MODULE 1: INTRODUCTION TO AUTONOMOUS ROBOTS AND VEHICLES

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About Nicholas Ho

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- Artificial Intelligence System (AIS) Lecturer at NUS ISS; Courses covered include:
  - Robotics Systems
  - Autonomous Robots and Vehicles
  - Human Robot Systems Engineering
- Consultant for SME manufacturing company; Services provided include:
  - Design an Intelligent Voice Prosthesis Manufacturing Workcell system, integrated with advanced AI, IoT and other state-of-the-art technologies
  - Technical expertise in AI and IoT to optimize the performance of the Intelligent Workcell
  - Research on the latest AI and IoT technologies to continuously improve the system's capabilities
- BEng and PhD degree from School of Mechanical Engineering, NUS

Dr Nan Zhou Myo LEE

- Senior Lecturer in Software Systems Practice
- PhD and Bachelor of Mechanical Engineering with Robotics Specialization from NTU
- More than 14 years of sensorization, software simulation, intelligent system, digital solution development and integration using industrial IoT and automation technologies in both public and private sectors
- Worked at Data Storage Institute (DSI) (A*STAR) and Advanced Remanufacturing & Technology Centre (ARTC) (A*STAR)
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Course Outline

- Day 1
  - Module 1: Introduction to autonomous robots and vehicles
  - Module 2: Holistic design approach for autonomous systems
- Day 2
  - Module 3: Technical Fundamentals – Autonomous Vehicles & Robotics Technology
- Day 3
  - Module 4: Standards/Technical Reference for autonomous vehicles
  - Module 5: Technical Fundamentals – In-depth Technologies and Basics of Simulation & Analysis for Autonomous Vehicles
- Day 4
  - Module 6: Developing Basic Autonomous Vehicle Systems
- Day 5
  - Module 7: Developing an MVP (Minimum Viable Product) for your Organization
  - Final Written Assessment

Topics

- Introduction to autonomous systems
- Applications and Use Cases
- Future of Autonomous Systems
- Envisioning Exercise

Introduction to Autonomous Systems

Definition of Autonomous Systems

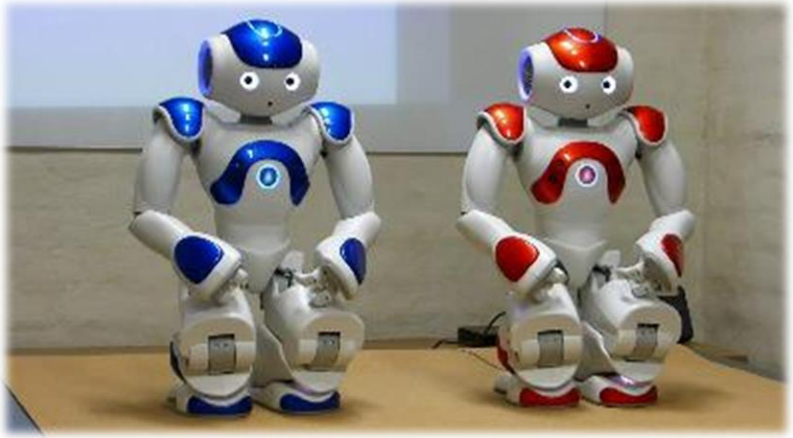
- **Able to operate with no or minimal human intervention**
- The system should be able to operate in an environment where not everything is known prior
- React to unforeseen events
- Make decision based on sensor input

https://www.industryweek.com/robotics/autonomous-robots-start-european-delivery

Characteristics of Intelligence

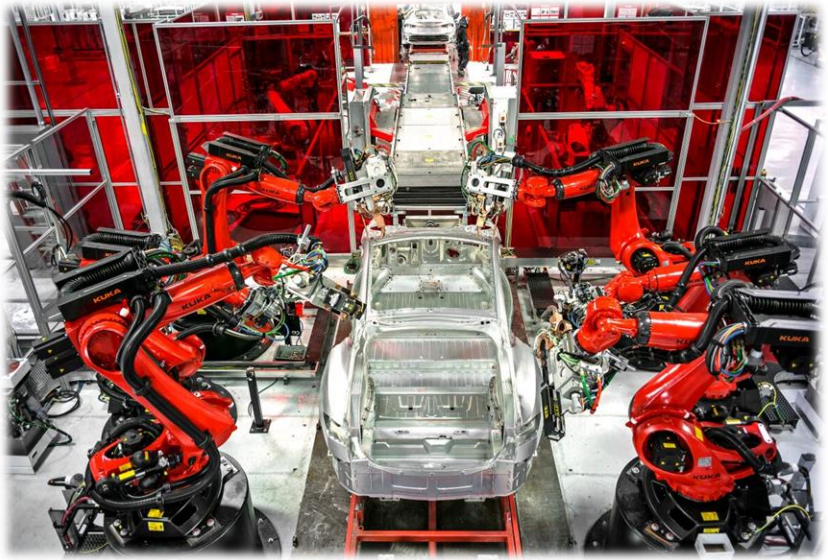
Description: **Systems that are aware and interact with their environment**. DARPA defines intelligent systems as **"systems that know what they're doing"** and **exhibit the following abilities:**

- will be able to infer and reason, using substantial amounts of appropriately represented knowledge
- will learn from their experiences and improve their performance over time
- will be capable of explaining themselves and taking naturally expressed direction from humans
- will be aware of themselves and able to reflect on their own behavior
- will be able to respond robustly to surprises and explore in a very general way
- will be able to **interact/interface with humans**, if in the loop, using the **same language as the human nervous system**



Mobility in Autonomous Robots?

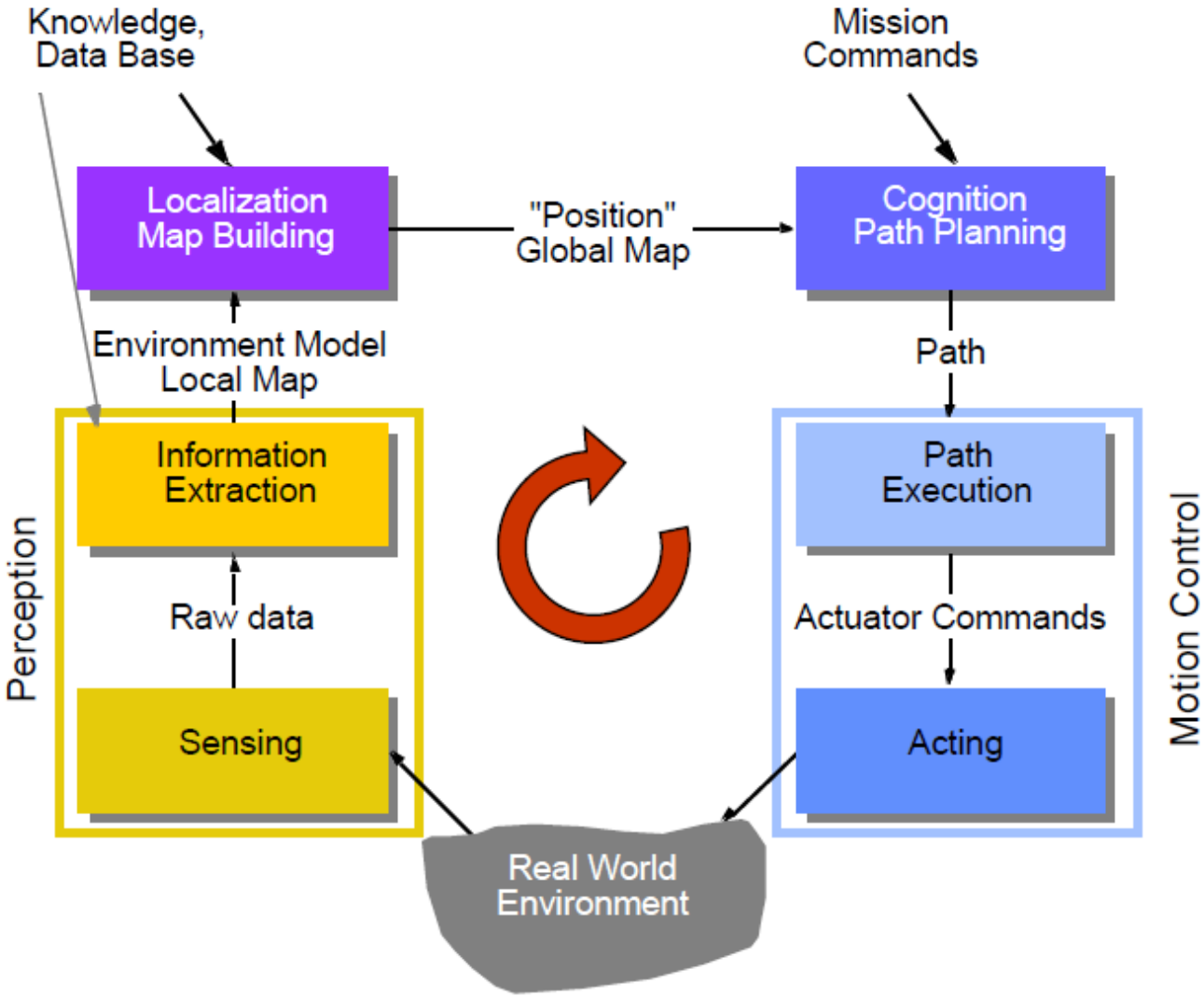
- Traditional (industrial) robots are bolted and fixed to the floor
- Are very good at what they do
- But they cannot move!



Reflection and Sharing

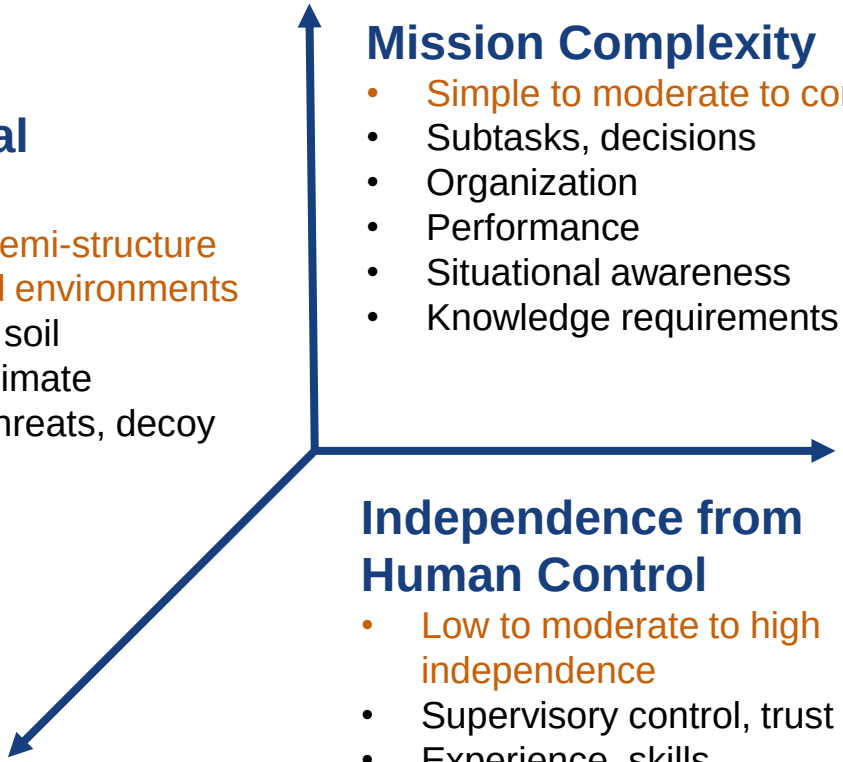
- Why do we need autonomous robots in Singapore now and in the future?
- Will autonomous systems pose a threat in any way?
- Can humans be replaced by autonomous robots?
- What are the ethical, safety and security considerations we need to have with autonomous robots?

System overview (RECAP for MTech students)



Contextual Autonomous Capability (ALFUS Model)

A comprehensive framework that provides a structured way to assess and categorize the autonomy of unmanned systems.



Mission Complexity

- Simple to moderate to complex tasks
- Subtasks, decisions
- Organization
- Performance
- Situational awareness
- Knowledge requirements

Environmental Difficulties

- Structured to semi-structure to unstructured environments
- Static: Terrain, soil
- Urban, rural, climate
- Operational: Threats, decoy

Independence from Human Control

- Low to moderate to high independence
- Supervisory control, trust
- Experience, skills
- % of decisions/time
- Operator to Unmanned System ratio and comm.types

Top 5 Requirements for Autonomous Vehicles

1. **Greater computing power**
   - Approximately 1 GB of data will need to be processed each second
   - This data will need to be analyzed quickly enough that the vehicle can react to changes in its surroundings in less than a second
2. **A reliable supply chain**
   - The past story of LiDAR
3. **A centralized approach**
   - Currently, new technologies added to the car often come with their own computer and software
   - Each new addition presents more challenges for the automaker in managing multiple disparate systems
   - A centralized computing approach can streamline these systems, reducing complexity and improving efficiency
4. **A small, low-power solution**
   - The processors in tomorrow's cars must deliver increasing computing power, and must do so as efficiently as possible
5. **Security and privacy**

Conclusion

- For self-driving vehicles, it remains critical that the growing volumes of data transmitted to, from, and within the vehicle are safe
- The vehicle will need to rely on its data and the source of that data to make quick, accurate decisions (aka edge computing)

Basic Physical Ecosystem of an Autonomous Vehicle

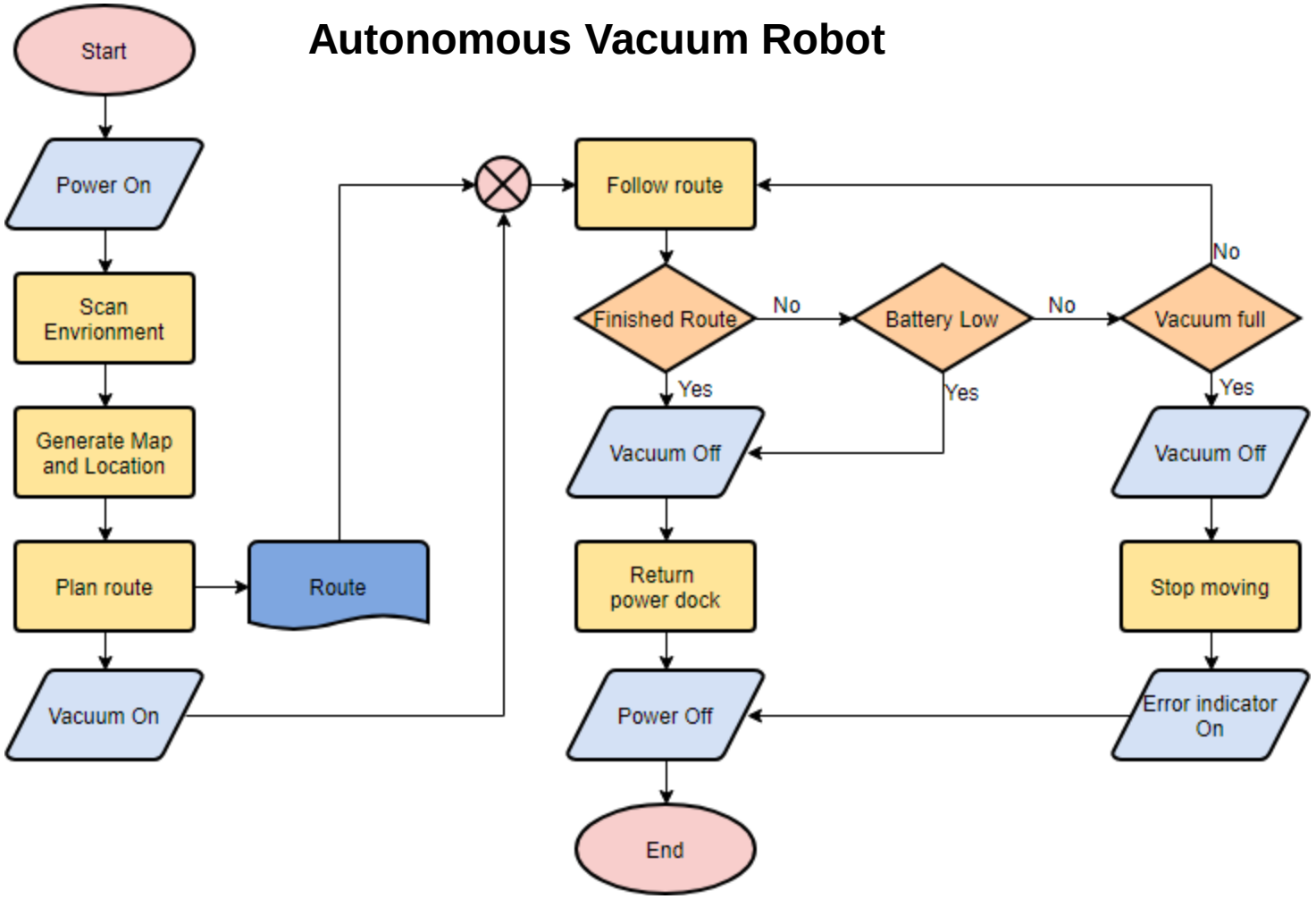
- **Cameras** – Provide real-time obstacle detection to facilitate lane departure and track roadway information (like road signs).
- **Radar** – Radio waves detect short & long-range depth.
- **LIDAR** – Measures distance by illuminating target with pulsed laser light and measuring reflected pulses with sensors to create 3-D map of area.
- **GPS** – Triangulates position of car using satellites. Current GPS technology is limited to a certain distance
- **Ultrasonic Sensors** – Uses high-frequency sound waves and bounce-back to calculate distance. Best in close range.
- **Central Computer** – "Brain" of the vehicle. Receives information from various components and helps direct vehicle overall.
- **DRSC (or Cellular)-based Receiver** – Communications device permitting vehicle to communicate with other vehicles (V2V)

*DRSC = Dedicated short-range communications

Robotic Flow Process (RFP) Design [e.g. Decision Flowchart]

- **Design of robotic automation algorithm** is an important aspect for AI engineer
- Applicable for robots, intelligent systems and other “behavioral” and “rule-based” systems
- Provide developers and users the **transparency and control to understand and alter behavior and decision-making processes** in autonomous systems

Example of a RFP



https://www.visual-paradigm.com/tutorials/flowchart-tutorial/

Flowchart Symbols

Terminator

The terminator symbol represents the starting or ending point of the system.

Process

A box indicates some particular operation.

Document

This represents a printout, such as a document or a report.

Decision

A diamond represents a decision or branching point. Lines coming out from the diamond indicates different possible situations, leading to different sub-processes.

Flowchart Symbols

Input or output of Data

It represents information entering or leaving the system. An input might be an order from a customer. Output can be a product to be delivered.

On-Page Reference

This symbol would contain a letter inside. It indicates that the flow continues on a matching symbol containing the same letter somewhere else on the same page.

Off-Page Reference

This symbol would contain a letter inside. It indicates that the flow continues on a matching symbol containing the same letter somewhere else on a different page.

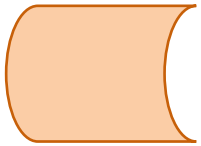
Delay or Bottleneck

Identifies a delay or a bottleneck

Flowchart Symbols

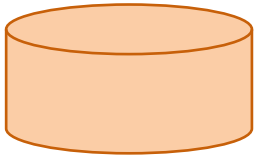
Stored Data

It represents information that has been stored in the system

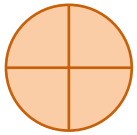


Database

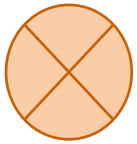
It represents information that is stored in a database



OR Operation



AND Operation



ARV Tutorial (RFP Practices)

- There are 2 questions in total
- Take ~30 mins to complete this tutorial
- The presenters will be chosen randomly (2 for each question; total 4 presenters)

Local Applications and Use Cases

Autonomous Systems in SG

Cleaning Industry

- HiveBotics' Abluo, an autonomous cleaning bot that cleans urinals, toilet bowls, sinks and mirrors
- Guided by sensors that give it a 3D view of its surroundings
- Robots need to be trained to recognize if toilet is clean; might utilize ultraviolet sensors to detect stains
- Inspired when Co-founder's friend, an owner of a cleaning company must clean toilets himself due to shortage of staff
- Supported by NUS and JTC
- Public testing phase will begin in the 2nd quarter of 2024

https://www.straitstimes.com/tech/autonomous-cleaning-bot-to-start-scrubbing-public-toilets-in-early-2024

Autonomous Systems in SG

Hospitals

Changi General Hospital has started deploying robots to:

1. Deliver medication, blankets, documents, etc
2. Guide patients to specific areas (e.g. consultation room)

https://www.channelnewsasia.com/singapore/tech-ai-healthcare-ttsh-smart-ward-cgh-ae-emergency-robots-3634801

Autonomous Systems in SG

Autonomous Baggage Handling Vehicle (Aurrigo's Auto-DollyTug) at Changi Airport

Autonomous Systems in SG

Autonomous Baggage Handling Vehicle (Aurrigo's Auto-DollyTug) at Changi Airport

https://www.youtube.com/watch?v=1uU5y2Rz9Ac&t=10s

Autonomous Systems in SG

Service and Hospitality

- Robot waiters that will bring food to your table; intelligently navigates around obstacles (if there are any)
- Robot arms will pick out the dishes and send it to a sorting area

https://mothership.sg/2022/11/smart-haidilao-northshore-plaza/

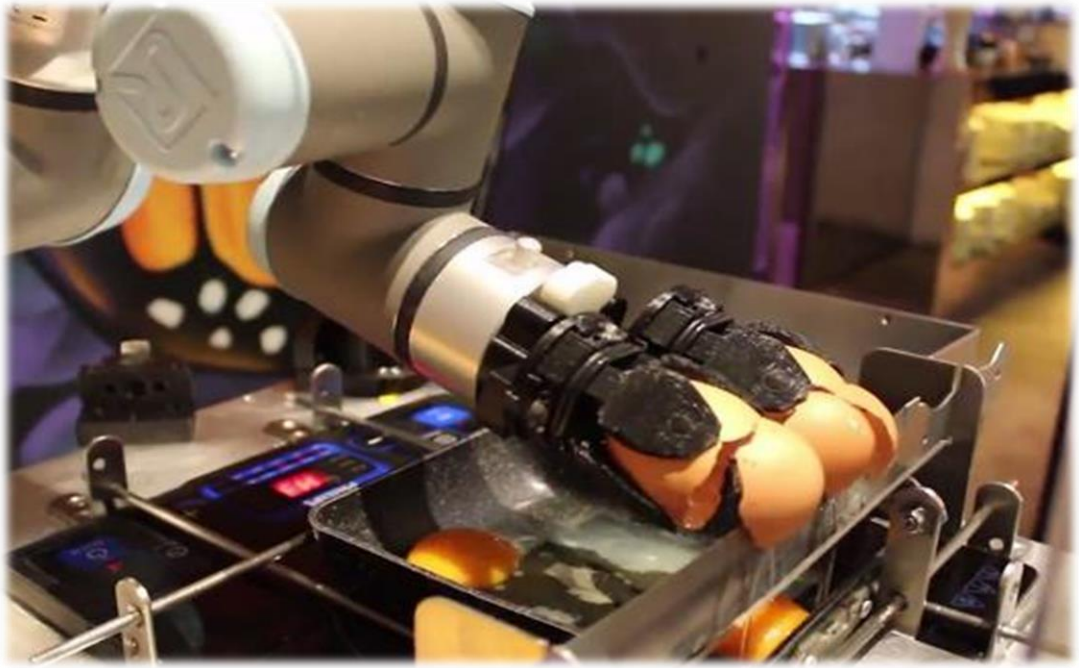
Autonomous Systems in SG

Room Service in Hotels

- Deliver room service orders like food and toiletries to guests' rooms
- Transport dirty linens out and replace them with fresh sheets
- Hotel Jen, Park Avenue Rochester Hotel, Sofitel and The Millennium Group

Autonomous Systems in SG

Cooking Food



https://vulcanpost.com/675764/robot-workers-singapore/

- At M Social, AUSCA (Automated Service Chef Associate) helps to whip up the perfect sunny-side-ups and omelettes
- Guests just have to select their choice and give the robot an empty plate
- Good for live food stations during catering events

Autonomous Systems in SG

Cooking Food

https://www.youtube.com/watch?v=N9-gtnHAiIw

Autonomous Systems in SG

Transport

- NTU, Volvo and the Land Transport Authority (LTA) jointly launched a full-sized autonomous electric bus in March 2019
- Can carry 80 passengers and travel 25km on a full charge

Autonomous Systems in SG

Delivery Robots

https://govinsider.asia/intl-en/article/what-delivery-robots-in-singapore-can-tell-us-about-the-future-of-smart-cities

- From Aug 2024, office workers at Woodlands North Coast, an upcoming mixed-use estate, will be able to get their food delivered by autonomous robots
- Initiated by JTC

Autonomous Systems in SG

Healthcare

https://vulcanpost.com/675764/robot-workers-singapore/

At the pharmacy in Tan Tock Seng Hospital, a system of robots speeds up the time taken to dispense medication with accuracy

https://vulcanpost.com/675764/robot-workers-singapore/

Emma (Expert Manipulative Massage Automation) can be found giving acupressure massages at Traditional Chinese Medicine (TCM) and sports therapy clinics

Robot at Pharmacy in TTSH

https://www.youtube.com/watch?v=B1EHyRcCXcc

Autonomous Systems in SG

Security

https://vulcanpost.com/675764/robot-workers-singapore/

- Singapore Police Force deploys autonomous security robots to help them patrol areas, especially during the 33rd ASEAN Summit and the Trump-Kim Summit
- Transmit a 360-degree view of their surroundings back to the police command posts,
- Video analytics capabilities to detect suspicious activity on their own

Autonomous Systems in SG

Security (MATAR 3.0)

https://www.youtube.com/watch?v=N50XM3Ruw4E

Autonomous Systems in SG

Military

- “Spider Dog” by Ghost Robotics, further developed by DSTA
- Create 3D models and maps of the terrain using light detection and ranging sensors; useful for soldiers
- Able to detect targets autonomously in the field

Future of Autonomous Systems

Future Autonomous Systems

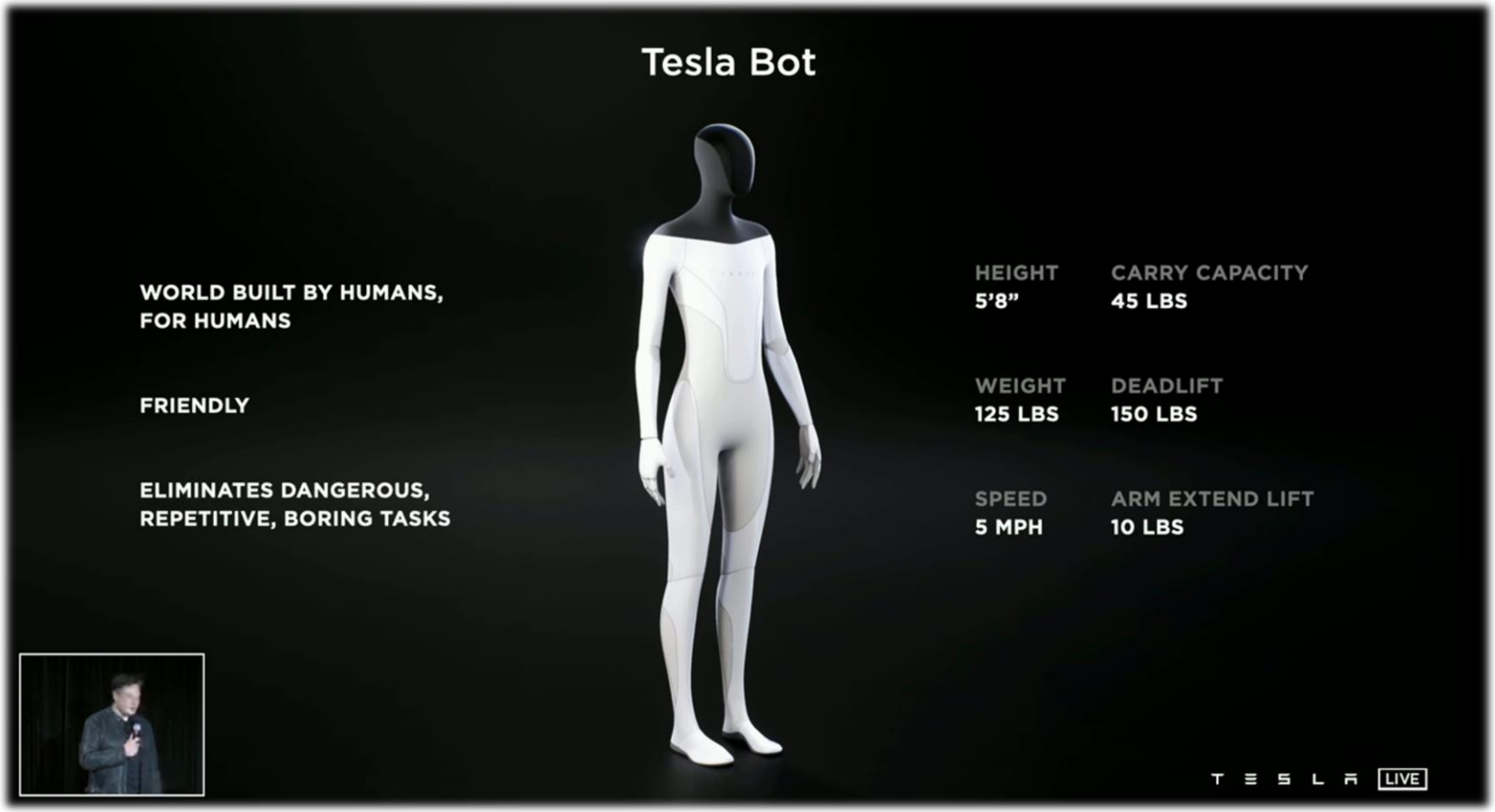
Missions

1. Replace humans (in certain tasks)
   - Unattended exploration (e.g. Space missions, undersea exploration, hazardous environments)
   - Unattended monitoring (situational awareness applications such as environmental monitoring, security surveillance, disaster response)
2. Assist humans
   - Overcome handicaps (assist individuals with mobility difficulties)
   - Repetitive boring tasks (non-intelligent to human, e.g. assembly line work, routine maintenance)
   - Requires robust human-machine interface to ensure seamless interaction and control
3. Augment/Enhance human capabilities
   - Enhancing human abilities through technology, such as wearable devices, cognitive augmentation, and enhanced physical capabilities
   - Requires robust human-machine interface to maximize efficiency and effectiveness

Inspiration

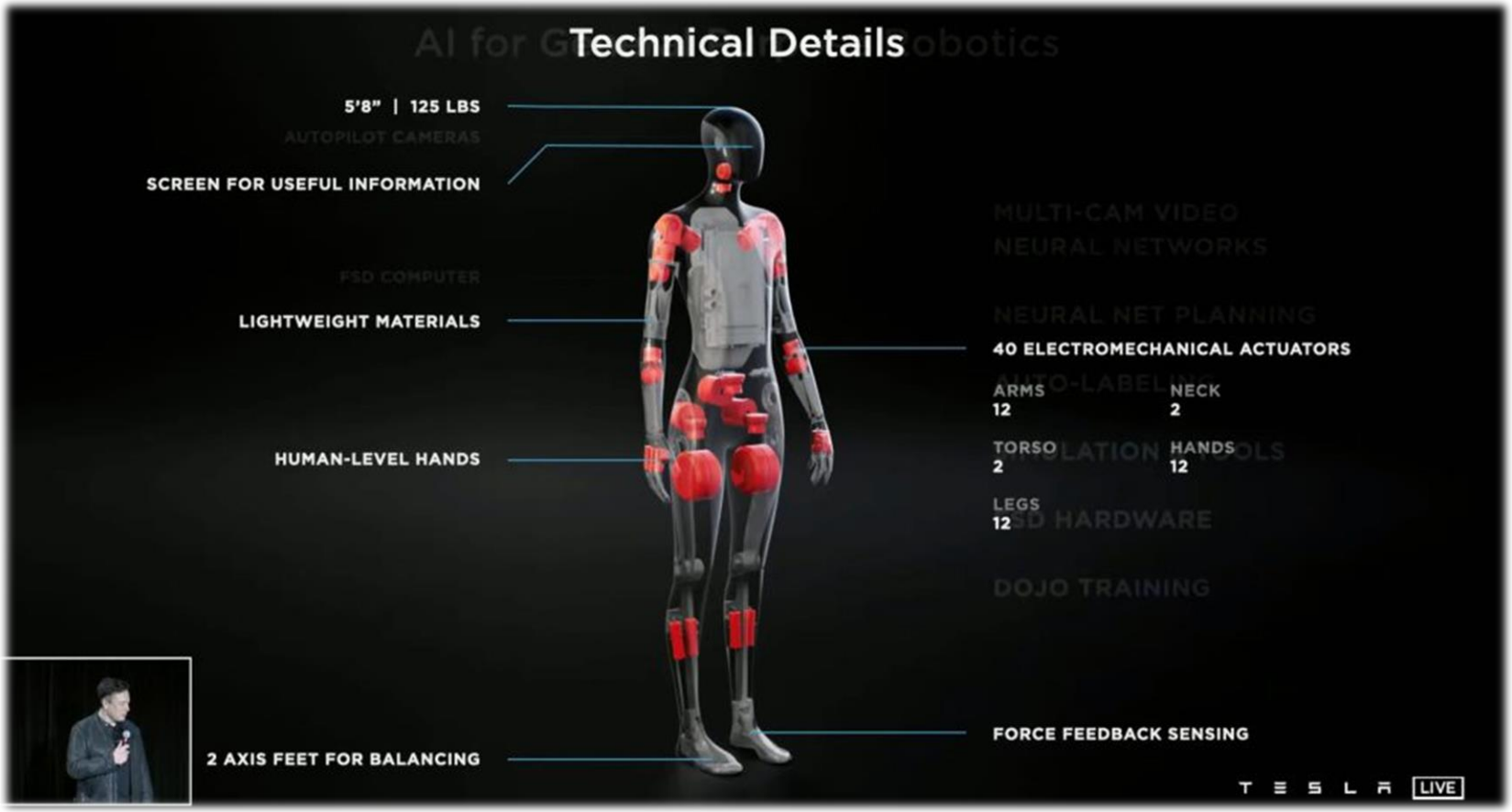
- Biology/nature inspired (biological organisms)
  - E.g. robotic limbs mimicking animal movement, swarm robotics inspired by insect behavior, and adaptive systems modeled after natural ecosystems
- Science fiction inspired
  - Example: In the book "Lock In" by John Scalzi, humans use robots, known as **“threeps”**, to interact with the world on their behalf, showcasing advanced human-robot interaction and the potential for remote presence technology

Autonomous Domestic Workers



https://www.bloomberg.com/news/articles/2022-06-03/musk-says-tesla-may-have-optimus-robot-prototype-within-months

Autonomous Domestic Workers



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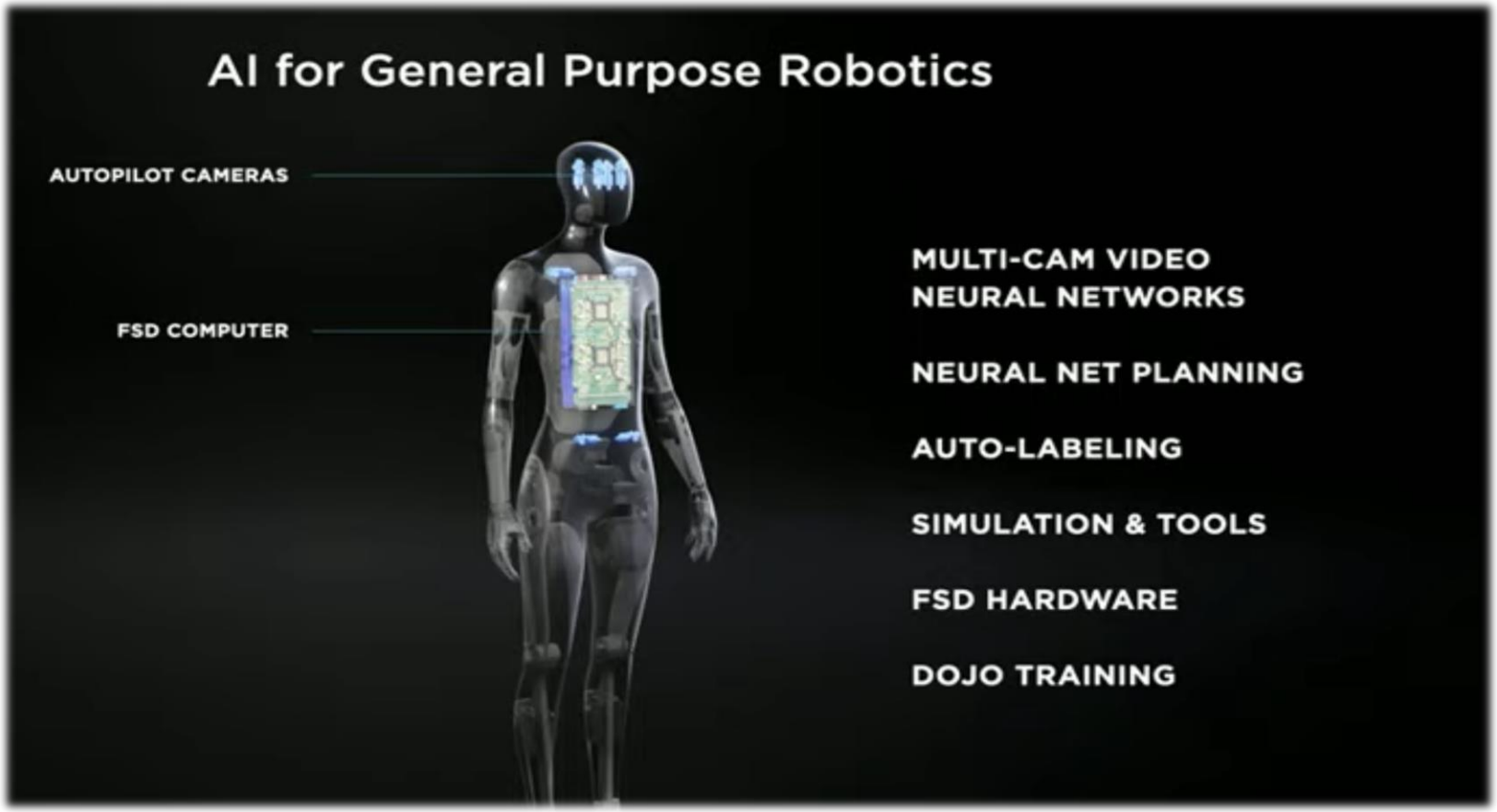
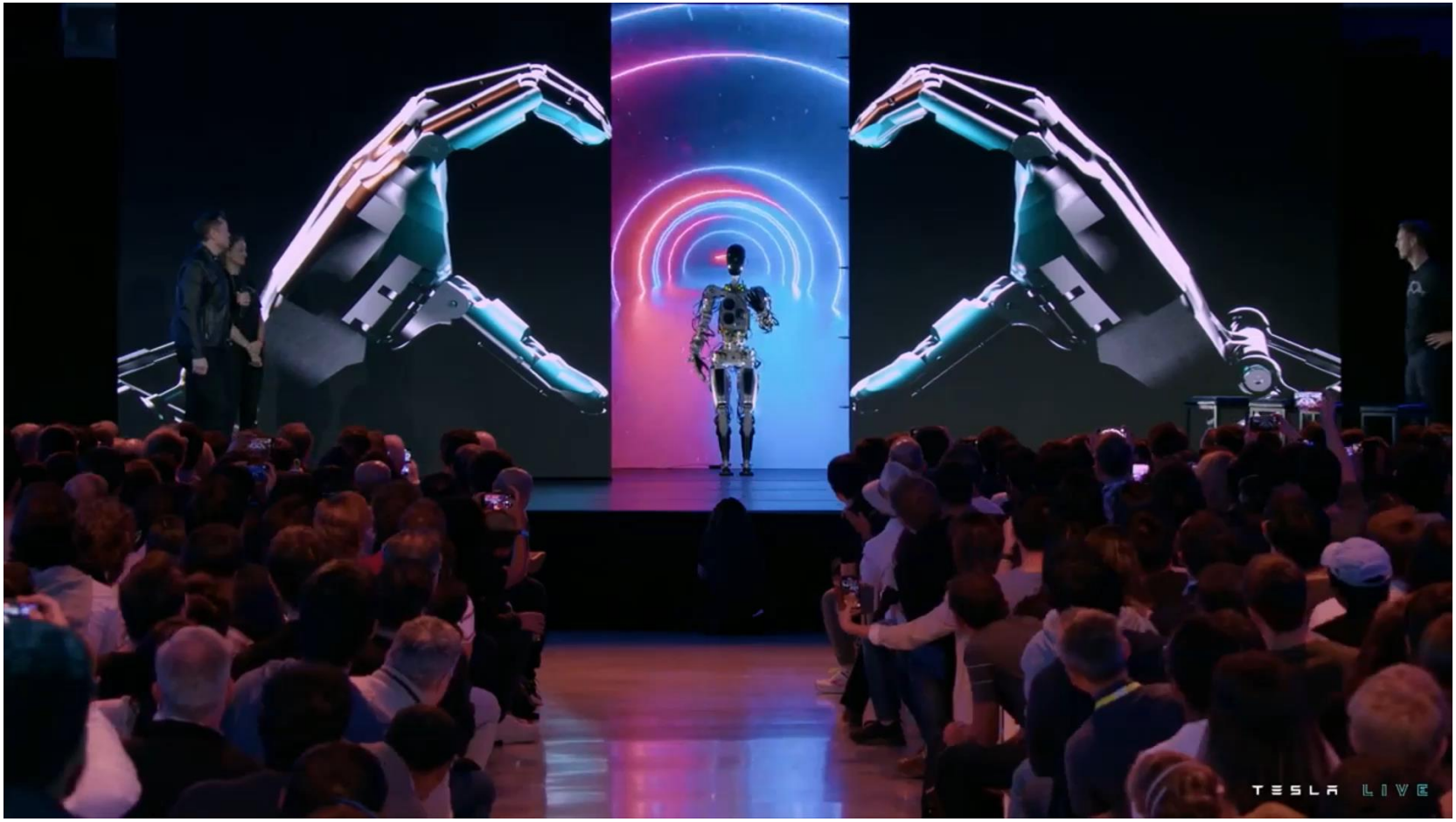


https://www.bloomberg.com/news/articles/2022-06-03/musk-says-tesla-may-have-optimus-robot-prototype-within-months

Extra: Tesla Bot



Source: https://www.youtube.com/watch?v=ODSJsviD_SU

Autonomous eVTOL

https://newatlas.com/aircraft/ehang-evtol-autonomous-air-tourism/

eVTOL = Electric Vertical Takeoff and Landing

Autonomous eVTOL

https://www.youtube.com/watch?v=nnPkCYlNf1E&t=30s

eVTOL = Electric Vertical Takeoff and Landing

Autonomous Bicycles

https://www.youtube.com/watch?v=LSZPNwZex9s

Swarm Robotics

Swarm Robotics: Autonomous systems with distributed communication and control

- Biological inspiration: Mimics behaviors of ant colonies and bird flocking for efficient cooperation and navigation
- Advantages of Swarm Robotics:
  1. Efficient Convoying & V2V Communication: Optimized routes and real-time data exchange
  2. Faster Search & Rescue Operations: Quick, coordinated coverage of large areas
  3. Wider Coverage: Effective for environmental monitoring, surveillance, and agriculture

Key Features:

- Distributed Computing & Communication: Independent operation with shared information and high-level human oversight
- Robustness: Adaptive, learning and reconfigurable systems for versatile applications

https://www.theengineer.co.uk/sheffield-robot-swarm-exhibits-turing-learning/

Swarm Robotics

https://www.youtube.com/watch?v=c82SXK9ne7Q

End of Module 1