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A Review Comparing the Advantages and Disadvantages of Hydraulic and Electric Drives in Robots

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Abstract: The choice of driving mode will significantly affect the overall performance of the robot. Therefore, this article mainly focuses on the two mainstream driving technologies: hydraulic drive and motor drive. By analyzing the actual operational data of some typical products, we can understand their performance characteristics, core advantages, and inherent limitations, and then conduct multidimensional comparative analysis. This research result has the potential to provide a theory that can be directly used as a reference for system developers and mechanical designers.

Keywords: Robot design, Hydraulic drive, Motor drive, Energy conservation and consumption reduction

1. Introduction

Driving devices is the key to turning control algorithms into actual actions. If the hardware is not working, even the best model cannot be used. So, choosing which driving method is not only a design issue, but also directly determines what kind of environment the robot can work in. Various driving technologies have their advantages, but they are also limited by physical laws and have their own disadvantages.

Nowadays, robots are mainly driven by hydraulic and electric motors. The hydraulic system has strong force and is not afraid of collisions. Because liquids can amplify power, their power density is much higher than that of motors. In heavy industrial processing or certain medical equipment where heavy work is required, hydraulic pressure is often used. But there are also problems with strong force: hydraulic oil will compress, making the machine shake easily, and the system is prone to heating up. In addition, the friction of the valve and the inertia of the liquid make it difficult to accurately control its position, especially at low pressures.

The characteristics of motors are fast response, high accuracy, and simple control. Electric signals transmit much faster than liquids, so motors can react faster. This makes it very important in the fields of service robots and precision assembly. For example, the robotic arm in the factory can achieve very precise positioning by relying on servo motors. Of course, motors also have energy losses. Magnetic leakage and friction in the gearbox can cause electricity and make the machine hot; After adding a reducer, the mechanical structure becomes more complex and the noise increases, making maintenance more expensive in the future.

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In terms of total numbers, motor drives have the upper hand and are most commonly used in the consumer and light industry markets. However, the overall growth rate of hydraulic drive is increasing, mainly driven by heavy industry and defense sectors. In contrast, the growth of motors has slowed down because the physical properties of permanent magnet materials are approaching their limit. Although motor-driven systems start early and have obvious advantages, research in hydraulic systems is progressing rapidly and with great momentum. Engineers are busy making hydraulic pumps smaller.

1.1. General structure of electric drives

Figure 1 shows a common robot actuator: a motor-driven device. The device is mainly composed of a motor, a reducer, and a connecting rod. The motor generates rotational kinetic energy, while the reducer is used to reduce speed and amplify torque. According to their development schedule, they are divided into rigid actuators, elastic actuators, and quasi direct drive actuators.

Rigid actuators emphasize system stiffness. They ensure precise positioning of the end effector, but have poor ability to handle external impacts. Elastic actuators contain physical springs. The series elastic actuator (SEA) can absorb sudden impact forces and protect the gearbox teeth from shear damage. Direct drive actuators represent the latest technological development direction. This design optimizes the driving components as a whole, reduces resistance during reverse driving, and is beneficial for improving driving speed and work efficiency.

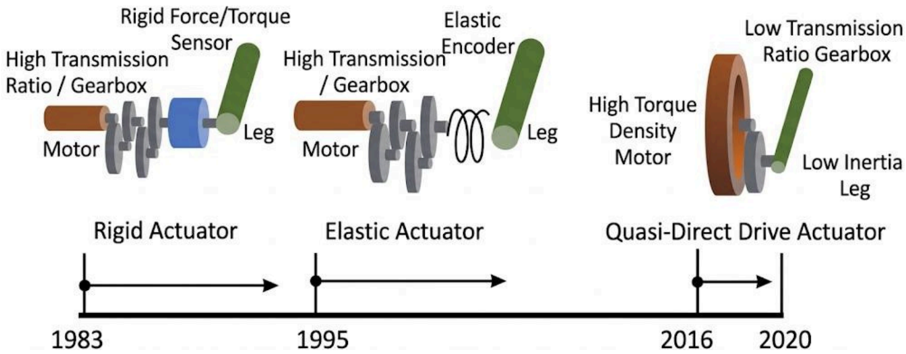

Figure 1. General structure of electric drives [1]

1.2. General structure of hydraulic drives

There are various forms of hydraulic drive devices. For the convenience of introduction, the article includes figures to summarize several common solutions, which will be explained in detail when discussing specific cases later.

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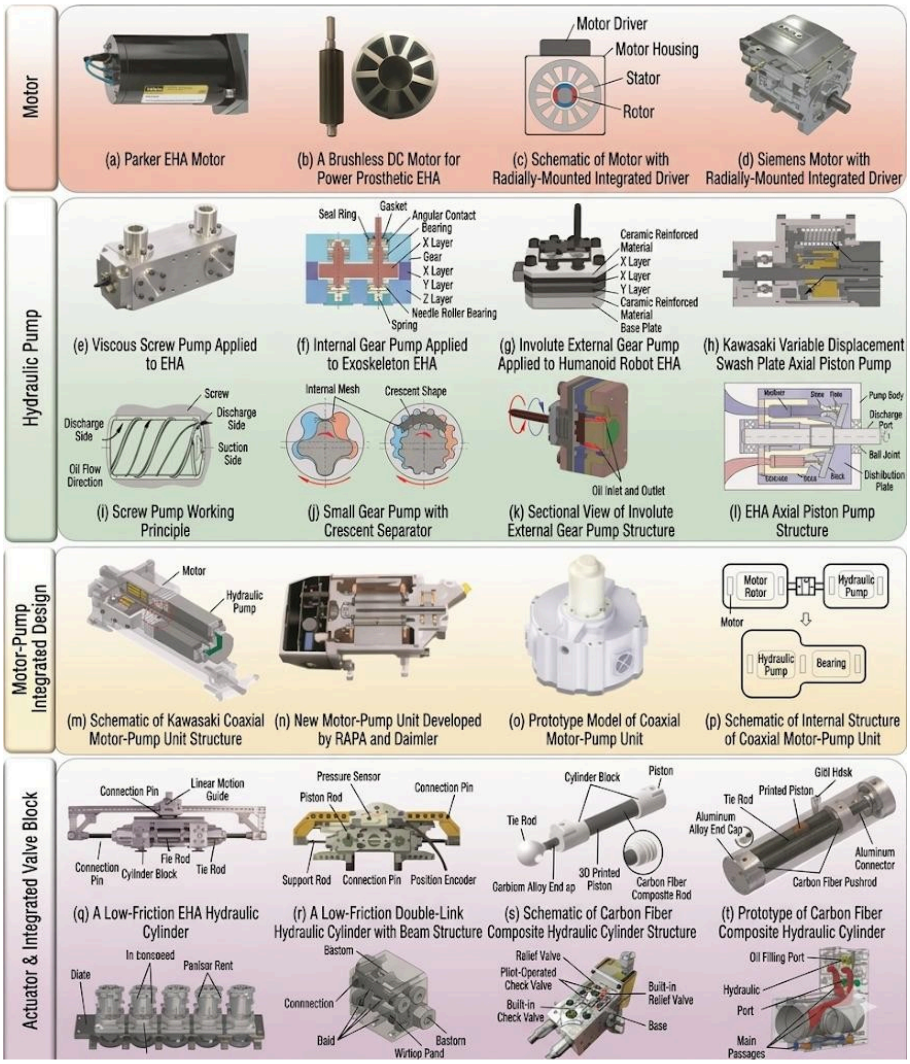

Figure 2. General structure of hydraulic drives [2]

2. Applications and features of hydraulic drives

2.1. Applications and features in medical robots

Main medical applications include hydrogel actuators, liquid artificial muscles, and wrist-type structures.

As shown in Figure 3, YUK H et al. developed a high-speed, high-force hydraulic hydrogel actuator in 2017. It can operate underwater. Hydrogel has excellent biocompatibility and low toxicity. It offers adjustable physical and mechanical properties. It also has good permeability and mass transfer capabilities. This gives the mechanical structure broad prospects for targeted drug delivery and minimally invasive surgeries.

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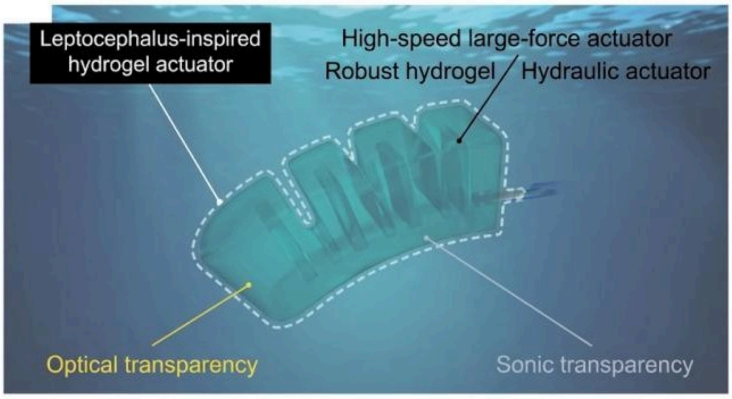

Figure 3. Hydrogel actuator [3]

As shown in Figure 4, KURUMAYAS developed a modular fiber-reinforced soft robot wrist mechanism in 2018. This structure is highly effective in biomimetic surgical operations. The core reason is the high similarity between hydraulic drives and human body movements.

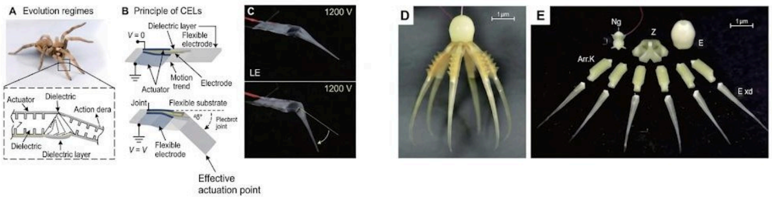

Figure 4. Soft robot wrist [3]

As shown in Figure 5, this hydraulic artificial muscle was developed by LI Shuguang et al. in 2017. It comprehensively applies the above two points. The non-rejection property of this material allows it to be implanted inside the body. Its human-like drive method allows it to replace damaged human muscles. It has long-term prospects in treating diseases like ALS and muscle strains.

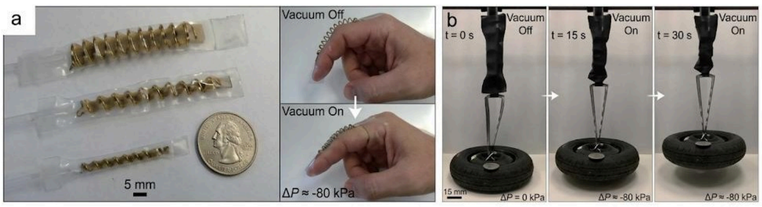

Figure 5. Hydraulic artificial muscle [3]

2.2. Applications and features in hydraulic robots

HyQReal is a driven robot developed by the Italian Institute of Technology (IIT) in 2019. In May of that year, it successfully pulled a 3300kg Piaggio P180 Avanti small passenger plane. In contrast, the robot is only about 1.3 meters long and weighs roughly 130 kg. This striking size difference demonstrates the powerful driving force of hydraulic systems.

Furthermore, this robot does not require any external pipelines. It achieves a highly integrated hydraulic power system (pump, valve, tank) and lithium batteries.

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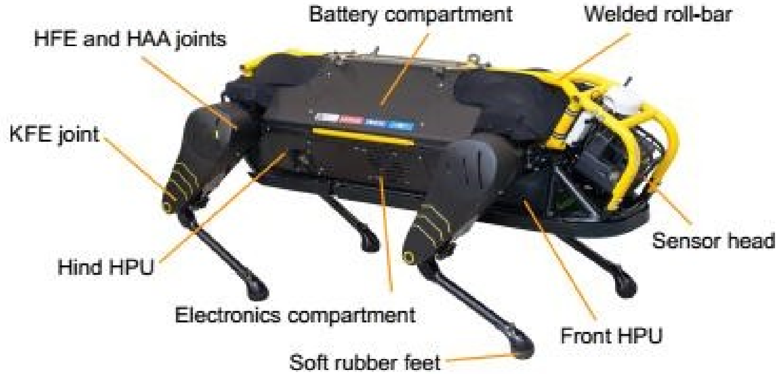

Figure 6. HyQReal [4]

2.3. Applications and features in exoskeleton robots

Figure7 demonstrates the application of a "reconfigurable hydrostatic drive" in an exoskeleton, developed by JEFF D et al. Its special structure primarily uses an accumulator to provide static support during non-moving periods. The average power of the prototype's main motor dropped by 4.8 times (from 41W to 8.6W). This highlights another advantage of hydraulic drives: bio-mimetic self-stability under static conditions.

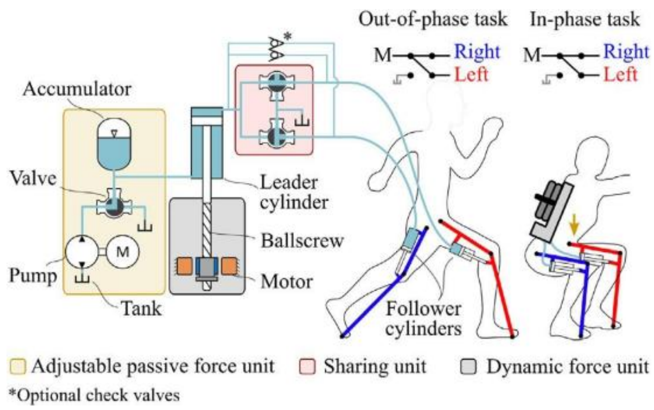

Figure 7. Hydrostatic exoskeleton [5]

2.4. Summary of advantages

They mimic biological properties, output massive force, and provide self-stability when static. Therefore, they have promising prospects in heavy engineering machinery, precision humanoid operations, heavy industrial manufacturing, underwater robots, and medical interventional robots.

3. Examples of electric drives

3.1. Applications and features in exoskeleton robots

The figure below shows the Exosuit robot developed by the Wyss Institute at Harvard University. It is a typical soft lower-limb exoskeleton. Rigid frames often restrict the user's natural kinematic freedom. Soft exosuits solve this. Its goal is to reduce human metabolic consumption during load-bearing walking or prolonged work. It is suitable for infantry load-bearing, logistics handling, or long-distance outdoor

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trekking. The controller is placed at the waist. This greatly reduces leg inertia and barely interferes with natural gaits. It can reduce biological metabolic energy by up to about 16%. The system uses electric motors to pull Bowden cables. The relatively independent drive units brought by motor drives provide a foundation for cable-linked transmissions.

Figure 8. Exosuit [6]

This reflects a disadvantage of motor drives: they cannot directly conduct and fix gravity.The figure below shows the Hualex robot developed by the University of Electronic Science and Technology of China. It is a rigid powered exoskeleton for load assistance. It directly drives the hip and knee joints using motors. This direct drive provides significant assistance torque, resulting in high load transfer efficiency. For example, when walking at 1.04 m/s, the device can transfer 72% of the load to the ground. However, this structure will exert great pressure on the user's joints. This shows a disadvantage of motor drivers: they cannot directly transmit and support gravity. The motor must be kept running at all times to prevent collapse of the rigid frame.

Figure 9. Hualex robot [6]

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3.2. Summary of advantages

In contrast, the biggest advantage of motor-driven systems is accurate control and flexible operation. Especially with the addition of the Field Oriented Control (FOC) algorithm, its force output is very stable, effectively avoiding mechanical jolts and impacts. Another major advantage of pure electric systems is that they are energy-efficient and clean. Because there is no need to use hydraulic oil, the risk of pipe oil leakage or environmental pollution is directly eliminated.

4. Conclusion, comparison, and outlook

The upper limit of robot operation capability is ultimately limited by the physical characteristics of its underlying driving system. The hydraulic system relies on liquid pressurization, and its core advantage is its extremely high power density. However, the risk of pipeline oil leakage still exists, fluid viscous friction leads to low overall energy efficiency, and relatively high maintenance costs in the later stages.

In contrast, the electric motor system performs excellently in terms of high control accuracy, good energy efficiency, and zero pollution. However, when subjected to extreme heavy loads or strong impacts, the performance of electric drives is usually worse than hydraulic systems, the gears of reducers are easily damaged, and the heat dissipation bottleneck of enclosed motors can easily lead to the risk of thermal runaway.

Therefore, future driving technologies are no longer limited to a single physical mechanism, but tend towards deep integration of technology. Taking the electric static hydraulic actuator (EHA) as an example, this hybrid solution uses a motor to directly drive a servo pump and control nearby hydraulic cylinders, while maintaining high horsepower output while considering energy efficiency.

On the other hand, advances in materials science, such as high thermal conductivity resins and high-strength neodymium iron boron magnets, have also enabled high-performance direct drive motors to replace traditional hydraulic solutions in certain situations. Direct drive technology eliminates the need for a gearbox and achieves extremely high mechanical (torque) transparency.

Overall, robot drivers are developing towards mechatronics and intelligent integration. Future hardware systems will heavily rely on algorithms to dynamically allocate power by predicting thermal loads, thereby enhancing the adaptability of robots to working conditions.

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