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The Year of Humanoid Robots

It's astonishing that in just over two years, Tesla has already unveiled the second generation of its humanoid robot Optimus Gen2, which is lighter, faster moving and more dexterous in its fingers than the first version. Musk estimates the final price may be less than $20,000, with mass production of hundreds of thousands of units possible within 3-5 years. The future market space can potentially be larger than even electric vehicles. Following smartphones and electric vehicles, can humanoid robots become the next era-defining super product? What aspects will face bottlenecks during its accelerated growth, and where can we find high beta opportunities?

To understand AI's role in humanoids, we must first introduce the concept of embodied cognition. Originating from Turing in 1950, it refers to cognition being tightly coupled to an entity's interactions within and with its environment. Traditional machine learning requires large datasets for training, but embodied cognition mimics human learning through first-hand experiences to continuously improve. This first-person intelligent perspective is key to humanoid evolution.

Embodied AI essentially means having an AI inhabit a physical form like humans, using perception and understanding to complete tasks. Top Chinese AI scientist Zhu Songchun noted embodied cognition integration spans six disciplines in a highly complex way - but large models now enable such fusion, heralding an era of embodied AI.

The emergence of generalized AI platforms optimizing machine perception, decision-making, actuation, and feedback loops in physical space could significantly accelerate humanoids. Continuous learning from physical interactions also bypasses limitations of simulated-only training. Core technologies of computer vision, tactile sensing, motion control and decentralized planning/execution with edge computing will determine development speed.

In summary, while technical hurdles remain, convergence of AI, robotics and automation has potential to transform numerous industries with humanoid help. The coming decade promises enormous advances as embodied AI rises.

1. The era of industrial production approaches

Stanford Professor Li Feifei proposed combining large language models with vision models to achieve embodied cognition. In one experiment, researchers gave the instruction "open the top drawer, watch out for the vase." The LLMA then decomposed the instruction into three steps: 1) grab the top-drawer handle, 2) pull it outward, 3) avoid the vase area.

Next, the vision-language model (VLM) assigned high value to the drawer handle (target object) and low value to the vase surroundings (avoidance zone). It used this generated value function to automatically plan motion trajectories without any task-specific training data - achieving the goal with zero-sample learning.

Google's robotics team embedded multimodal large models into robotic arms, imbuing them with strong reasoning abilities. For example, if instructed to "put the banana in the sum of 2+1", it would place the banana in location number 3.

Additionally, it displayed visual reasoning by correct inference. In another example where robot was instructed to “put the strawberry into the correct bowl,” even though no explanation was provided on which bowl was correct, the robot identified the bowl with strawberry already inside as the correct bowl. This understanding is approaching human-level linguistic and behavioral common-sense.

The emergence of large models is a key step in humanoid evolution, likely enabling widespread application in manufacturing and everyday life. While teams like Feifei Li's at Stanford and Google lead in AI research, Tesla currently has a clear edge in industrial-level production capabilities. This includes Tesla’s hardware architecture design prowess - introducing linear actuators to boost power-to-weight ratio for humanoids, with continued fast design iterations.

From Optimus demo videos, it has already demonstrated motion control, path planning and object manipulation, with its main limitation being AI. However, Tesla's July 2023 announcement of establishing XAI to shore up AI abilities suggests humanoid mass production timelines could accelerate rapidly with Tesla’s involvement.

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2. Search for knowledge gap and embrace certainty

The core segment of humanoids will likely be the final system integration. Similar to smart vehicles where functionality relies heavily on AI capabilities, humanoids will also depend heavily on AI capabilities. Mass production depends greatly on cost reductions through supply chain improvements. So companies strong in autonomous driving's final assembly will have a natural advantage in humanoids manufacturing.

Compared to smart vehicles, humanoids move more slowly. Therefore humanoid will have less need for sensory and decision prioritization than autonomous vehicles. We will focus on incremental actuators, structural components, and mechanical sensors which are more critical for humanoid performance. Motion control costs make up a higher proportion of the humanoid supply chain where domestic manufacturing has a cost advantage. Core components like gearboxes, linear actuators, finger joints and motors/magnets present good competitive landscapes and decent market size. 3D printing and composites also offer some potential.

The humanoid robot industry has developed through two main stages so far: conceptual and early mass production stages. In the conceptual stage, our investment strategy was driven by research to identify knowledge gaps.

One area of research is gearboxes. When Tesla first proposed humanoids, the market saw harmonic gearbox as very suitable. But in 2023, two changes emerged: first, a California professor proposed a "low speed high torque motor + planetary gearbox" solution for hip/leg motors (he later joined Tesla's robotics team); second, many Chinese startups also adopted planetary gear gearboxes. Planetary gear gearboxes have simple structures and lower costs which make them suitable for mass production. Some analysts in the market believe planetary gearboxes will replace harmonic gearboxes. However, we believe harmonic drives will remain core due to the following three reasons:

First, the core player in the robotic industry chain is Tesla. According to their plan, the first application scenario of Tesla's robot is its own manufacturing plant. When used in factories, robots have higher requirements for output torque and motion accuracy. From this perspective, planetary gearboxes are not suitable, as their accuracy is significantly lower than harmonic gearboxes. Second, although harmonic gearboxes are more expensive, their structure is still simple with only three main components: wave generator, flex spline and circular spline. In the future, large-scale standardized mass production will have more potential for cost reduction, thus likely to reduce the price gap between harmonic gearboxes and planetary gearboxes. Third, harmonic gearboxes have a lot of innovative potential in terms of structure. Industry chain companies are actively cooperating with OEMs to innovate structures, which can better meet the needs of humanoid robots.

The second case is rare earth magnetic materials. Electric vehicles are already using rare earth magnetic materials widely. Taking Tesla's Model 3 car as an example, the total power of the motor is 194KW, using about 1.5 to 2.0 kg of rare earth magnetic materials. Humanoid robots have higher requirements for motor power density and there are many structural design innovations. The manufacturing process of the rotor is more complex, and the usage of magnetic materials and the value of the rotor module have been greatly increased.

Currently, some assumptions have not been verified by the market, such as 3D printing and lightweight composite materials. First of all, the demand for lightweight material in robots is far greater than electric vehicles. When moving, human-shaped robots must overcome gravitational potential energy, while electric vehicles only need to overcome rolling kinetic friction. Therefore, from the aspects of energy saving and motion stability, the demand for lightweight robots is much greater than lightweight electric vehicles. Secondly, there may be scenarios such as falling over or bumping during the movement of human-shaped robots, and the strength requirements for lightweight materials are also significantly higher than electric vehicles. Therefore, it can be inferred that high-strength lightweight materials are very likely to be applied to human-shaped robots. 3D printing may be a good way for processing such materials.

Industry companies and research institutions have already applied 3D printing technology to humanoid robots. The entire Poppy robot is completed through 3D printing technology, reducing production costs by 1/3 compared to traditional robots, while the structure is more complex with simulated human spine and joints. Shanghai Jiao Tong University also used 3D printing technology to make a micro six-legged bionic robot with a small size and complex structure. These cases all indicate that 3D printing is very likely to have a very good application prospect in the field of robotics.

Looking ahead to 2024, the humanoid robot industry may enter the stage of small batch industrial production. This will allow us to verify which companies can become key suppliers for main robotic manufacturers. This will unveil the real winners from the candidate companies and provide more certainty for our investment.

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