



Metis

Study

Humanoid robots

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[AI]*

Summary

Two of the key challenges facing the Bundeswehr are personnel growth and technical innovation. Humanoid robots sit, stand and walk at the intersection of these two

areas of responsibility. The study outlines the current state of technology, maps the innovation landscape and considers the military use of humanoid robots, including corresponding development scenarios.

State of the art

Ten years ago, human-like machines with two legs, two arms and a head were, at best, a source of amusement. Images of their sometimes spectacular failure at the simplest of tasks – such as opening a door – in the DARPA Challenge went around the world in 2015.

Technology has made remarkable progress over the last decade. It is still true that hardware is hard. Robots that are supposed to operate successfully and independently in the complexity of the physical world pose a unique and greater technical challenge than the development of software. Nevertheless, there are increasing signs that a Cambrian explosion is imminent in the field of humanoid robotics, similar to – and linked with – that of large language models (LLMs) in the field of artificial intelligence (AI). Affordable humanoid robots could soon prove useful outside of laboratories or niche applications.

Innovation drivers

The overview in Table 1 illustrates that two different approaches are currently competing among leading manufacturers of humanoid robots. Most companies are initially focusing on the application of humanoid robotics for clearly defined, repetitive tasks in structured, controlled environments in industry. Even there, surprises sometimes arise in the interaction between humans and machines – for example, because humans are not used to the “body language” of robots and find it difficult to anticipate their next movement. The idea behind this approach is to first gather important learning experiences in environments with clear occupational safety rules before the company

exposes itself to liability risks from possible damage in private households.

NEURA Robotics is taking the opposite approach and is aiming for applications in private households and the service industry right from the start. To this end, the robot is equipped with sophisticated sensor technology to enable it to interact safely with humans in collaborative, hand-in-hand scenarios. Thanks to a networked infrastructure, what one robot learns will then be mastered by all the others in the “robot fleet”. The idea here is to achieve commercial success by entering the mass market directly with consumer-friendly consumer goods.

Key factors

The famous dance moves, walks, parkour runs and somersaults performed by Boston Dynamics’ Atlas robot (see Table 1) follow pre-programmed sequences and are therefore only a limited indicator of the state of the art.

The decisive factor for progress in this field is whether humanoid robots can handle objects and everyday items and solve tasks, especially in unstructured and previously unknown environments. This is the essential prerequisite for passing the ultimate litmus test of humanoid robotics: making a cup of coffee in a strange kitchen on demand.

Actuators

Current robot models do without hydraulic drives and instead use more compact, quieter electric motor-gear units. Movement at human level, including climbing stairs and avoiding or overcoming simple obstacles, is now much more successful than it was at the time of the DARPA Challenge in 2015.



Company	Country	Model	Goal	Special Features	Status 2025 → ...
Boston Dynamics	United States	Atlas	Basic research	Traditionally the gold standard for mobility	Primarily research; strongly influences technological development and other manufacturers; limited application in the industrial sector
Tesla	United States	Optimus	Work robot / universal assistant	Uses sensor technology and AI from the automotive industry; announced target price < 30,000 USD (timeline unclear)	Prototypes; often still remote-controlled; sorts objects; masters simple tasks; initially used in industry; later in households
Figure AI	United States	Figure 02	Work robot / universal assistant	35 degrees of freedom; voice interface from OpenAI	Industrial test applications at BMW since 2024; up to 12,000 units / year from 2025 (initially for own use and research)
Unitree	China	G1, H1, R1	Price war	The simple R1 presented in July 2025 – weighing 25 kg, 26 degrees of freedom, no hands – is expected to cost less than USD 6,000	Affordable for research and development purposes; mass market not expected for another 5–10 years
NEURA Robotics	Germany	4NE1	Household and service robots	Safe around humans, developed for use in private environments and in the service sector	Planned: 5 million robots by 2030

Table 1 Selection of some relevant companies and models in the field of humanoid robotics

Actuators are among the most expensive components of a humanoid robot. There is a global race to reduce costs and enable mass production to achieve economies of scale. In this context, there is still a need for research into haptic dexterity to grasp a wide variety of objects safely and handle them appropriately.

Sensors

Significant performance gains and cost reductions have also been achieved in the field of cameras and LIDAR systems for distance and spatial perception. Sensor technology in the field is benefiting from spillover effects from the field of autonomous driving. Challenges lie in the development of sensor systems that mimic the touch sensitivity of human skin.

AI

Advances in this field already make it possible to communicate with humanoid robots in natural language. They can also recognise objects and perform simple actions on command or through imitation. Challenges lie in edge computing to make humanoid robots more responsive, as well as in world models and multimodal vision-language-action models. Using these models, robots will no longer communicate solely via LLM and engage in limited “reasoning”. Instead, thanks to an internal representation of the environment, they will be able to understand and generalise

spatial, causal and physical relationships, plan contextually, and act appropriately, quickly and purposefully in any given situation.

Energy supply

The operating times of current humanoid robots are still limited to a few hours. Here, too, spillover effects from electromobility and the general trend towards electrification are to be expected.

Currently, the field of humanoid robotics is still predominantly in the prototype stage. Production is carried out in small-batch manufacturing, at best in small series. No manufacturer has yet brought mass-market products to market (see Table 1).

From a technical perspective, the amount of capital invested worldwide and the need for automation due to growing demographic pressure, combined with rapid advances in AI (software) and actuators, batteries and sensor technology (hardware), however, suggest that humanoid robots will be able to make the transition from demonstrators and prototypes to affordable and massively useful helpers in some real-world environments within the next five to ten years. Economies of scale and better components (primarily manufactured in China) should enable unit prices of around USD 15,000 or less (see Table 1).



It remains to be seen whether service and industrial jobs for humans will disappear almost completely because humanoid robots can be deployed en masse and flexibly in almost all work contexts 24 hours a day, 7 days a week, at a lower cost than humans. If so, this could have a negative impact on the social acceptance of the machines. However, in view of demographic change and the increasing shortage of skilled workers in many countries, the mass availability of reliable humanoid robots could, conversely, also lead to enormous production gains and, from a European perspective, enable the reshoring and friendshoring of labour-intensive industries.

In short, other key factors such as social acceptance (labour market), (IT) security and regulation (liability), as well as society's overall approach to the new machines once they enter a wide variety of areas of life outside of industry and service contexts, from hospitals and care facilities (robot ethics) to households (privacy), also influence development and are more difficult to assess than technological trends.

Implications and scenarios for military use

For the Bundeswehr, robotics and AI already offer new opportunities in the use of unmanned systems (UxS), accompanied by risks that must be mitigated by means of appropriate defensive measures and concepts for responsible use, such as meaningful human control.¹

Humanoid robots are out of place in application contexts for which specialised form factors are better suited. This will remain the case in the future. Quadcopter UAVs flying over a forest for reconnaissance purposes or UGVs crossing a field on tracks for transport purposes will always perform these tasks more effectively and efficiently than a humanoid-shaped robot.

The advantage of humanoid robots is that they can flexibly integrate into *environments optimised for humans* and, at some point, possibly be

universally capable of acting there. The much-discussed “dirty, dull and dangerous” jobs, for which machines are preferred, can therefore be taken over by a humanoid system where drones cannot fly and tracked vehicles cannot drive.

You need arms and legs to climb into the truck and unload the crates, which then have to be carried down a narrow staircase and stacked in the basement. A human form can also be useful for opening doors in a building, finding a hidden explosive device and defusing it with various special tools.

For the time being, humanoid robots in armed forces such as the Bundeswehr will primarily perform tasks *with* and *alongside* humans. There are technical reasons for this: the autonomy of the systems will not be sufficient for the foreseeable future to entrust them with mission-critical tasks or even tasks involving the use of lethal force. Added to this are legal and ethical reasons for exclusion, cost considerations and the forces of inertia typical of armed forces when it comes to the use *of* and trust *in* technology.

Nevertheless, humanoid robots need to be considered conceptually in a different way than specialised UxS platforms. Ultimately, they do *not* fit into the manned-unmanned teaming scheme that guides the use of UxS. This is because humanoid robots do not raise the question of how they can best *complement* humans so that humans and machines can cooperatively play to their respective strengths,

but rather in which contexts they can *replace* humans – assuming technical maturity, trust and cost efficiency.

Figure 1 summarises the considerations regarding the use of humanoid robots in the Bundeswehr, systematically drawing on the key factors discussed in the previous section. It ranks four possible futures up to 2035 from very likely to very unlikely. Scenario transitions after 2035 – in the logic of the figure, most likely from “unskilled labourer” to “force multiplier” – are of course not ruled out.

It should be kept in mind that armed forces in authoritarian political systems, which are based on a different view of humanity than that of responsible citizens in uniform with inner leadership, are likely to see other possible uses for humanoid robots. Those who do not trust their fellow human beings with the supervision and direction of machines are not building centaurs, but minotaurs, using machines to control people.² Consequently, humanoid robots in such a system could possibly be used as automated “political officers” who monitor the behaviour of soldiers and sanction behaviour undesirable to the regime with threats and coercive measures. Humanoid robots can thus also be an instrument of oppression, enabling totalitarian rule beyond the coercive measures available with UxS.

2 See section “Centaurs vs. Minotaurs” in “Artificial Intelligence in the armed forces”, Metis Study No. 40 (April 2024).

1 See “Artificial Intelligence in the armed forces”, Metis Study No. 40 (April 2024).



Unskilled labourer – very likely –

UxS dominate. Humanoid robots work in niche areas.

They are used for research, demonstration purposes and limited support tasks in logistics and maintenance, in hazardous environments and, on a trial basis, in search and rescue operations. Costs and technical shortcomings prevent wider use in military environments. Ethical, legal and operational uncertainties and the inertia of the Bundeswehr organisation further slow down their integration.

Force multiplier – likely –

Humanoid robots are becoming an important military resource in various operational scenarios.

Surprisingly rapid technological advances combined with cost reductions are enabling the cross-context deployment of humanoid robots in a wide variety of military

applications. Their use is not limited to logistics and hazardous environments (search and rescue operations), but also includes supporting specialised forces in urban and house-to-house combat, where their human-like form factor offers advantages. However, humanoid robots are slow to gain trust and are used in limited numbers and as force multipliers. Humans retain the decision on the use of force for legal, ethical and operational reasons.

Probability

Terminator – unlikely –

Humanoid combat robots take over warfare.

Revolutionary breakthroughs in key technological factors enable the mass deployment of humanoid robots in all areas of life, including the armed forces. These forces switch to robot-centred doctrines worldwide and drastically reduce the human presence on the battlefield. This is accompanied by a global arms race and the beginning of profound changes in international humanitarian law and military ethics. Humanoid robots are being used extensively in all areas of organisation, in combination with UxS also on the front line. They are entrusted with weapons and, depending on the context, sometimes also with decisions about life and death on the battlefield. In Germany, the image of the soldier in uniform and the concept of inner leadership are being re-discussed.

Paria – highly unlikely –

Strict regulation of humanoid robots and a global ban on military use.

Massive negative effects on labour markets worldwide, combined with high-profile incidents in which people are

harmed, lead to increasing social and political rejection of humanoid robots in general. This results in legally binding international treaties and strictly regulating national laws that completely ban the development and use of humanoid robots for military purposes (“Stop Killer Robots”). Enforcement varies greatly around the world, but in a world that is generally sceptical of humanoid robots, any military use is heavily stigmatised as a perverse dehumanisation of violence.



Fig. 1 Four scenarios for the use of humanoid robots in the Bundeswehr by 2035



Recommendations

The *Zeitenwende* presents the Bundeswehr with two major challenges: increasing personnel numbers and catching up in terms of technical innovation. Humanoid robots sit, stand and walk at the intersection of these two areas of responsibility.

On the one hand, against the backdrop of demographic change and the generally post-heroic nature of German society, the volunteer model (there is currently no parliamentary majority in favour of extended conscription) does not allow for any immediate and major increase in personnel (apart from the fact that the creation of the necessary infrastructure for this has only just begun). On the other hand, the *Zeitenwende* has already had astonishing effects on society. There is a greater willingness to engage with security, defence and resilience issues; civil clauses, dual-use requirements and environmental, social and governance (ESG) criteria are being reconsidered; private and venture capital is flowing into the defence sector; and a start-up ecosystem focused on innovative defence solutions has emerged.

Entrusting people in the armed forces with higher-value tasks not only makes their service safer, but also more attractive – and the armed forces more effective overall. Against this backdrop, the Bundeswehr should already be

asking itself today which tasks could potentially be delegated to humanoid robots in a period of five to ten years. In many areas of the Bundeswehr, intensive consideration, development and testing is already underway regarding UxS and automation in general – a new centre for innovation is emerging. If the path from idea to application in the armed forces is to be shortened in the field of humanoid robotics, then the recommendation is to start looking at this future topic immediately. Four specific ideas for application trials, sorted in ascending order of difficulty, are as follows:

Logistics

transporting various loads in complex environments

Explosive ordnance disposal (EOD)

detecting, classifying and defusing explosives in areas that are difficult to access

Sentry

security tasks including autonomous drone defence

Casualty evacuation (CASEVAC)

under fire or in danger zones, in combination with “Grille” for transport

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