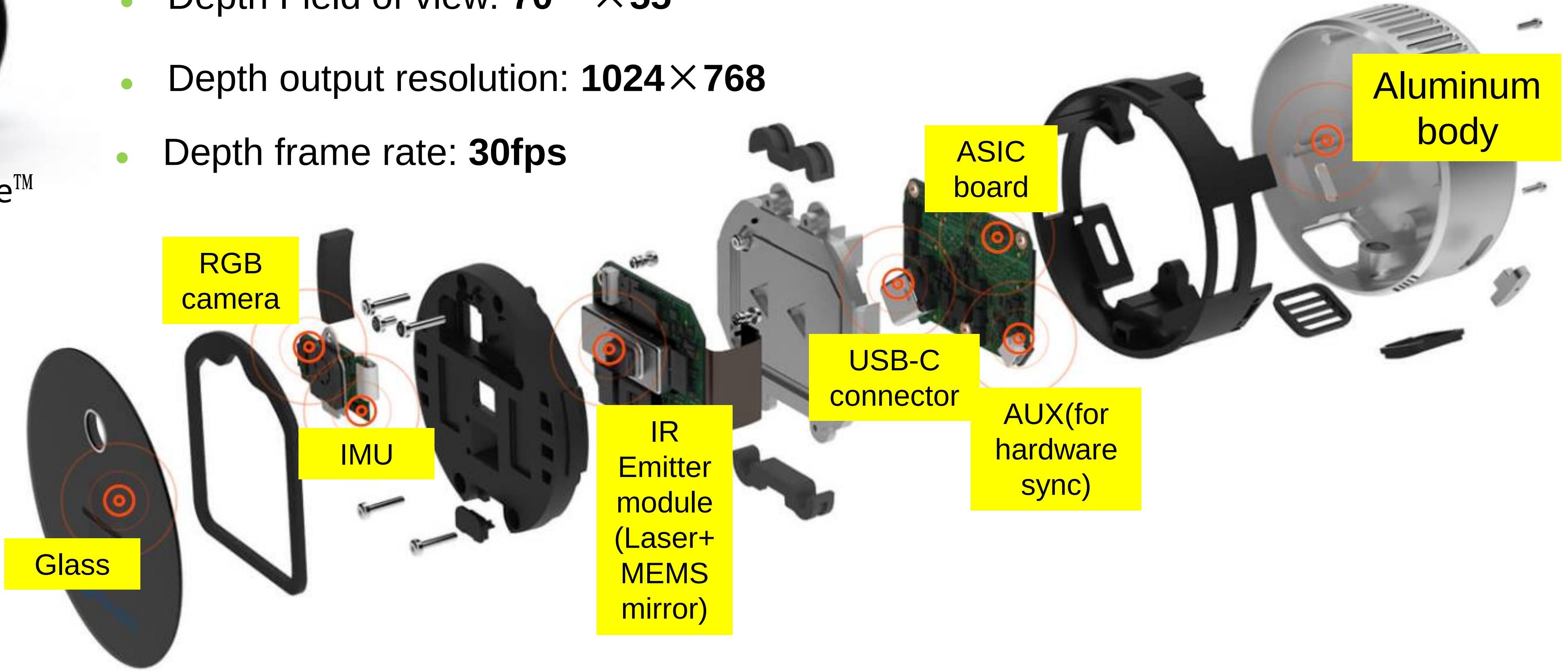
Working principle of LiDAR



Working principle of LiDAR

Intel® RealSense™ LiDAR L515

- Min-Z at max resolution: **~25cm**
- Depth Field of view: **70° × 55°**
- Depth output resolution: **1024×768**
- Depth frame rate: **30fps**
- Depth Accuracy:
  ~5mm to ~14mm for 9m²

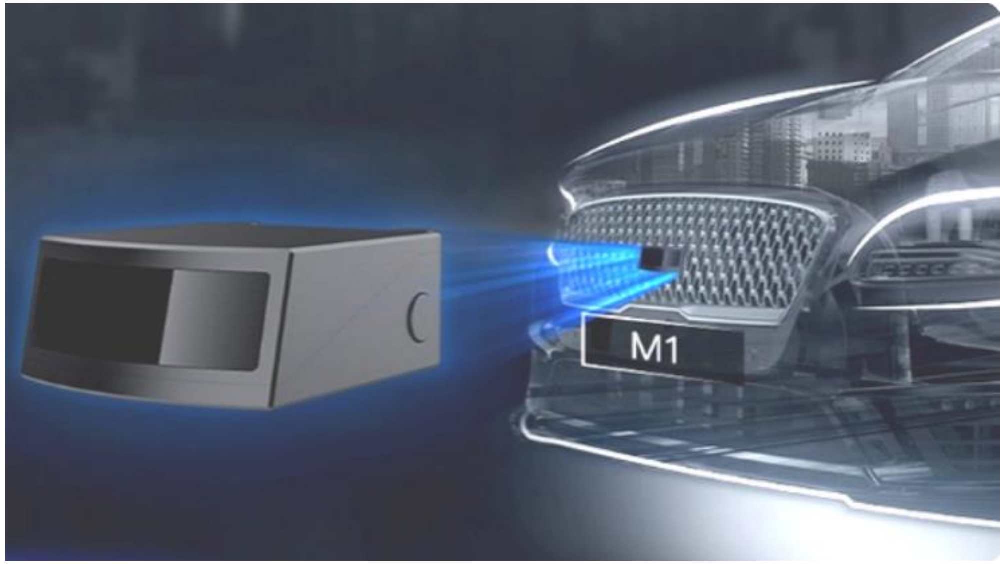


Benefits of MEMS Mirror based LiDAR

Small Size (Thin) ***Enables new class of integration***	**Cost Effective** (Re-uses mature LBS technology) ***Enables use of multiple and redundant sensors***
High Resolution (~5.5M-16.5M points/sec) ***Ability to resolve small features***	**Dynamic** (Programmable Resolution and Frame Rate) ***Adapt latency and fidelity to the application or driving situation***

Today’s LiDARs: Autonomous Vehicle Prototypes

- Single long-range LiDAR
- Typically mounted on the front of the car
- Environmental mapping and modelling



Today’s Representative LiDAR Specification

- Range: 100 - 150m
- FOV: 360° ×30°
- Data rate: 300k - 2.2M points/sec
- Frame rate: 5 - 20Hz
- Horizontal Resolution: 900 - 3600
- Vertical Resolution: 16 - 64
- Price: $5K - $80K

Future Opportunity: Mid-Range Exterior LiDAR

- Multiple low-cost mid-range LiDARs for performing different functions
- High resolution
- Multiple sensors for redundancy and safety

Mid-Range LiDAR Target Specification

- Range: 10 - 15m
- FOV: 90° ×30°
- Data rate: 5.5M points/sec
- Frame rate: 30Hz
- Horizontal Resolution: 512
- Vertical Resolution: 360

Future Opportunity: Short-Range Interior LiDAR

- High resolution point cloud for gesture recognition and driver monitoring

Short-range LiDAR Target Specification

- Range: 0.2-2m
- FOV: 90° ×50°
- Data rate: 16.5M points/sec
- Frame rate: 30Hz
- Horizontal Resolution: 768
- Vertical Resolution: 720

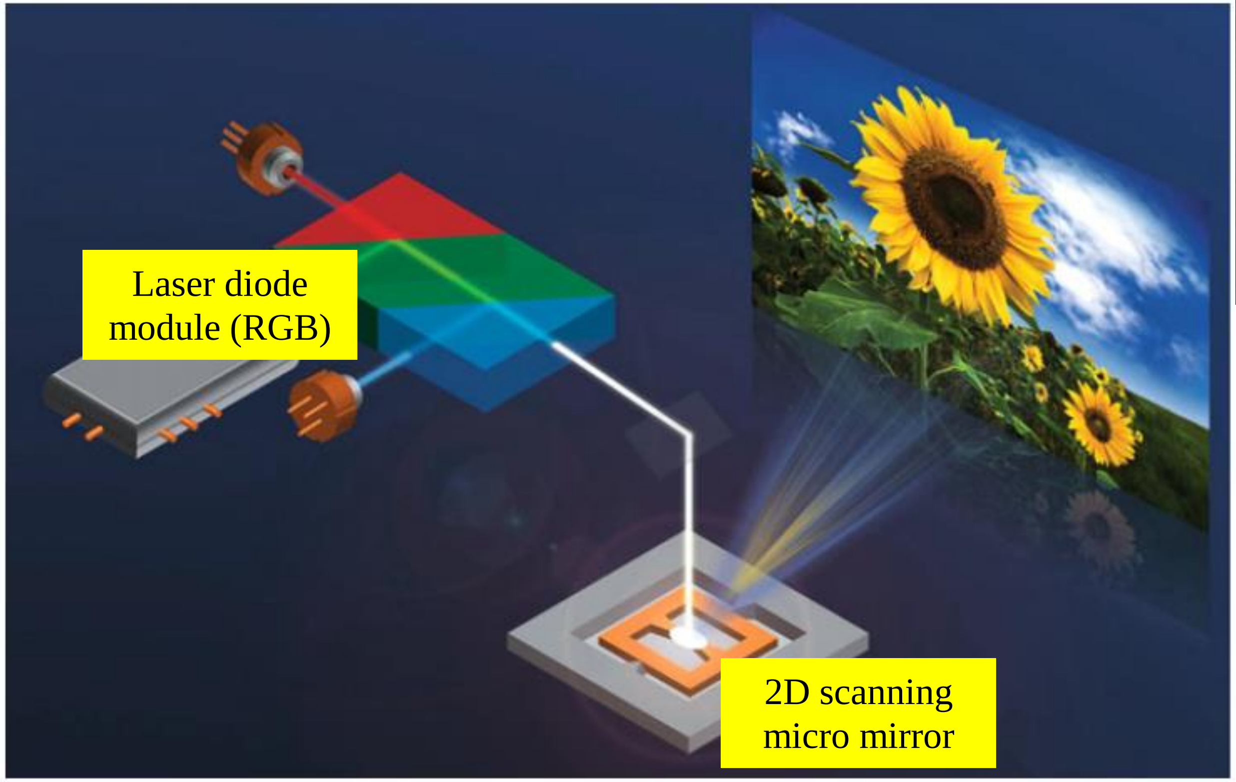
Future Opportunity: Short-Range Interior LiDAR

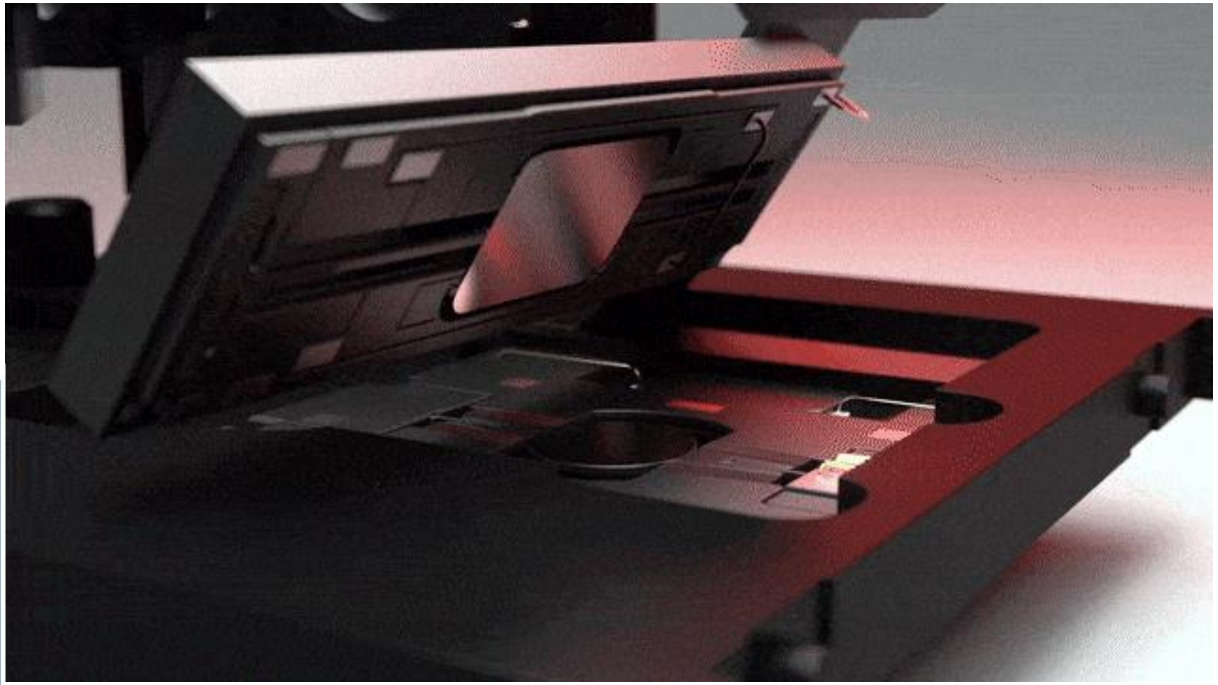
Automotive Gesture Recognition Application utilizing interior 3D depth sensors

- **Touchless controls**
  - Infotainment
  - Navigation
  - Interior lighting
  - Climate control
  - Windows
- **Driver monitoring**
  - Driver identification
  - Facial Recognition
  - Gaze detection
- **Driver awareness**
  - Head drooping
  - Eyes closing

Laser Scanning Projection

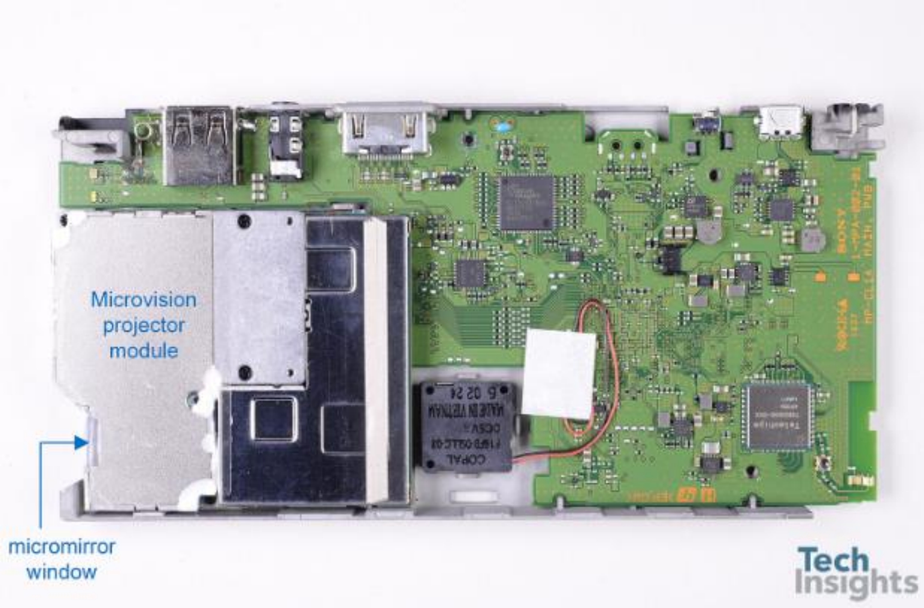
MEMS Mirrors are typically used in laser beam scanning systems (LBS) to project visible images or infrared patterns.

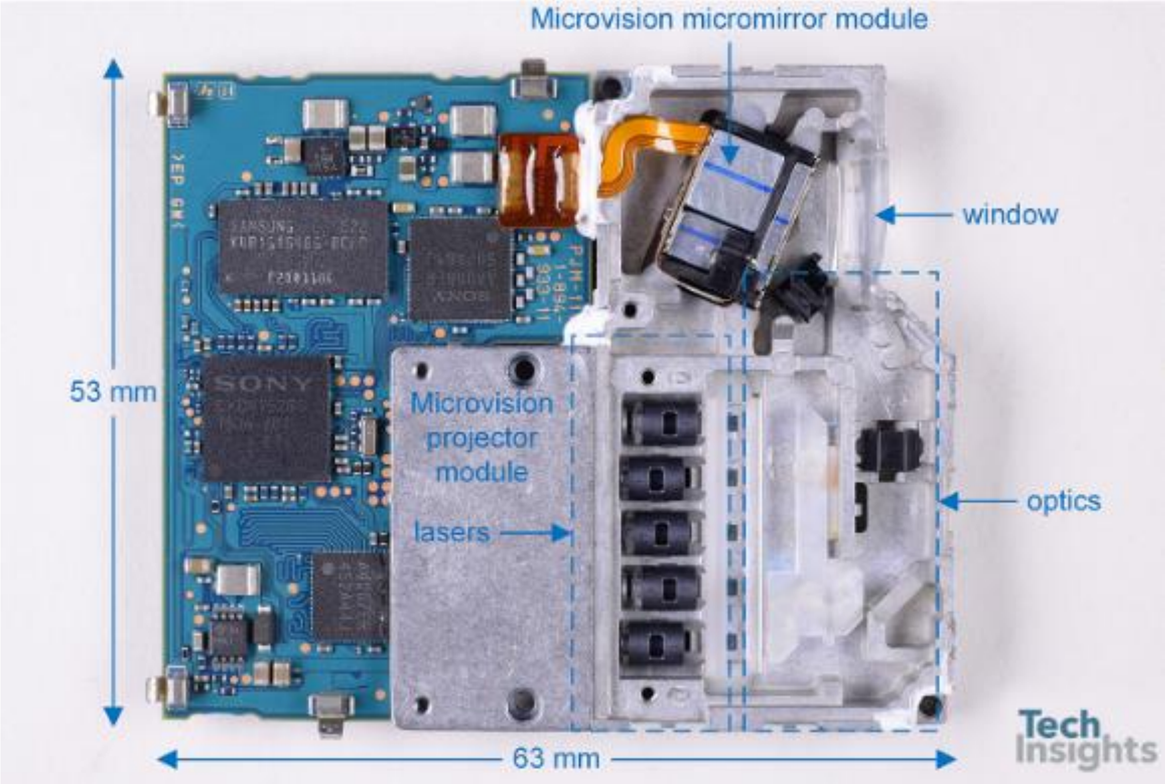




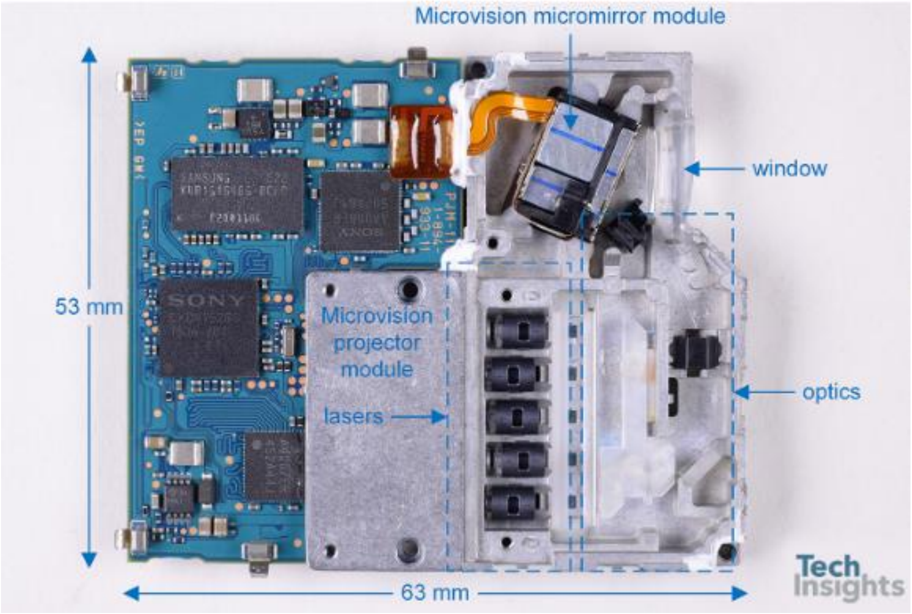
- **Merits**
  - Coherence and Compactness
  - Low power consumption
  - High brightness
  - Long lifespan

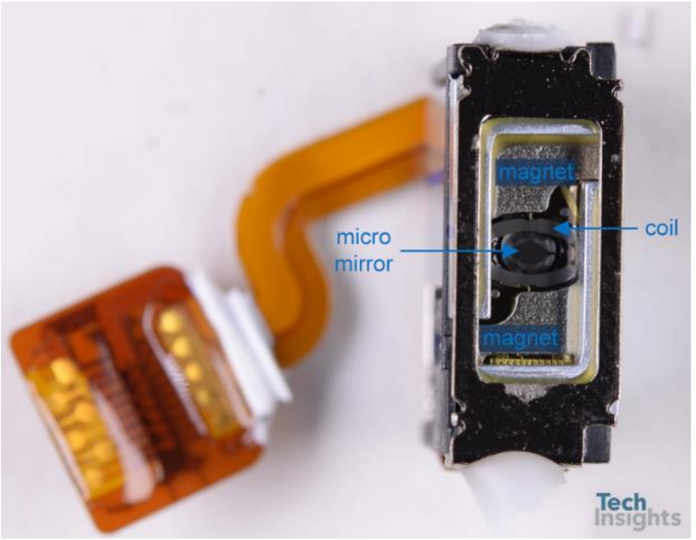
A Look Inside Laser Scanning Projector





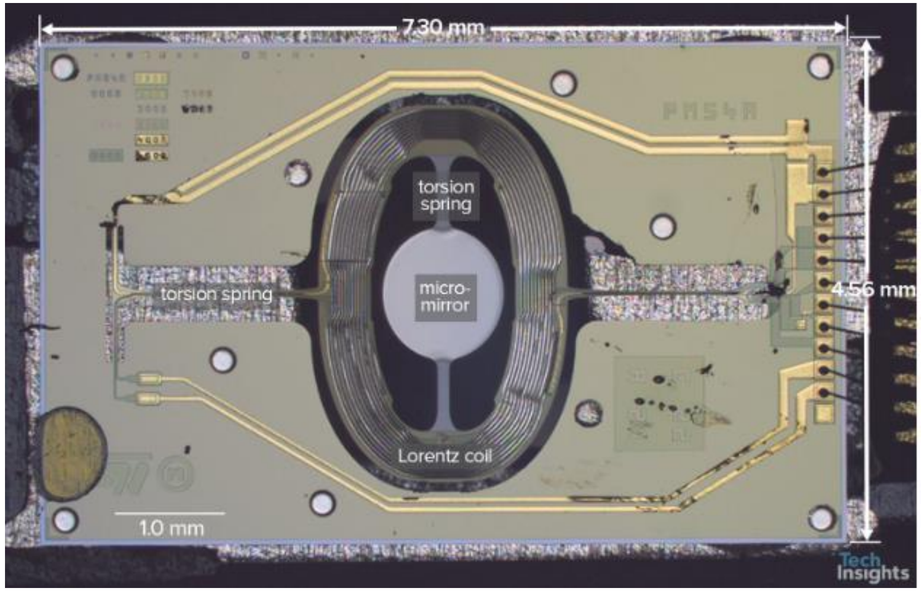
A Look Inside Laser Scanning Projector

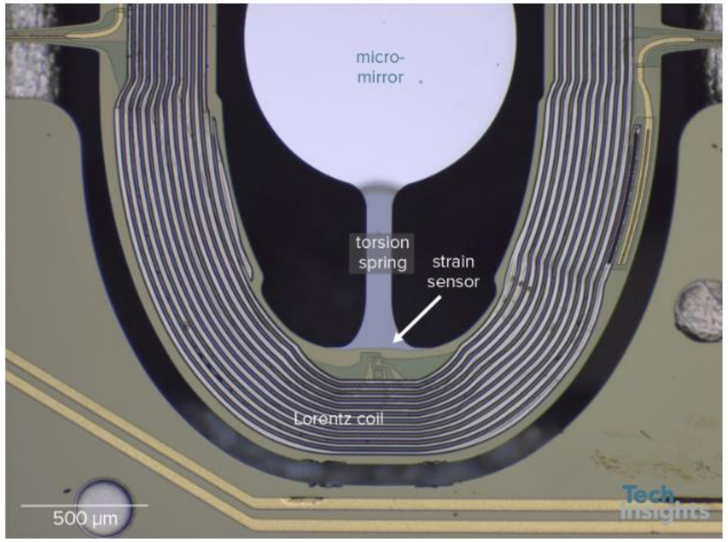




Actuation Mechanism:

electromagnetic



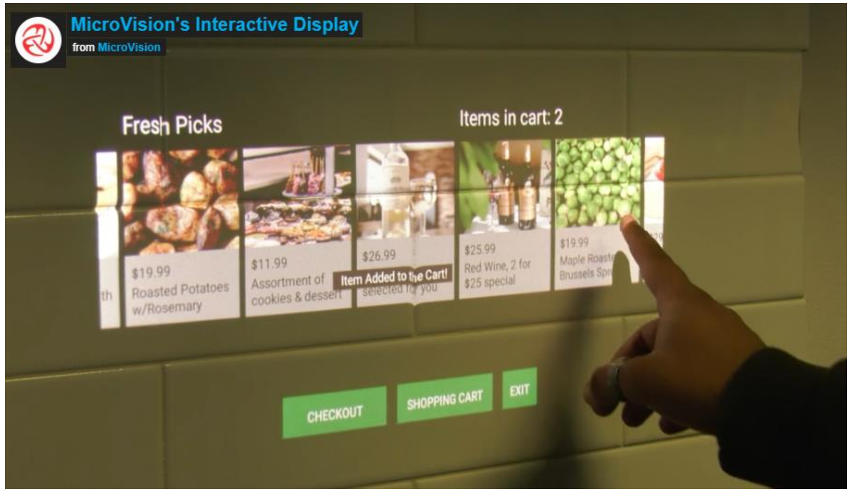


- Strain sensor as a feedback control for real-time projection

Applications of Laser Display

Ultra-short Laser TV

Interactive Display

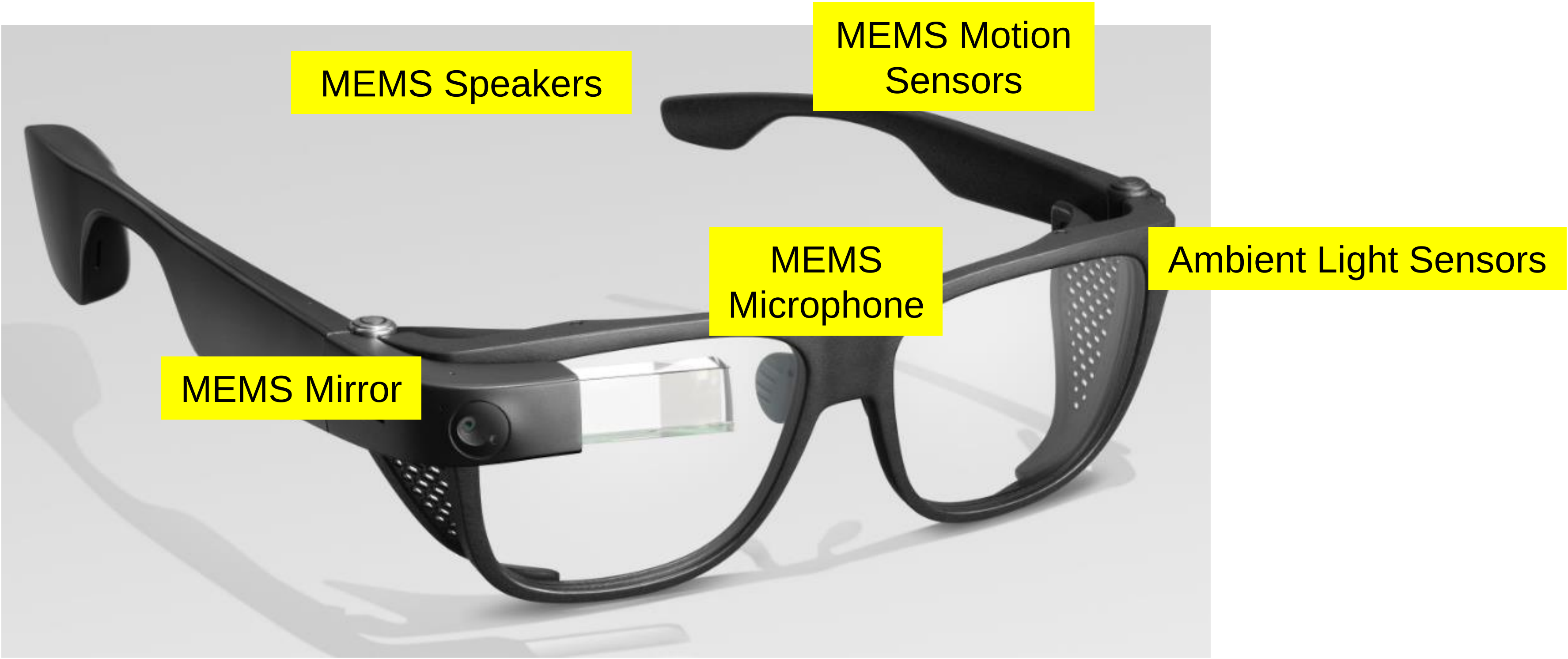


Head-up Display

Laser Display for AR glass

Future Opportunities in Smart(AR) Glass

MEMS actuators and sensors can be widely used in next-generation smart glasses



google glass

The LaSAR Alliance

Accelerating the adoption of laser beam scanning in smart glasses and AR headsets

life.augmented

APPLIED MATERIALS®

OQMENTED

OSRAM
Opto Semiconductors

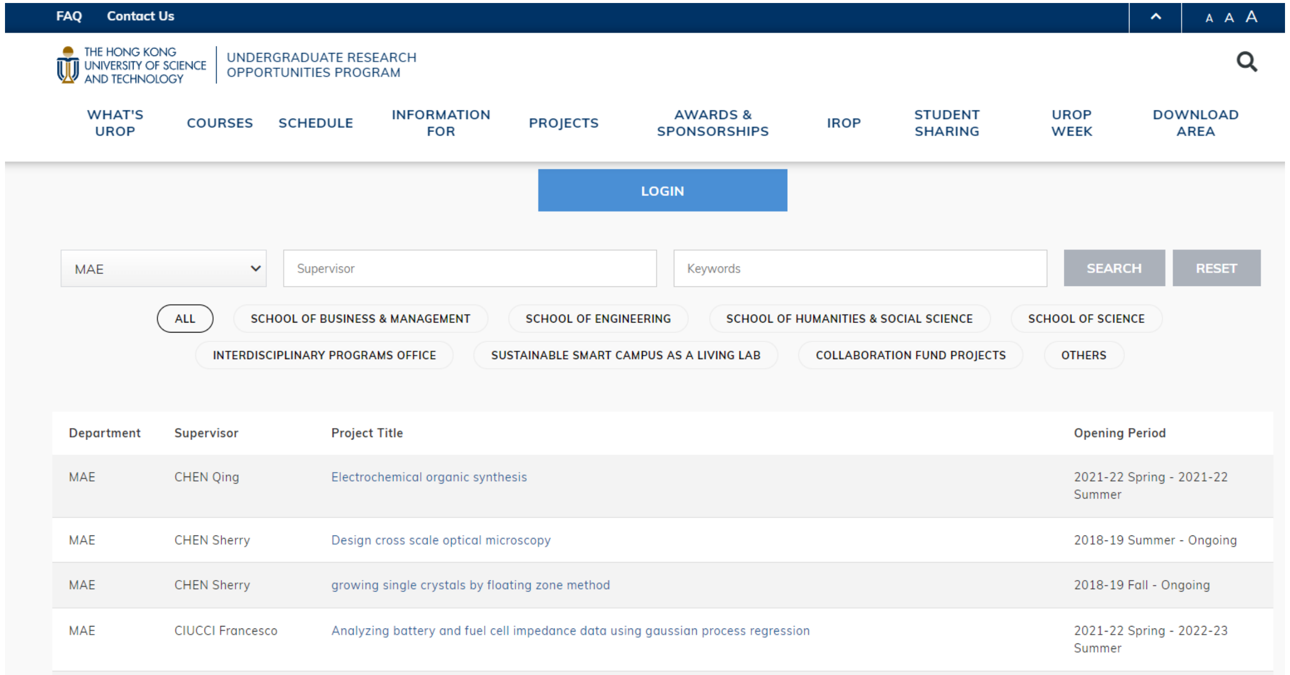
dispelix

UROP project in HKUST

What’s UROP in HKUST?

- The UROP project is designed for UG students to engage in academic research with stipend paid by HKUST.
- For details: https://urop.ust.hk

Find what you’re interested in



UROP Faculty Research Award of HK$20,000

UROP Collaboration Fund of HK$100,000

UROP project about MEMS Mirror is to be released

UROP project about MEMS Mirror

Design, Fabrication and Testing of MEMS Mirror for Laser Scanning Projection (to be uploaded)

Project description: MEMS Mirrors are key components of laser beam scanning (LBS) devices, which can be used in automotive/entertainment industry. This project is to design a MEMS mirror and the mechanical packaging using commercial foundry fabrication process to achieve excellent performance for LBS.

Quota:4

Supervisor: LEE Yi-Kuen

Complexity of the project: Chanllenging

Applicant's role:

1. Design a micro mirror using Matlab and COMSOL;
2. Design the mechanical packaging for micro mirror;
3. Testing of the fabricated MEMS micro mirror;

Applicant's learning objectives:

1. Understand the fundamental of MEMS fabrication technologies;
2. Understand the actuation mechanism for micro mirror.
3. Understand the basic principle of different types of micro mirror;
4. Able to design a micro mirror with the required performance.