COMP 5413-AA (AI for Autonomous Systems)

Department of Computer Science / Faculty of Science and Environmental Studies

Lakehead University

Term (Summer 2024)

Course Identification

- **Course Number**: Comp 5413-AA
- **Course Name**: AI for Autonomous Systems
- **Course Location**: AT-2001
- **Class Times**: Tuesday and Thursday from 09:00 pm – 12:00 pm

- **Instructor**: Dr. Bashier Elkarami.
- **Office hours:** Tuesday and Thursday from 12 pm – 1 pm.
- **Office Location**: TBA
- **E-mail**: belkaram@lakeheadu.ca
- **Teaching Assistant (TA) Information**: Farin Fallahpour (ffallahp@lakeheadu.ca)

Course Description/Overview

- This course explores the application of artificial intelligence (AI) in the design, development, and deployment of autonomous systems.
- Students will learn about the fundamental AI techniques used in autonomous systems, including machine learning, computer vision, and Deep Learning.
- Students will Learn about various sensors and actuators used in autonomous systems.
- Students will Learn about Autonomous Navigation, Decision Making and Control.

Grading and Evaluation

- Assignments: there will be 3-6 assignments 35%
- Projects 30% (Presentation via Zoom)
- Midterm 35% (Date: July 23rd)

- **Late Assignments:** Please note that any assignment submitted after the due date will be subject to a 10% daily deduction.

- **Assignments:** There will be 3-6 assignments to be submitted to the TA this term.

- **Attendance**: class attendance is not obligatory but important. you're responsible for class content.

Resources

Recommended books:

1. Artificial Intelligence: A Modern Approach by Stuart Russell and Peter Norvig

2. Probabilistic Robotics by Sebastian Thrun, Wolfram Burgard, and Dieter Fox

3. Deep Learning by Ian Goodfellow, Yoshua Bengio, and Aaron Courville

Course Topics (Tentative and subject to be switched)

1. Introduction to Autonomous Systems
2. Fundamentals of Artificial Intelligence.
3. Sensors and Actuators.
4. Data Processing and Feature Extraction.
5. Machine Learning for Autonomous Systems.
6. Deep Learning for Perception.
7. Autonomous Navigation.
8. Decision Making and Control
9. Autonomous Driving Systems
10. Drones and Aerial Robotics
11. Ethical Considerations and Safety

Course Policies

Students are referred to the departmental course pages with official policies and directions regarding exam deferrals, special accommodations, etc, as indicated in

Student Code of Conduct - Academic Integrity | Lakehead University

Academic Integrity

Academic Integrity is a fundamental principle in university education, which includes doing one's own work, accurately citing sources, properly paraphrasing, and collaborating appropriately. A student who breaches Academic Integrity is committing a serious offense. To learn more about academic offenses, procedures for suspected breaches, and sanctions for breaches of Academic Integrity, students should refer to the

Student Code of Conduct - Academic Integrity | Lakehead University

- let’s watch these videos

- https://www.youtube.com/watch?v=vE9tIYGyRE8

- https://youtu.be/2GsDcwp9uk4?feature=shared

- https://youtu.be/UcEyfQ1I8jg?feature=shared

- https://youtu.be/4sCK-a33Nkk?feature=shared

Introduction to Autonomous Systems

- Autonomous systems are sophisticated technologies designed to function without direct human intervention.

- They use sensors, processors, and algorithms to perceive their surroundings, process data, and make decisions.

- Drones, self-driving cars, and robots are examples of autonomous systems.

- Their goal is to optimize efficiency, precision, and safety across various applications.

Key Characteristics:

- **Perception**: Ability to sense the environment using cameras, lidar, radar, and other sensors.
- **Processing**: Data processing and decision-making using AI and machine learning algorithms.
- **Action**: Execution of tasks based on processed data and decisions.

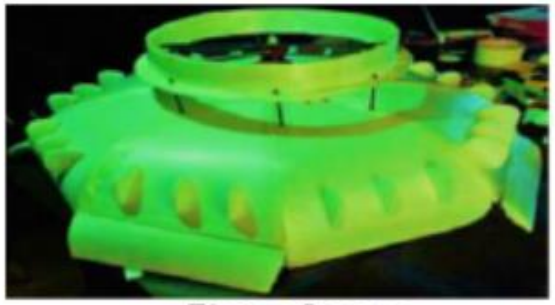
Drones (Unmanned Aerial Vehicles, UAVs)

- Drones, or Unmanned Aerial Vehicles (UAVs), consist of several key components that work together to enable flight and functionality.


DJI Phantom-Quad copter


Quad copter


Quad Air


Flying Saucer

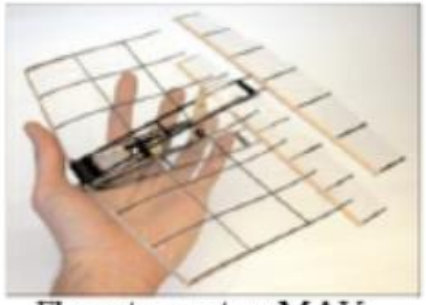

Hexa copter


AR-Drone quadcopter


Octo copter


Quad-rotor MAV


MAV-T Hawk


Flapping-wing MAV

1. **Motors**

- **Function**: Motors convert electrical energy into mechanical energy, providing the necessary thrust to lift and propel the drone.

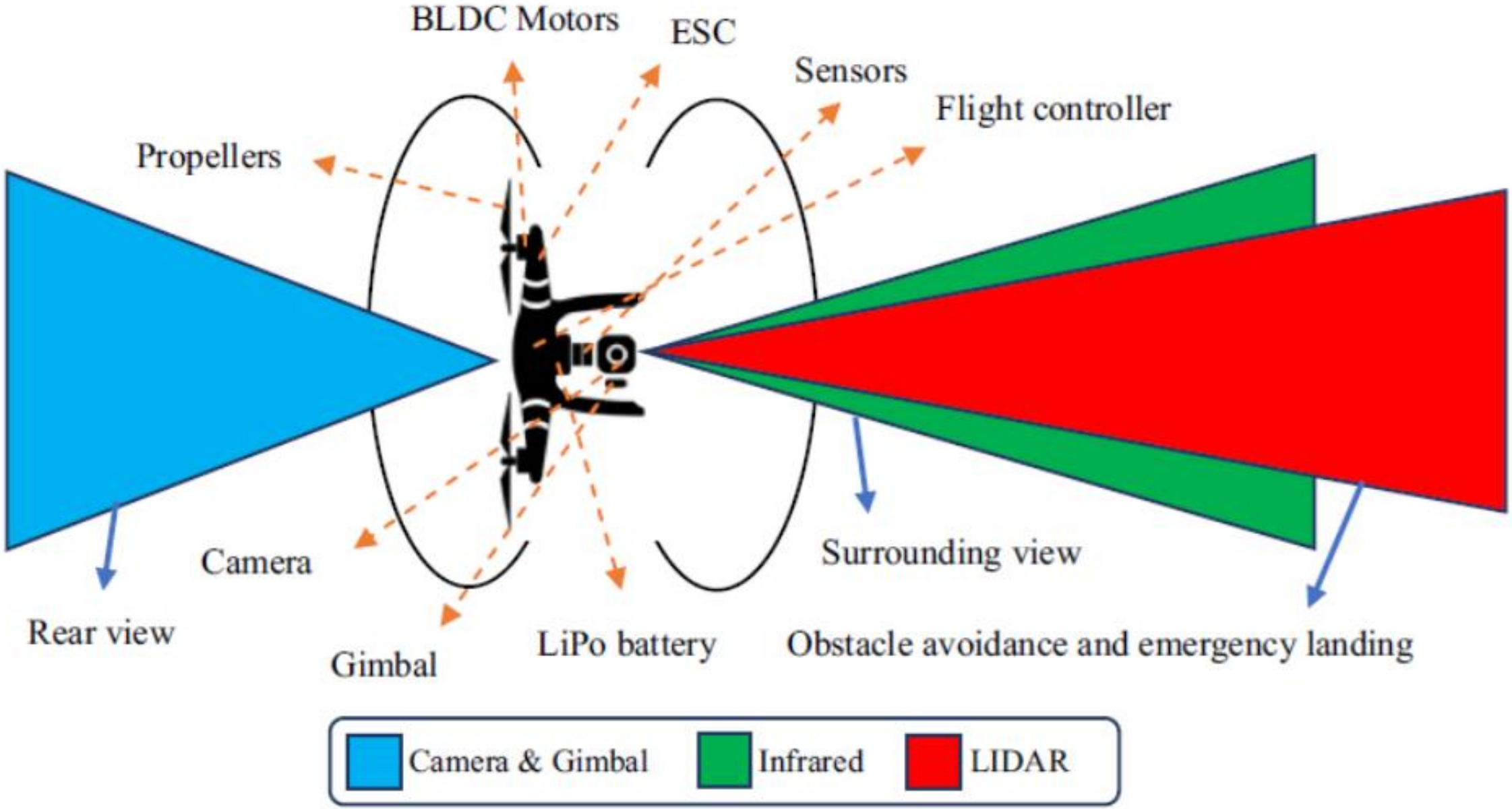
- **Types**: Brushless motors are commonly used in drones due to their efficiency and durability.

2. Propellers

- **Function**: Propellers generate lift by spinning and creating a pressure difference between the upper and lower surfaces.
- **Design**: Typically made from plastic or carbon fiber, they vary in size and pitch, affecting flight stability and speed.

3. Flight Controller

- **Function**: The flight controller acts as the drone’s brain, processing input from sensors and the remote control to maintain stable flight.
- **Features**: It includes accelerometers, gyroscopes, and barometers to monitor the drone's orientation and altitude.



Components of UAV[1]

4. GPS Module

- **Function**: The GPS module provides precise location data, enabling navigation, waypoint tracking, and return-to-home functions.
- **Importance**: Essential for autonomous flight and location-based operations.

5. Cameras

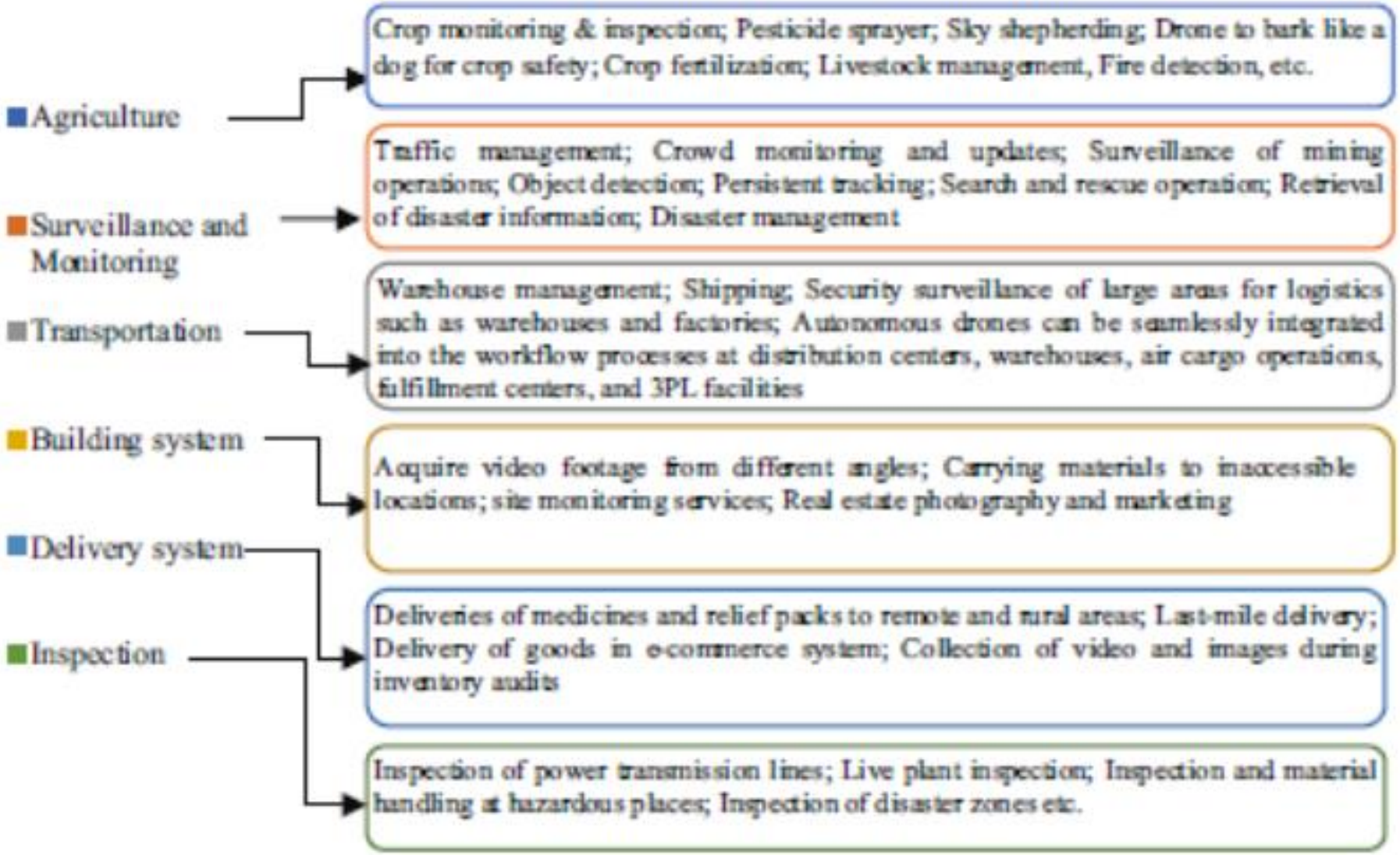
- **Function**: Cameras capture high-quality images and videos, often used for aerial photography, surveillance, and mapping.
- **Features**: Stabilized by gimbals to reduce motion blur and vibration, providing clear footage

6. Sensors for Obstacle Detection

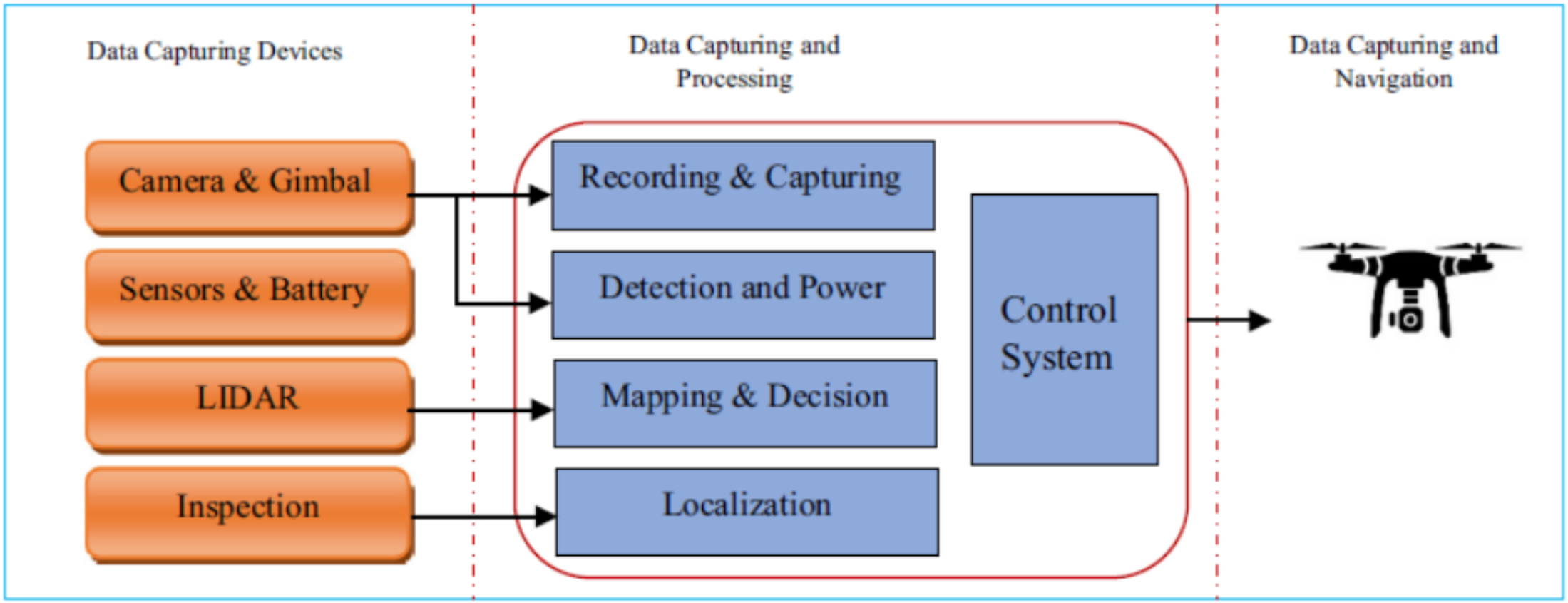
- **Function**: Sensors detect obstacles in the drone's flight path to avoid collisions.

- **Types**:

  - **Ultrasonic Sensors**: Use sound waves to measure distance to objects.
  - **Infrared Sensors**: Detect obstacles by measuring reflected infrared light.
  - **Lidar Sensors**: : Provide detailed 3D maps of the environment.



The expected reach of UVAs in various applications.[1]



Functional components of UAV [2]

Self-Driving Cars (Autonomous Vehicles)

- **Description**: Vehicles capable of sensing the environment and navigating without human input.
- **Components**: Lidar, radar, cameras, central computing system, GPS module, communication systems.
- **Applications**: Passenger transport, logistics, public transportation, personal use.

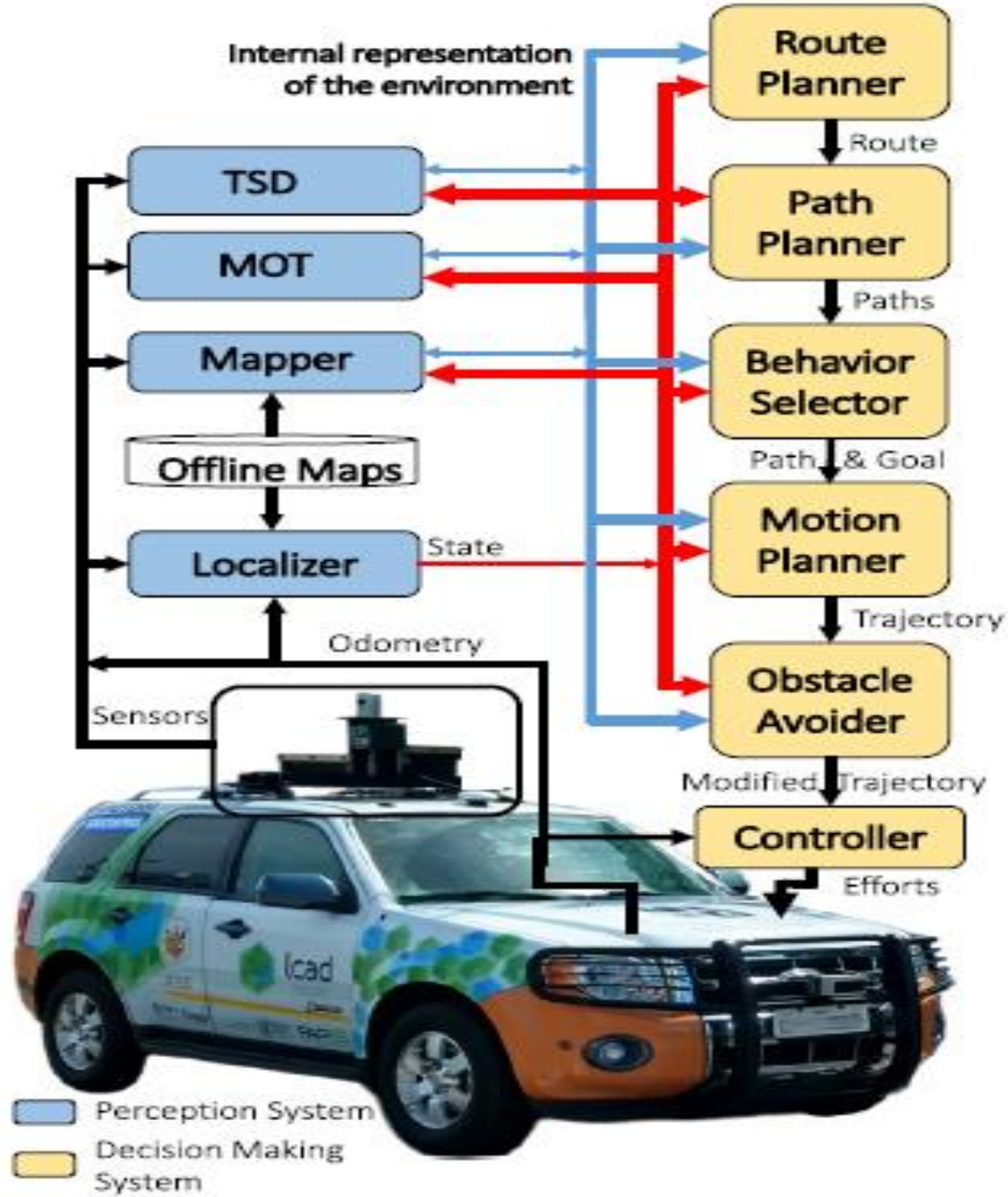


Fig. 1. Overview of the typical architecture of the automation system of self-driving cars. TSD denotes Traffic Signalization Detection and MOT denotes Moving Objects Tracking. 3

Robots

- **Description**: Machines designed to perform specific tasks autonomously or semi-autonomously.

- **Components**: Actuators, sensors, control systems, computing hardware, software.

- **Applications**: Manufacturing automation, healthcare (surgical robots), logistics (warehouse robots), domestic (cleaning robots).

Historical Context and Evolution

Early Concepts and Beginnings:

- **Ancient Times**: The idea of automated machines dates back to ancient Greek and Roman civilizations, where simple mechanical devices like Heron of Alexandria's steam-powered devices were conceptualized.

- **Middle Ages**: Automata, such as mechanical clock towers and programmable automata, were developed in medieval Europe.

- **20th Century Developments:**

- **1940s-1950s**: The development of early computers and control systems laid the groundwork for modern robotics. Norbert Wiener's invention of cybernetics emphasized control and communication in animals and machines.

- **1960s**: The first industrial robots, like Unimate, were introduced, revolutionizing manufacturing with automation.

Advancements in Robotics and Computing:

- **1970s-1980s**: Progress in computing and AI research led to more sophisticated robots. Notable projects included Shakey, the first mobile robot capable of reasoning about its actions.

- **1980s-1990s**: The integration of AI into autonomous systems expanded applications, with developments in computer vision and sensor technology.

Emergence of Drones and Autonomous Vehicles:

- **1990s**: The U.S. military began using drones for reconnaissance. Developments in UAV technology expanded their use in civilian applications.

- **2000s**: The DARPA Grand Challenge spurred innovation in autonomous vehicles, leading to significant advancements in self-driving car technology.

21st Century and the Rise of AI:

- **2010s**: Rapid advancements in AI, machine learning, and sensor technology revolutionized autonomous systems. Companies like Google (Waymo) and Tesla led the way in self-driving car development.

- **Present Day**: Autonomous systems are now prevalent in various fields, including logistics, healthcare, agriculture, and public transportation. Drones are widely used for commercial deliveries, while robots assist in manufacturing and home automation.

Role of AI in Autonomous Systems:

1. Perception and Sensing:

- **Computer Vision**: AI algorithms analyze visual data from cameras and sensors, allowing autonomous systems to recognize and interpret their surroundings. This is crucial for applications such as obstacle detection in drones and self-driving cars.
- **Sensor Fusion**: Combining data from multiple sensors (e.g., lidar, radar, cameras) to create a comprehensive understanding of the environment. AI algorithms enhance the accuracy of this process, essential for reliable navigation and decision-making.
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2. Decision Making

- **Path Planning**: AI helps in determining the optimal path for autonomous systems to follow, avoiding obstacles and efficiently reaching their destinations. This is especially important for self-driving cars and delivery drones.

- **Real-Time Processing**: AI processes sensor data in real-time, enabling quick and accurate responses to dynamic environments. For example, an autonomous car can instantly react to a pedestrian stepping onto the road.

3.Learning and Adaptation

- **Machine Learning**: Autonomous systems use machine learning algorithms to improve their performance over time. By learning from past experiences, these systems can better handle new and unforeseen situations.

- **Reinforcement Learning**: A type of machine learning where systems learn by receiving rewards or penalties based on their actions. This is useful in scenarios where autonomous systems need to optimize their behavior through trial and error.

What Is AI?

- AI is a rapidly growing field generating over a trillion dollars annually.

- AI is a universal field that covers a vast range of subfields, from general tasks like learning and reasoning to specific ones like playing chess, writing poetry, driving cars, and diagnosing diseases.

- The field of AI is concerned with building intelligent machines that can act effectively and safely in novel situations.

- ChatGPT

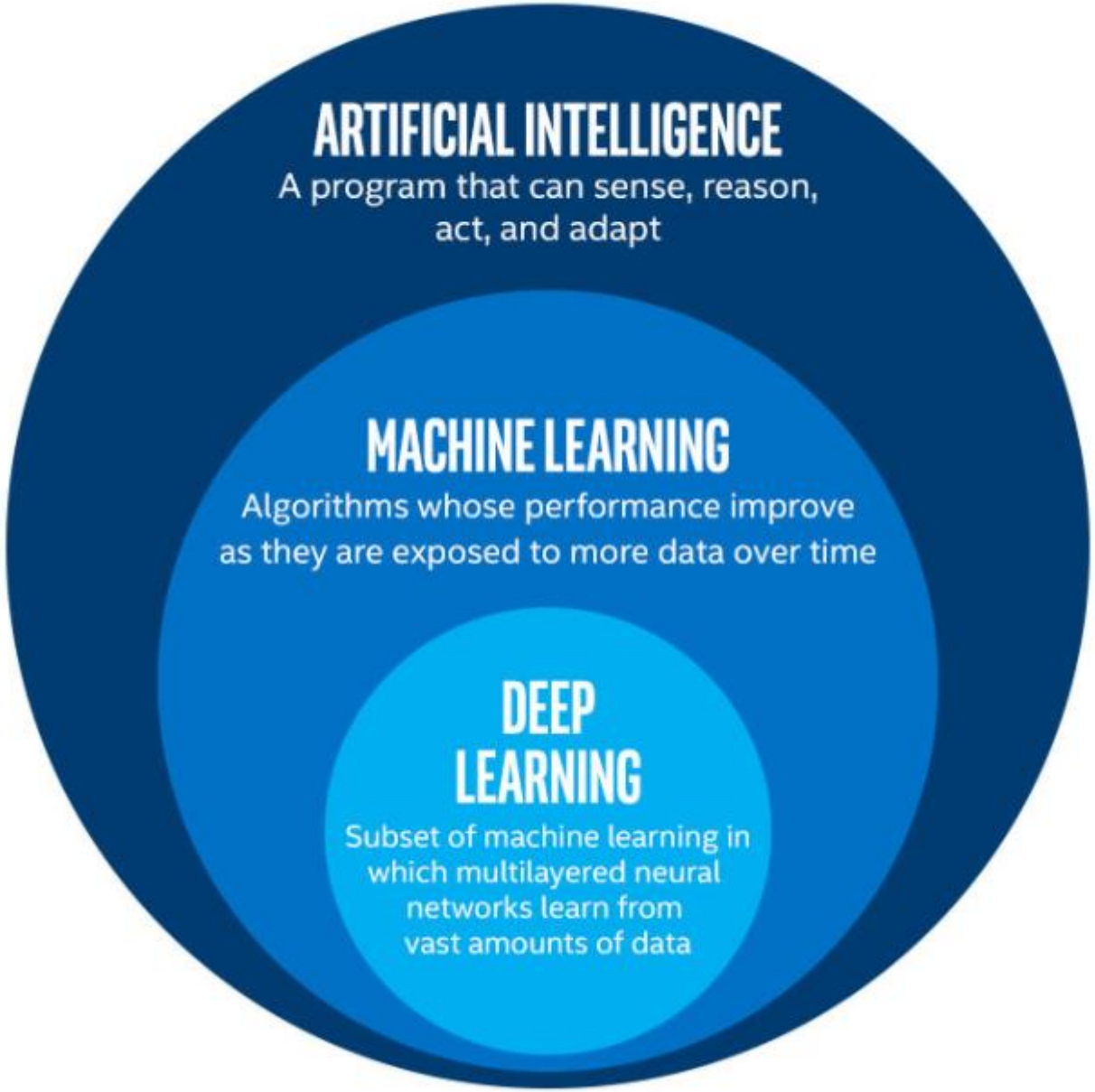
- AI, or Artificial Intelligence, refers to the development of computer systems or machines that can perform tasks that typically require human intelligence.

- These tasks include learning, reasoning, problem-solving, perception, understanding natural language, and even interacting with the environment.

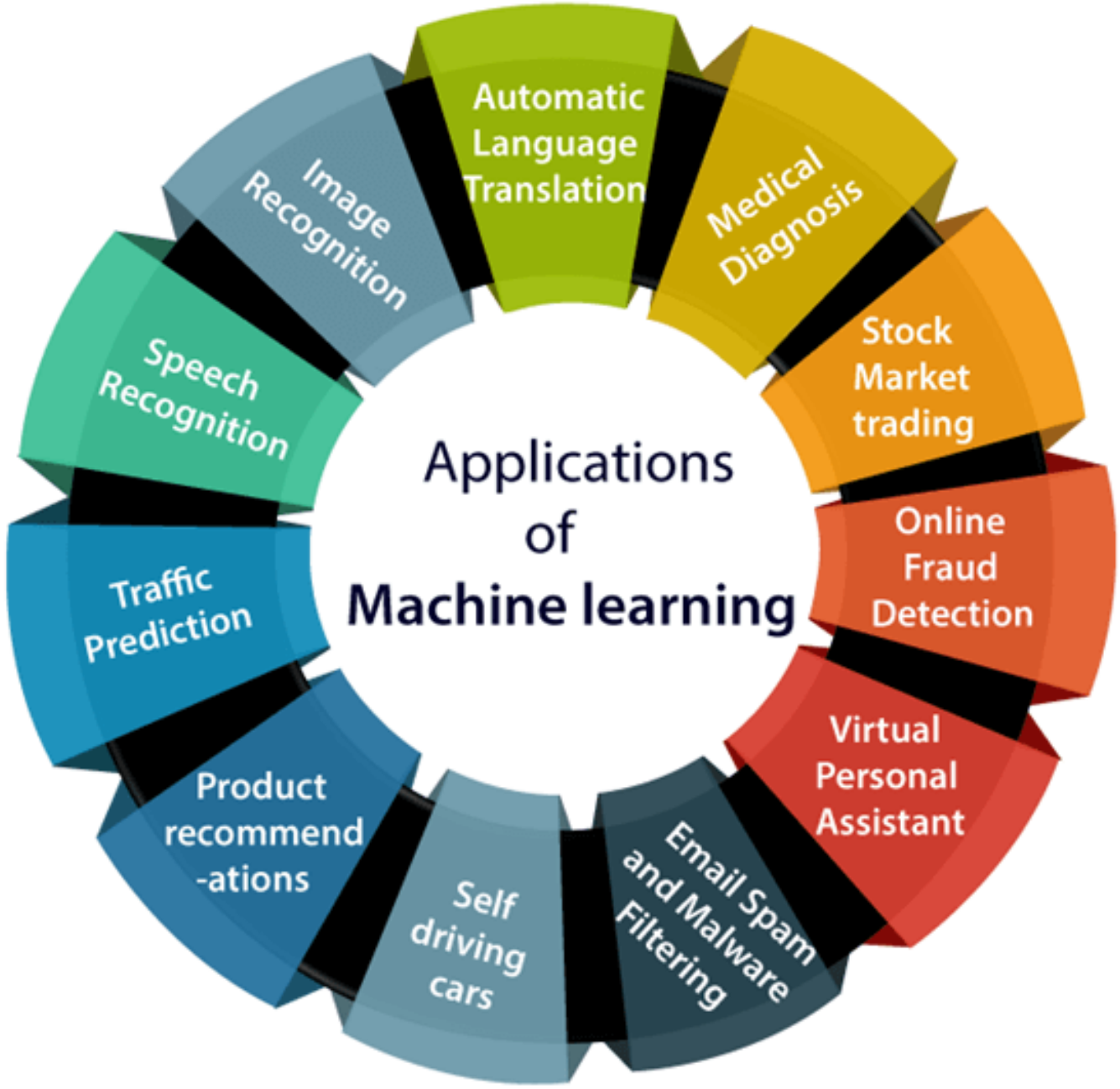
- The goal of AI is to create systems that can mimic, augment, or replicate human intelligence to some degree.

- **Understanding AI and ML**

- Machine Learning is a subset of AI.
- It enables machines to learn from data without explicit programming. [4]



- **Applications of ML**[4]



What is Intelligence?

- The concept of intelligence varies, some view it as internal thought processes, while others view it as external behavior.

- Some have defined intelligence by comparing it to human performance, while others prefer an abstract, formal definition of intelligence called rationality.

- Rationality can be loosely understood as doing the "right thing."

- There are four combinations of intelligent systems:

Think like a human vs. Think rationally

Act like a human vs. Act rationally

- Pursuing human-like intelligence requires empirical science related to psychology, while a rationalist approach involves a combination of mathematics and engineering.

Acting Rationally: Rational Agents

- An agent is a computer program that can perform tasks autonomously, perceive its environment, persist over time, adapt to change, and create and pursue goals.

- A rational agent acts to achieve the best-expected outcome, even in cases of uncertainty.

- Early agents used logic and definite plans to achieve goals, while later agents used probability theory and machine learning to make decisions under uncertainty.
- AI focuses on creating agents that make the right decisions based on the objective given to them.
- The theory of probability generalizes logic to uncertain situations, which is important for AI.
- The availability of data and formalization of probability led to the emergence of statistics as a field.

- There are six disciplines that compose most of AI.

- **Natural Language Processing** to communicate successfully in a human language;

- **Knowledge Representation** to store what it knows or hears;

- **Automated Reasoning** to answer questions and to draw new conclusions;

- **Machine Learning** to adapt to new circumstances and to detect and extrapolate patterns.

- **Computer Vision** and speech recognition to perceive the world;

- **Robotics** to manipulate objects and move about.

The Birth of AI

(1943–1956)

- In 1943, McCulloch and Pitts proposed the first model of artificial neurons based on brain neurons and logic theory.
- Each neuron could be "on" or "off" and turned "on" with sufficient stimulation from neighbors.
- This is considered the first significant contribution to AI.
- Hebbian learning, a simple rule for changing neural connection strengths, was introduced by Donald Hebb in 1949 and remains influential today.

- Marvin Minsky and Dean Edmonds constructed the first neural network computer in 1950 while they were undergraduates at Harvard University.

- Two checkers-playing programs were developed in 1952, one by Christopher Strachey at the University of Manchester and the other by Arthur Samuel at IBM. Both were early examples of AI.

- Alan Turing's 1950 article "Computing Machinery and Intelligence" introduced the Turing test, machine learning, genetic algorithms, and reinforcement learning

- In 1956, John McCarthy organized a two-month workshop at Dartmouth College, which brought together 10 US researchers, including Newell, Simon, Samuel, Solomon off, and Selfridge, interested in automata theory, neural nets, and the study of intelligence

- The study proceeds on the assumption that any aspect of intelligence or learning can be precisely described for a machine simulation.

- An attempt will be made to find how to make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve themselves.

(1952–1969)

- Nathaniel Rochester and his team at IBM developed early AI programs. In 1959, Herbert Gelernter created the Geometry Theorem Prover, which anticipated modern mathematical theorem provers.

- Arthur Samuel's checkers programs demonstrated that computers could do more than their initial programming by using reinforcement learning to play at a strong amateur level.

- John McCarthy founded Stanford's AI lab in 1963 and worked on using logic to create the ultimate Advice Taker, aided by J.A. Robinson's discovery.

- Early AI systems failed because
- They relied on "informed introspection" instead of a thorough analysis and
- lacked an understanding of the complexity of the problems they attempted to solve.
- Additionally, a fundamental limitation in their basic structures caused a third difficulty.

(1969–1986)

- Early AI research involved a search mechanism for problem-solving through basic reasoning steps. However, these “weak methods” had limited scalability and could not handle larger or more complex issues

- The use of domain-specific knowledge as an alternative to weak methods allows for larger reasoning steps and better handling of typical cases in narrow areas of expertise.

- DENDRAL was an AI program developed at Stanford in 1969 to infer molecular structure from mass spectrometer data.

- In 1971, Feigenbaum and his team at Stanford began the Heuristic Programming Project (HPP) to apply expert systems in various areas

- R1, the first commercial expert system, launched in 1982 at Digital Equipment Corporation, saved the company $40 million per year by 1986

- Overall, the AI industry boomed from a few million dollars in 1980 to billions of dollars in 1988, including hundreds of companies building expert systems, vision systems, robots, and software and hardware specialized for these purposes.

- After the early AI excitement, the "AI winter" followed, during which many companies failed because of

- The difficulty in creating and maintaining expert systems for complex domains.

- The systems' reasoning methods could not handle uncertainty, and they could not learn from experience

(1986–present)

- In the mid-1980s, at least four different groups reinvented the back-propagation learning algorithm that was first developed in the early 1960s.
- In the 1980s, hidden Markov models (HMMs) became the preferred approach and dominated the field
- Judea Pearl introduced Bayesian networks in 1988, which revolutionized probabilistic reasoning in AI
- In 1995, Yarowsky found that machine learning algorithms can accurately identify the meaning of words in sentences with over 96% accuracy

- Convolutional neural networks recognized handwritten digits in the 90s, but deep learning methods gained traction in 2011 with speech and object recognition

- In 2012, Geoffrey Hinton's group created a deep learning system at the University of Toronto that improved image classification beyond previous methods

- **Reference**

1. Ahmed F, Mohanta JC, Keshari A, Yadav PS. Recent Advances in Unmanned Aerial Vehicles: A Review. Arab J Sci Eng. 2022;47(7):7963-7984. doi: 10.1007/s13369-022-06738-0. Epub 2022 Apr 25. PMID: 35492958; PMCID: PMC9035982.
2. Aabid, Abdul & Parveez, Bisma & Parveen, Nagma & Khan, Sher & Raheman, Md Abdul & Zayan, Mohammed & Ahmed, Omar. (2022). Reviews on Design and Development of Unmanned Aerial Vehicle (Drone) for Different Applications. Journal of Mechanical Engineering Research and Developments. 45. 53-69.
3. Badue, C., Guidolini, R., Carneiro, R. V., Azevedo, P., Cardoso, V. B., Forechi, A., ... & De Souza, A. F. (2021). Self-driving cars: A survey. *Expert systems with applications*, *165*, 113816.
4. https://www.linkedin.com/pulse/machine-learning-101-understanding-fundamentals-ai-srivastava--ayk9c