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MACHINE LEARNING IN ROBOTICS: ADAPTIVE CONTROL AND AUTONOMY

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Abstract: This article explores the application of machine learning techniques in robotics to enable adaptive control and enhance robot autonomy. The study analyzes reinforcement learning algorithms, neural networks, and their role in autonomous navigation and decision-making. Examples of successful integration of machine learning in industrial and service robots are presented, along with a discussion on future developments in this field.

Keywords: Machine learning, robotics, adaptive control, autonomy, neural networks, reinforcement learning, autonomous navigation, intelligent systems, assistant robot, industrial robots, service robots, control algorithms, sensor systems, artificial intelligence, automation.

МАШИННОЕ ОБУЧЕНИЕ В РОБОТОТЕХНИКЕ: АДАПТИВНОЕ УПРАВЛЕНИЕ И АВТОНОМНОСТЬ

Аннотация: Статья рассматривает применение методов машинного обучения в робототехнике для обеспечения адаптивного управления и повышения автономности роботов. Анализируются современные алгоритмы обучения с подкреплением, нейронные сети и их роль в автономной навигации и принятии решений. Представлены примеры успешной интеграции машинного обучения в промышленных и сервисных роботах, а также обсуждаются перспективы развития этой области.

Ключевые слова: Машинное обучение, робототехника, адаптивное управление, автономность, нейронные сети, обучение с подкреплением, автономная навигация, интеллектуальные системы, робот-помощник, промышленные роботы, сервисные роботы, алгоритмы управления, сенсорные системы, искусственный интеллект, автоматизация.

MASHINANI O‘RGANISH ROBOTOTEXNIKADA: ADAPTIV BOSHQARUV VA AVTONOMLIK

Annotatsiya: Ushbu maqolada robototexnika sohasida mashinani o‘rganish (machine learning) texnologiyalarining ahamiyati, ularning adaptiv boshqaruv tizimlarini shakllantirishdagi roli hamda robotlarning avtonom harakatlanish imkoniyatlarini kengaytirishdagi o‘rni yoritilgan. Mustahkamlash orqali o‘rganish (reinforcement learning), chuqur o‘rganish (deep learning) va neyron tarmoqlarning robototexnikada qo‘llanilishi tahlil qilinadi. Maqolada robotlarning sanoat, tibbiyot va xizmat ko‘rsatish sohalarida mashinani o‘rganish algoritmlaridan foydalangan holda qanday avtonom tizimlarga aylanganligi misollar orqali ko‘rsatilgan.

Kalit so‘zlar: Mashinani o‘rganish, robototexnika, adaptiv boshqaruv, avtonomiya, neyron tarmoqlar, mustahkamlash orqali o‘rganish, avtonom navigatsiya, sun’iy intellekt, avtomatlashtirish, intellektual tizimlar.

INTRODUCTION

The rapid development of modern technology has made robotics an integral part of human activity. Early robots were limited to performing pre-programmed actions. However, with the emergence of machine learning (ML) technologies, robots have gained the ability to learn from data, adapt to new environments, and make autonomous decisions.

MAIN PART

AI stands for Artificial Intelligence. It is a technology that allows computers to think, understand, and make decisions like humans.

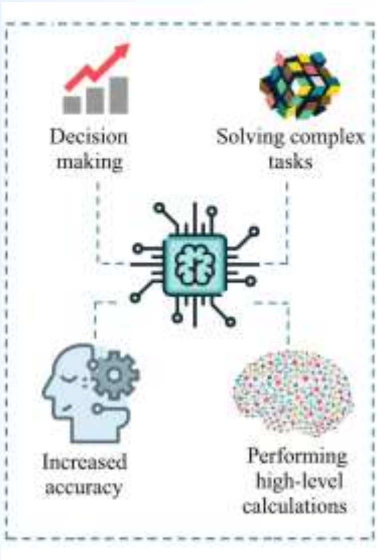

Fig 1. Forms of artificial intelligence

Machine learning, a branch of artificial intelligence, allows systems to learn from data without being explicitly programmed. In robotics, ML enhances flexibility, accuracy, and efficiency, enabling robots to perform complex tasks more effectively.

Fig 2. Forms of Machine learning

Robotics — is the branch of engineering and science that deals with the design, construction, operation, and use of robots.

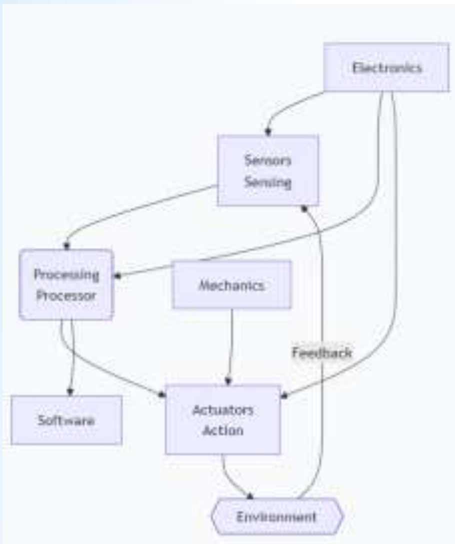

Fig 3. The working principle of robotics

Adaptive control — is a control method that adjusts itself to changing conditions.

Autonomy — is the ability of a system to operate independently without human intervention.

In robotics:

- Adaptive control – the ability of a robot to automatically adjust its actions and control parameters in response to changes in the environment or working conditions. For example, a robot can maintain stability when moving on different surfaces or carrying varying loads.
- Autonomy – the ability of a robot to perform tasks independently without human intervention. For example, an autonomous drone or cleaning robot can navigate and operate on its own.

Fig 4. Robotics aystem architecture: adaptive control & autonomy

In robotics, machine learning plays a key role in developing adaptive control and autonomy. For example:

- Toshiyuki Furukawa and Hamid Reza Vaezi used machine learning algorithms to enable robots to maintain stable movements in complex and changing environments.
- Sebastian Thrun conducted research on autonomous vehicles, demonstrating cars' ability to navigate and operate without human intervention.
- Pieter Abbeel and his team trained robots to learn tasks such as object manipulation and placement using adaptive control methods.

These studies show how machine learning allows robots to adapt to new situations and operate independently.

Table 1. Use of adaptive control and autonomy in robotics worldwide

Concept	Countries	Industry / Sector	Companies / Projects	Status in Uzbekistan	Analysis
Adaptive Control	USA, Japan, Germany	Industrial robotics, aviation, military	Boston Dynamics, FANUC, Mitsubishi Electric	Limited use in industrial enterprises, mainly in labs and technical research centers	Widely used in industrial robots and hazardous environment robots in the USA and Japan; in Uzbekistan, it is at an experimental stage for industrial automation
Autonomy	USA, Japan, South Korea, Germany	Autonomous vehicles, drones, logistics, service robots	Tesla, Waymo, DJI, Hyundai Robotics	Developing in urban transport systems and drone technology	Autonomous vehicles and drones are well-developed in the USA and South Korea; in Uzbekistan, mainly research and pilot projects
Application Trend	Global	Robotics, transport, healthcare, industry	Boston Dynamics, Tesla, DJI, FANUC	Universities, research centers, pilot projects	Adaptive control is more used in industry and hazardous

					environments; autonomy is mainly applied in transport and service robots; in Uzbekistan, both are at research and pilot

Neural networks simulate the human brain, processing data and recognizing patterns. Deep learning, a subfield of ML, helps robots interpret visual, auditory, and sensor inputs to make decisions in real time.

Autonomous vehicles, for example, use deep learning algorithms to detect obstacles, recognize traffic signs, and predict pedestrian movements — all of which are essential for safe navigation.

ANALYSIS AND RESULTS

Machine learning enables robots to perform tasks independently without human intervention. Such robots not only execute commands but also decide how to act in new, unforeseen situations. Autonomous robots are increasingly used in manufacturing, medicine, and even space exploration. For example, Boston Dynamics' Spot robot learns from its environment, maintains balance, and autonomously avoids obstacles, demonstrating high adaptability.

Table 1. Analysis of industrial and service robots

№	**Factor / Feature**	**Industrial Robots (Example)**	**Service Robots (Example)**	**Country Examples**	**Description / Analysis**
1	Task Type	Car assembly, welding	Delivery, hotel services	USA (Tesla), Japan (Toyota), Uzbekistan (Tashkent Technology Center)	Industrial robots perform repetitive tasks, while service

					robots interact with humans
2	Risk Level	Handling chemicals	Delivering medicine to patients	Germany (BASF), Uzbekistan (Tashkent Pharmaceutical Plant)	Industrial robots handle dangerous tasks, service robots operate in safer environments
3	Adaptability	Adjusts to load and material weight	Adjusts to navigation paths	USA, Japan, Uzbekistan pilot projects	Adaptive control allows robots to adjust to changing conditions
4	Sensor Systems	Pressure, temperature, weight sensors	Cameras, LiDAR, infrared sensors	Japan (FANUC), South Korea (Hyundai Robotics), Uzbekistan	Industrial robots monitor physical parameters, service robots monitor the environment
5	Decision Making	Automatically selects task execution sequence	Independently determines path and movement	USA (Boston Dynamics), Uzbekistan pilot projects	Autonomy allows robots to operate without human intervention
6	Speed and Efficiency	Completes assembly in seconds	Fast delivery or navigation	USA, Japan, Uzbekistan pilot projects	Adaptive control increases robot efficiency
7	Error Reduction	Prevents incorrect welding placement	Avoids obstacles, maintains safety	Germany, USA, Uzbekistan	ML algorithms help reduce errors

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8	Learning from Data	Learns from work experience	Learns from navigation and sensor data	USA (Waymo), Uzbekistan university experiments	Robots learn to perform tasks more efficiently based on experience
9	Compatibility	Integrates with other robots and systems	Adapts to medical or office systems	Japan, USA, Uzbekistan	Adaptive control systems allow robots to coordinate with other systems
10	Development Prospects	Expanding industrial automation	Expanding service, logistics, and medical robots	Global (USA, Japan, South Korea), Uzbekistan	Shows key directions of robotics development in Uzbekistan and globally

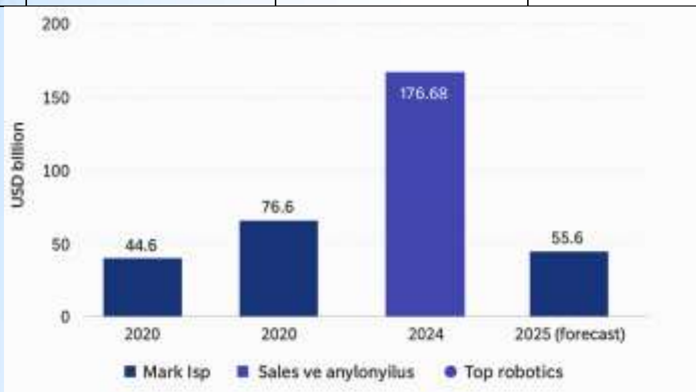

Fig 5. Global robotics key metrics (2020-2025)

Table 2. Autonomous transport and delivery systems: Country comparison

№	Area / System	Example / Technology	Country Examples	Description & Analysis
1	Autonomous Vehicles	Waymo, Tesla Autopilot	USA, China, Germany, Japan, Uzbekistan*	Improves road safety, reduces traffic congestion, increases energy efficiency. In Uzbekistan implementation is still in early

				stages, with some experiments i Tashkent.
2	Autonomous Delivery Systems	Amazon Prime Air, Starship robots	USA, EU countries, Singapore, Uzbekistan*	Speeds up package and foo delivery. In Uzbekistan, pilo projects for drone delivery o medicine and food are underway.
3	Logistics & Transport Management	AI-based route optimization, DHL smart logistics	Germany, USA, Japan, Uzbekistan*	Optimizes delivery routes, reduce costs. Transport companies i Uzbekistan are beginning to digitiz logistics systems.
4	Smart City Transport Systems	AI traffic management, smart traffic signals	Singapore, South Korea, USA, Uzbekistan*	Reduces traffic congestion, prevent accidents. In Tashkent, smart traffi lights and transport monitorin projects are being piloted.

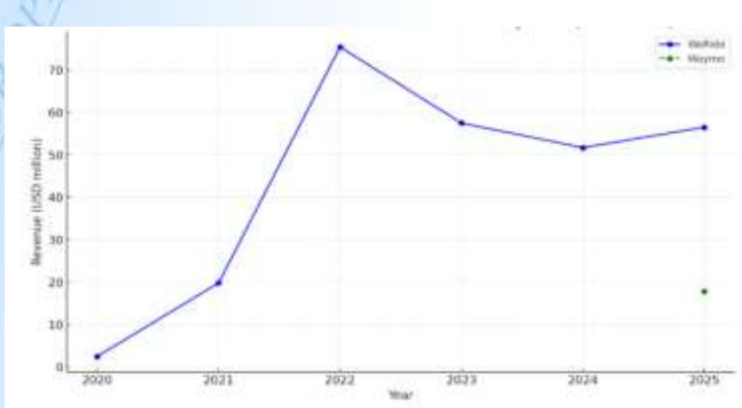

Fig 6. Estimated revenue of avtonomous vehicle companies (2020-2025)

Conclusion

Machine learning has become a fundamental driver of innovation in robotics, enabling adaptive control and autonomy across a wide range of applications. Industrial robots benefit from enhanced precision, efficiency, and safety, performing repetitive or hazardous tasks with minimal human intervention. Service robots, on the other hand, leverage ML to interact effectively with humans, navigate complex environments, and deliver goods or services autonomously.

Global examples, including autonomous vehicles, drones, and industrial systems, demonstrate that machine learning significantly improves decision-making, adaptability, and operational efficiency. While countries like the USA, Japan, and South Korea lead in practical implementation, Uzbekistan is actively exploring pilot projects and research initiatives to integrate these technologies into industry, logistics, and urban services.

In conclusion, the integration of machine learning into robotics is transforming both industrial and service sectors, enhancing productivity, safety, and autonomy. Continued research, investment, and experimentation will further expand the capabilities of robots, contributing to smarter, more efficient, and adaptive technological ecosystems worldwide.

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