

Humanoid Robots:

Great Promise, Hard Problems – A Research Perspective on Potential and Challenges

Tamim Asfour

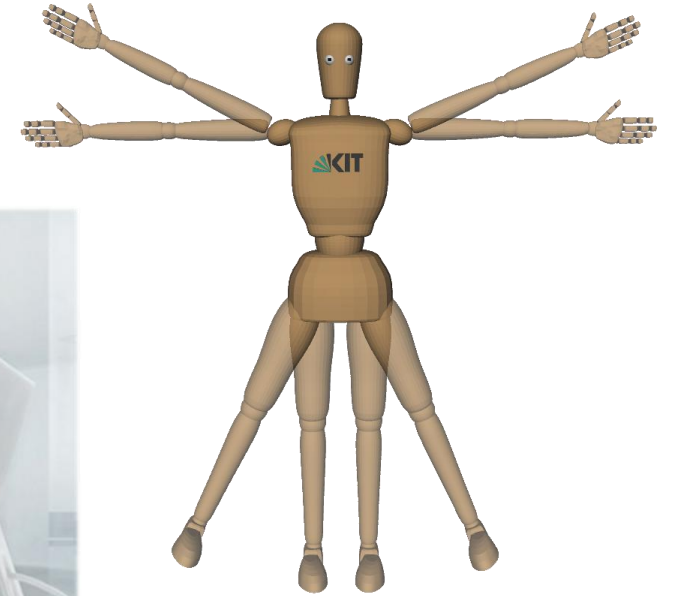
Robotics Institute Germany (RIG)

Karlsruhe Institute of Technology (KIT)

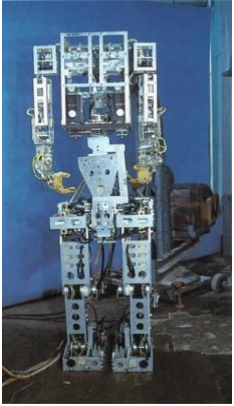


Humanoid Robotics

- Understanding human **versatility** and motion intelligence
- Creating multi-purpose machines with **physical intelligence**
- Engineering **human-centered technologies** to empower humans
- “Humanoid Robotics is a **Multi-Trillion Market**”



Humanoid Robotics has made Progress (1970 – 2023)



WABOT-I



ASIMO



Toyota



DB



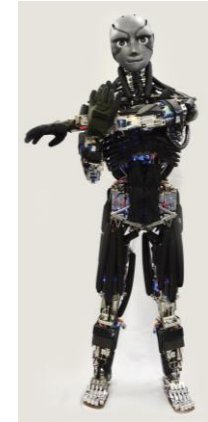
CB



HRP-2



HRP-4C



Kenshiro



HUBO



iCub



ARMAR-III



Justin



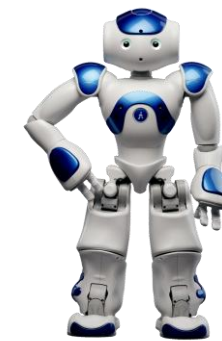
Robonaut



REEM-C



Valkyrie



NAO



ALTAS

Humanoid Robotics has made Progress (2022 – 2026)



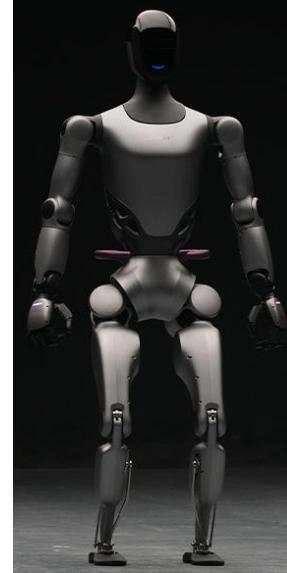
Unitree
H1 & G1



Figure AI
Figure 02



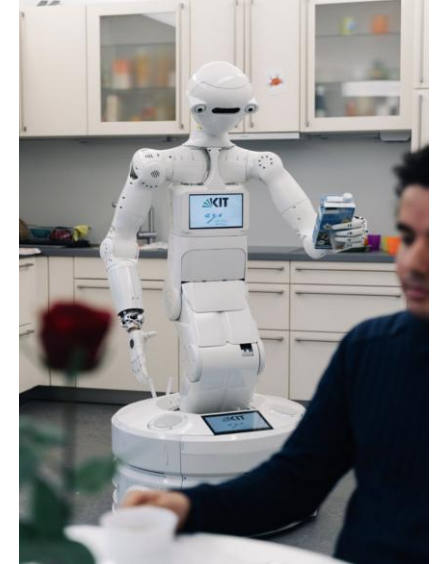
Apptronik
Apollo



Fourier
GR-2



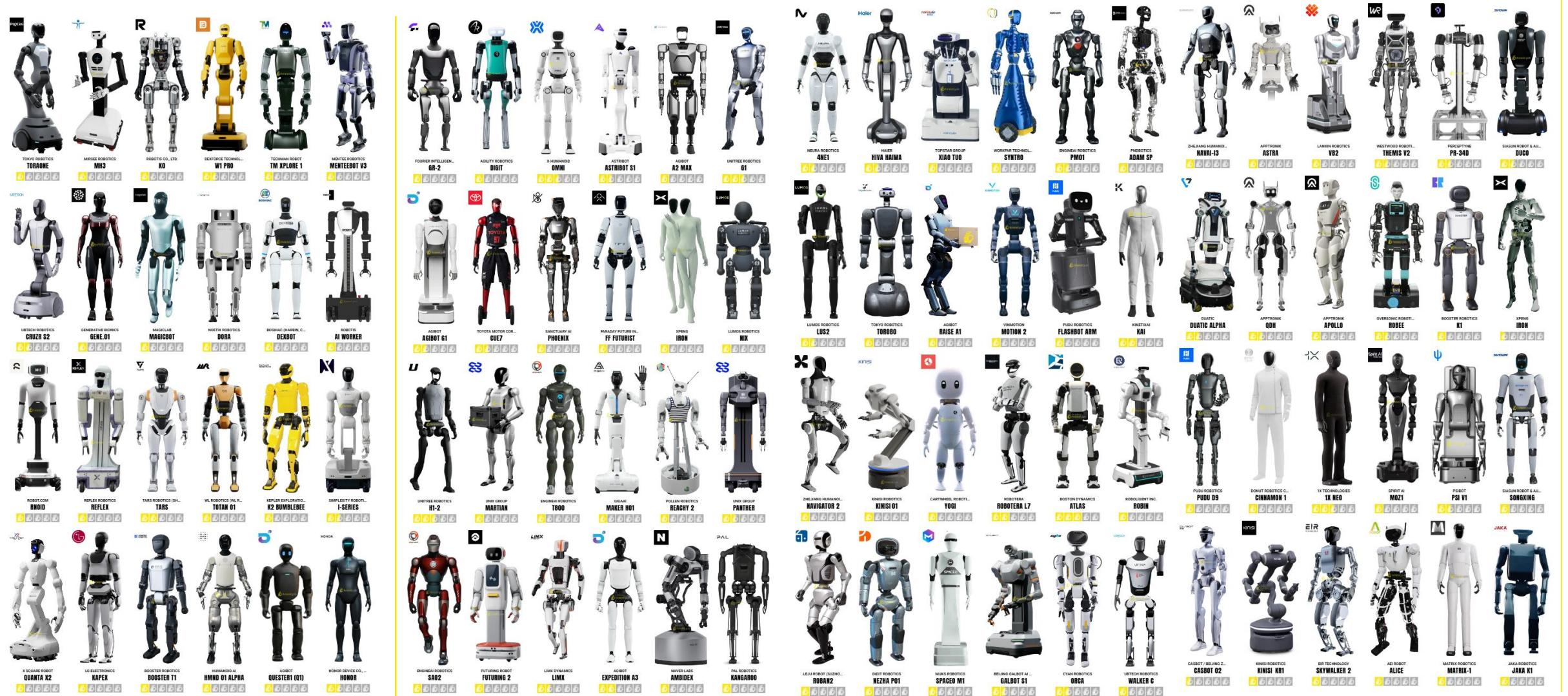
Tesla
Optimus



KIT
ARMAR-7

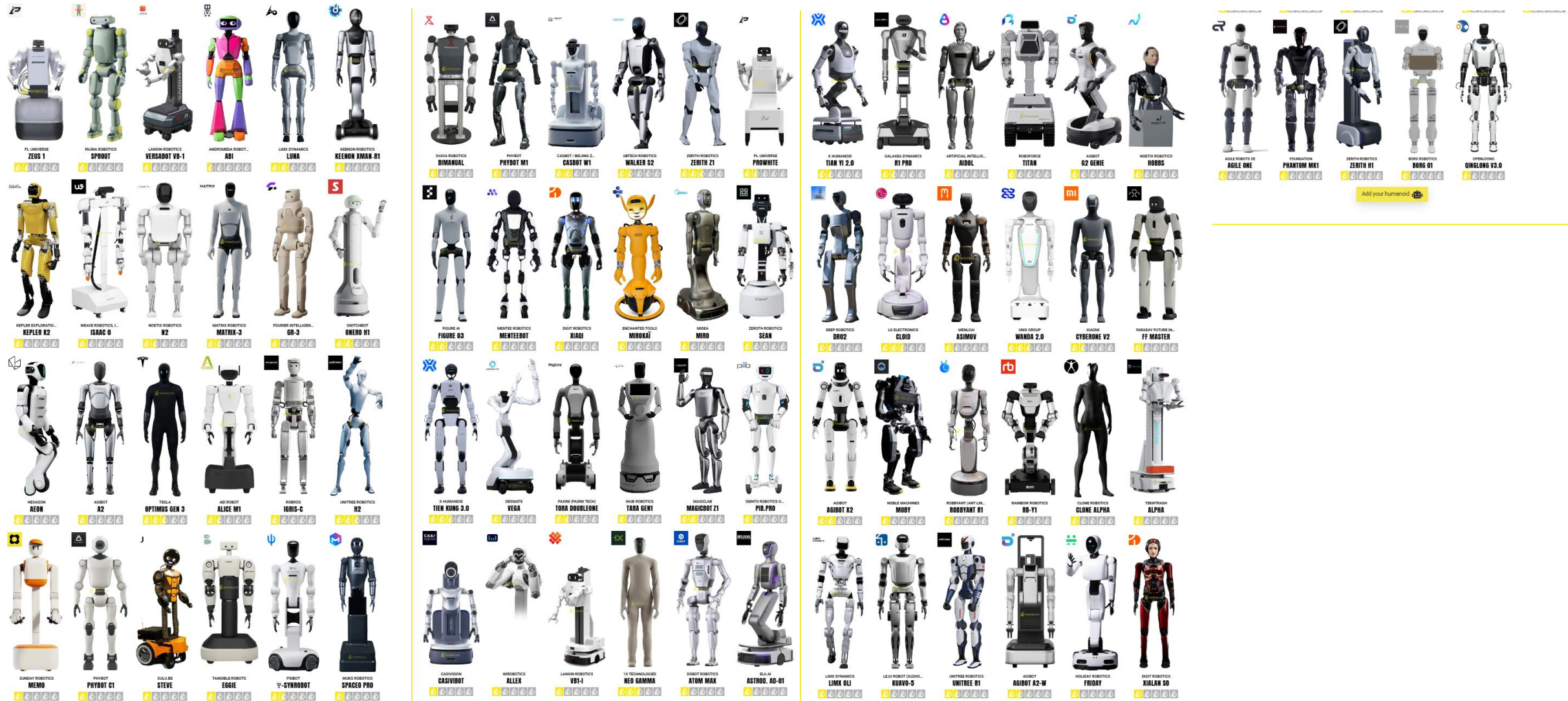
Today: Hundreds of new humanoids; bold investments (in China and US)

Hundreds of new Humanoids



<https://humanoid.guide/>

Hundreds of new Humanoids



<https://humanoid.guide/>

The Era of Humanoid Robotics

Martial Arts at Spring Festival Gala
(February 16, 2026)



<https://www.youtube.com/watch?v=R6T-Ea5CfRE>

Folk Dance Skills at Spring Festival Gala
(January 28, 2025)



<https://www.youtube.com/watch?v=1ZjDsRnpW74>

Humanoid Half-Marathon

2025 — First Humanoid Half-Marathon

April 21, 2025

- 20+ Humanoid robots ran against humans
- Winner robot: **Tiangong Ultra** **2:40 h**
(Beijing Humanoid Robot Innovation Center)
- Fastest human: **1:02 h**

human world record 57:20



2026 — Second Humanoid Half-Marathon

April 19, 2026

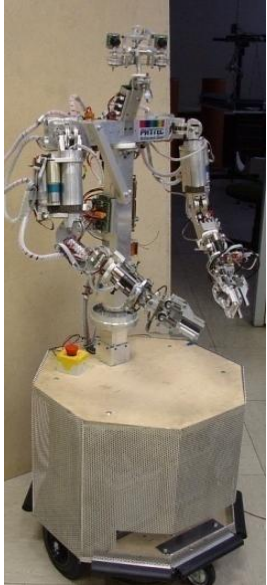
- 100+ Humanoid robots
- Winner robot: Honor **Lightning** **50:26 min**
- Fastest human: **1:07 h**



Video: NBC News

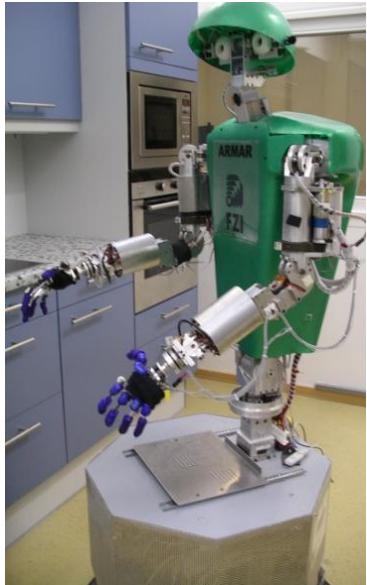
<https://www.youtube.com/watch?v=WnCfMRhbhZQ>

The ARMAR Family | Robots



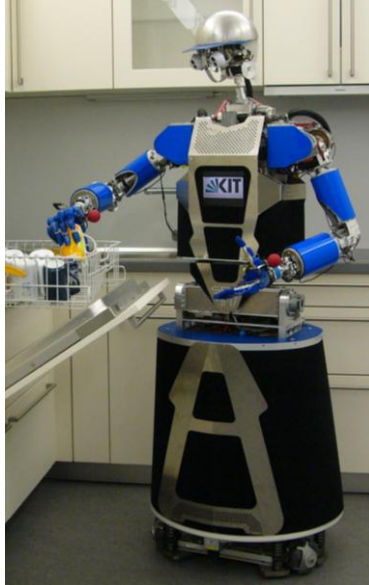
ARMAR-I

2000



ARMAR-II

2002



ARMAR-III

2006



ARMAR-4

2013



ARMAR-6

2017



ARMAR-DE

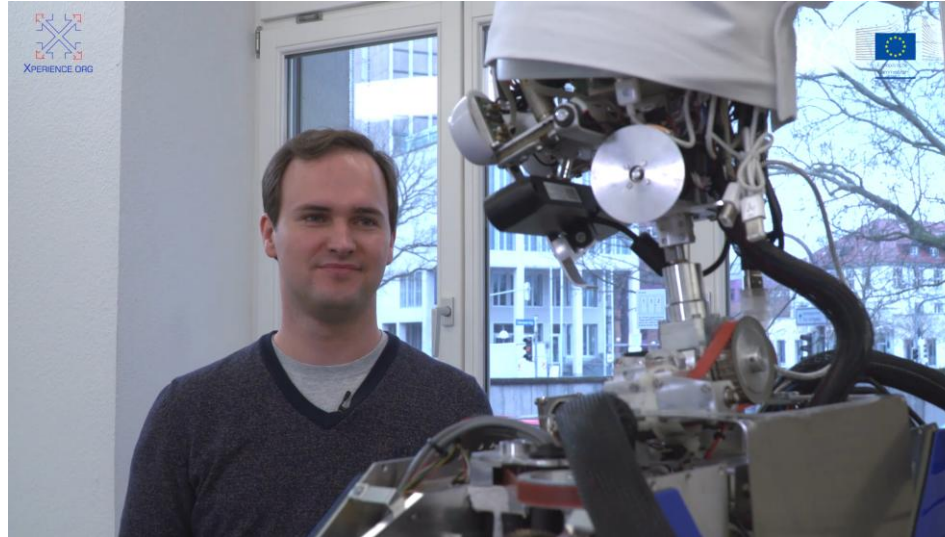
2020

ARMAR-7

2024

The ARMAR Humanoid Robots @ Home

- Versatile personal assistance for humans at homes, nursing and retirement homes, ...
- Self-determined life of humans



2016



2008



2004



2001

The ARMAR Humanoid Robots @ Home

- Versatile personal assistance for humans at homes, nursing and retirement homes, ...
- Self-determined life of humans



June 2025

ARMAR-7

Humanoid Robots in Care Facilities

7x – Autonomous Execution



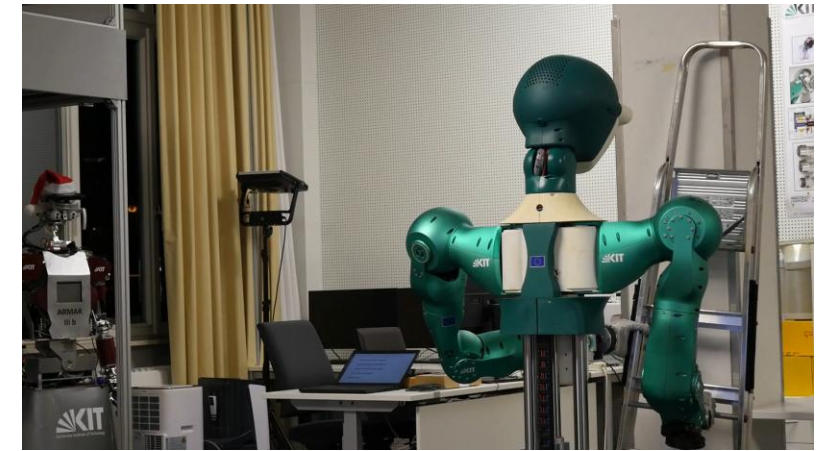
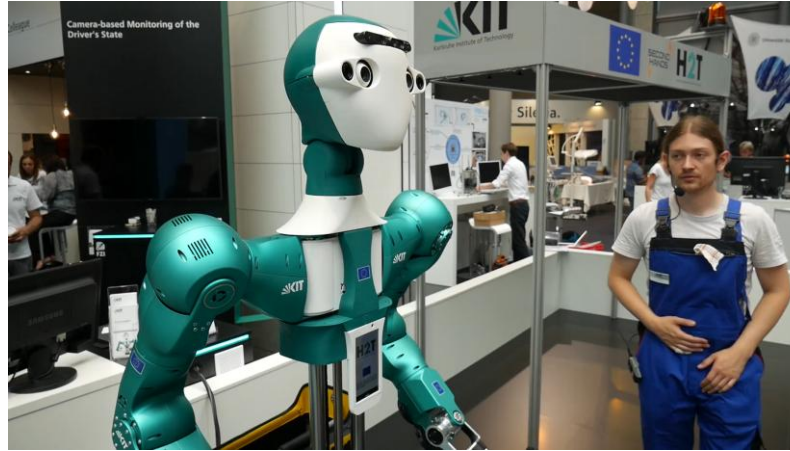
15x – Autonomous Execution



June 2026

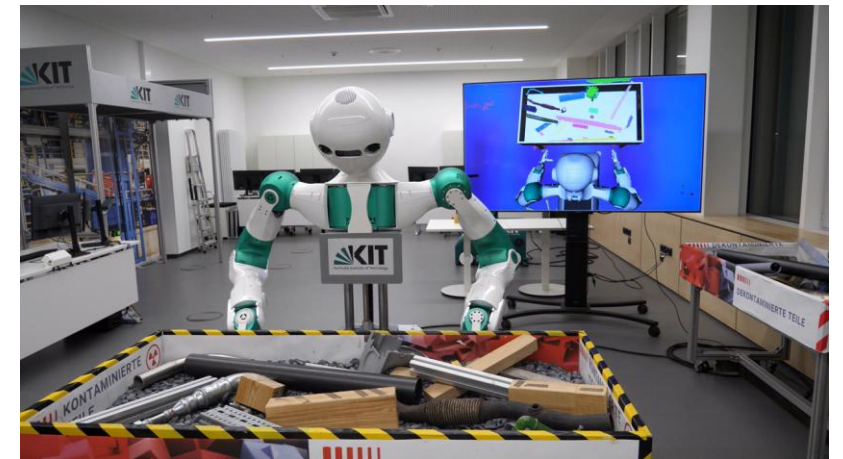
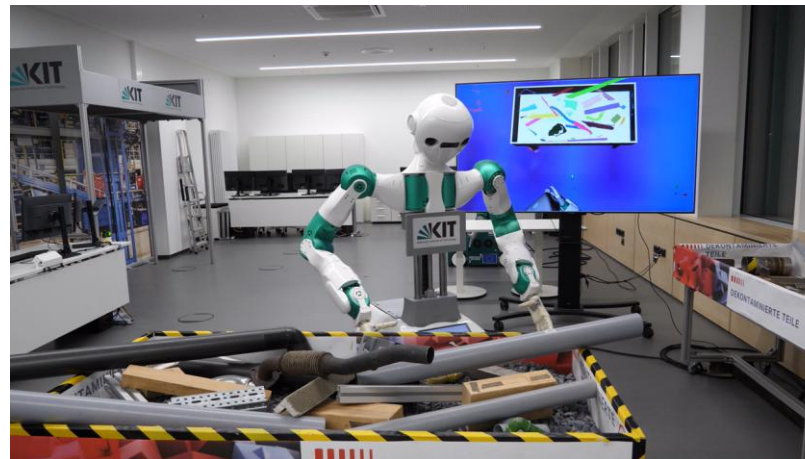
The ARMAR Humanoid Robots @ Work

- Pro-active and adaptive assistance for workers in 3D jobs
- Meaningful work for humans



The ARMAR Humanoid Robots @ Work

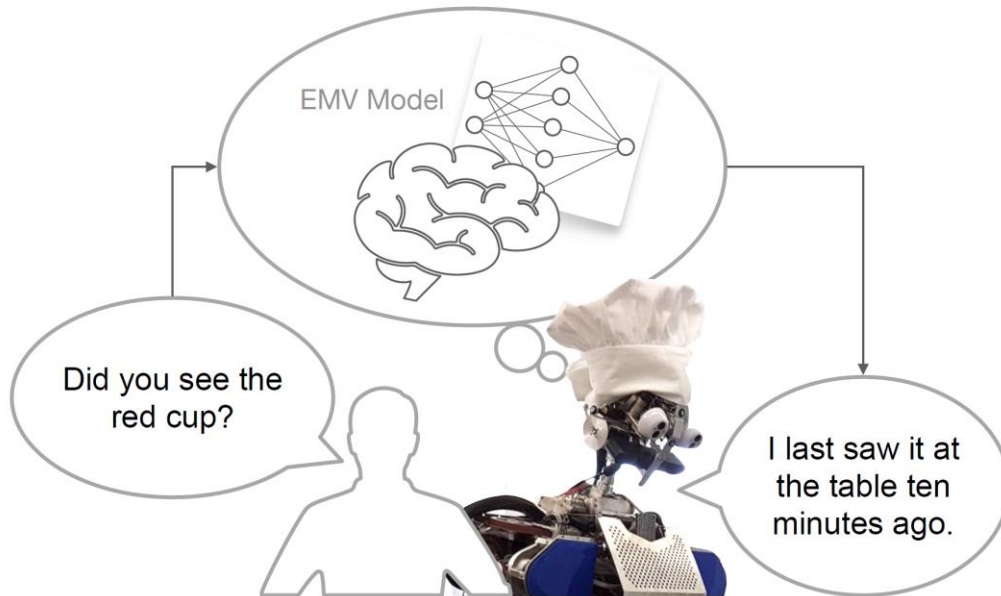
- Pro-active and adaptive assistance for workers in 3D jobs
- Meaningful work for humans



Deep Episodic Memory

Verbalization of Robot Experience

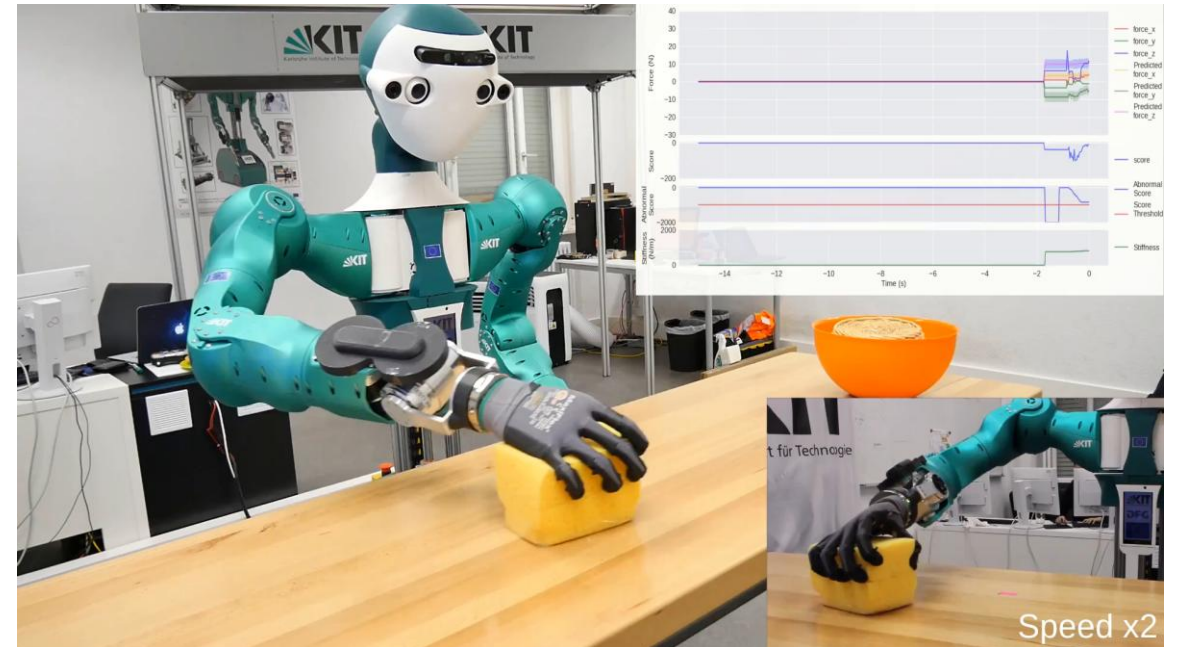
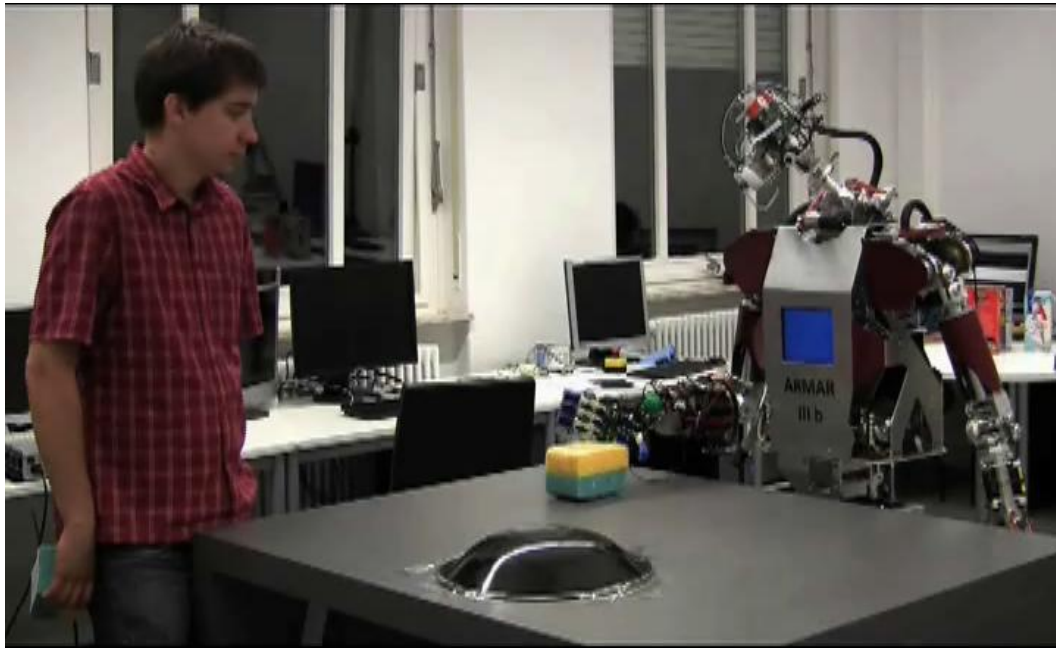
Deep neural end-to-end architecture



Learning Manipulation from Human

Imitation Learning

- Library of motion primitives (motion alphabet)
- Tasks as sequences of motion primitives



Learning from Human

Robot Internet of Skills

KIT whole-body human motion database: A Robot Motion Alphabet



42 hours of manually labeled human motion data (including object information); **9375 motions**; **234 (112/41)** subjects and **158** objects.

motion-database.humanoids.kit.edu
<https://gitlab.com/mastermotormp>

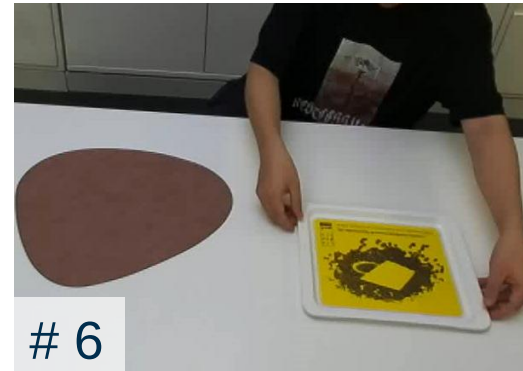
Keypoints-based Visual Imitation Learning

Bimanual Tasks

Coordinated
Loosely Coupled



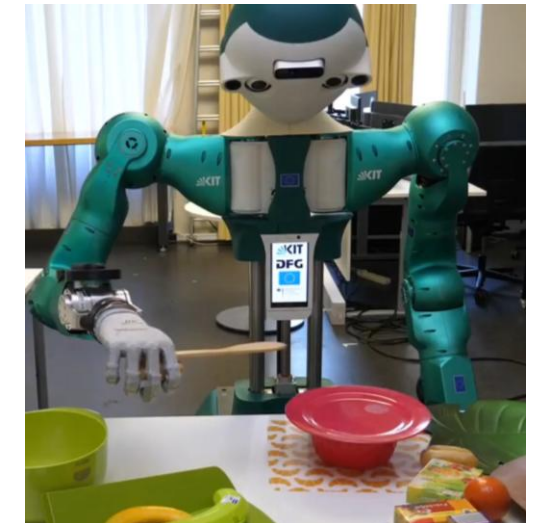
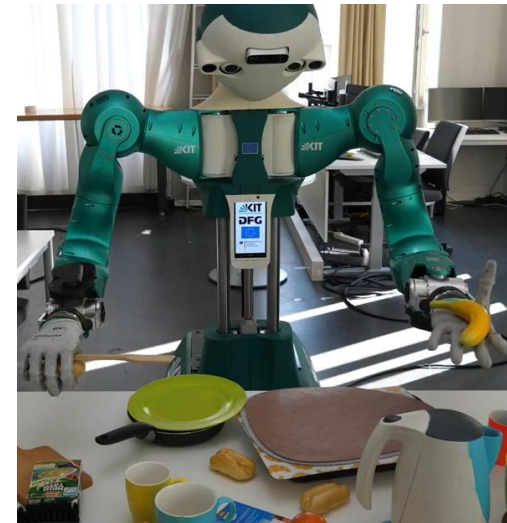
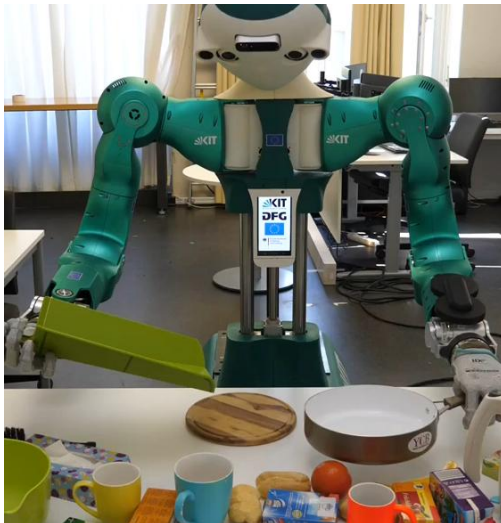
Coordinated
Tightly Coupled



Uncoordinated
Bimanual



Uncoordinated
Unimanual



Will Humanoids **Soon** Replace Most
Human Workers?

The Question is not IF, but WHEN

... and whether Germany/Europe will lead or follow

“Soon” = By 2050

That's **25 years** – the same time it took to go from Deep Blue beating Kasparov to humanoids doing backflips

Five Undeniable Forces

1. **Progress in Mechatronics:** Advanced actuators and sensors, 3D printing, ...
2. **Progress in AI:** Foundation models generalize from few examples
3. **Manufacturing Reality:** Unitree, Tesla, Figure, – mass production NOW
4. **Economic Inevitability:** Aging population + labor shortage = no alternative
5. **The Form Factor Wins:** Our entire infrastructure is built for humanoid bodies

This is Conditional

IF we solve the **hard problems**

- **manipulation**
- **robustness** to uncertainty
- **safety and trust**
- **cognitive architecture for embodied intelligence**

THEN 2050 is achievable

History Repeats: The Doubters Are Always Wrong

2026

“Humanoids won’t work”

2021

“AI cannot understand Language”

2007

“Nobody needs a smartphone”

1995

“Internet is a fad”

The Path is Clear

- **2026-2035: Structured Environments**
 - warehouses, factories, elder care
 - repetitive tasks in controlled settings
- **2035-2045: General Service Work**
 - retail, hospitality, delivery
 - learning from billions of real-world interactions
- **2045-2050: Complex Tasks**
 - construction, maintenance, healthcare
 - reason and predict to ethically act

We need to
prepare society
for this transition!

“Humanoids will soon replace most human workers”: A debate

HESHENG WANG , MICHAEL WANG , FRANK PARK , LIJUN HAN, HUICHAN ZHAO , XINGXING WANG, ANDRA KEAY , SHIGEKI SUGANO , YI GUO ,
TAMIM ASFOUR , YU SUN , AND KEN GOLDBERG  [fewer](#) [Authors Info & Affiliations](#)

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H²T Team

Thanks to...



Thank you!



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Robotics
Institute
Germany

