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DEVELOPMENT OF PARALELL ROBOTS FOR WELDING

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Abstract. *The industrial field robotics is a research area in strong development, and new solutions have to be designed to fulfill better the peculiarities of the task. This paper shows that parallel mechanisms can have similar characteristics to serial and prismatic manipulators, but without some of its shortcomings, as lack of rigidity, speed and payload to weight ratio. It is shown in this paper two manipulators designed to be assembled in a robot that moves along the work piece to be welded. The manipulator has four degrees of freedom and is capable of reproducing all the movements of the welder hand.*

Keywords: *industrial field robotics; parallel mechanisms; welding; manipulators*

1. INTRODUCTION

The correct manipulation of a welding torch demands peculiar degrees of freedom to the process. Other than the displacement of the torch throughout the welding line, it is important to have control of the torch angle in the displacement plane, to pull or to push the welding pool and, in the perpendicular direction to the movement, to correct the trajectory and to control the stick-out. The lateral angle movement in relation to the groove is also important, therefore when the pipeline is inclined, the angle helps to compensate the force of the gravity in the correct positioning of the welding pool. Then, considering that the mobile robot will execute the translation in the direction of the weld bead, there are necessary four degrees of freedom in the manipulator to get all the possible movements to be executed for the hand of a welder, as it can be seen in Figure 1.

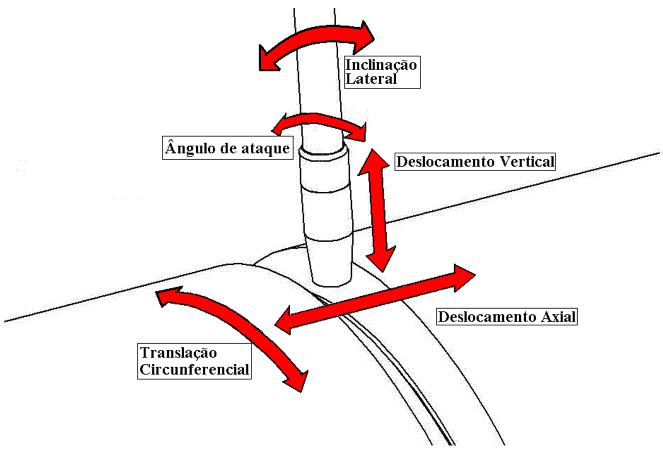

Figure 1: degrees of freedom at welding process

A mechanic manipulator capable to imitate all movements of an welder's hand allows a more precise control of the process, being able to be used the optimum welding parameters in accordance with the material to be welded, thickness of the plate, groove and welding position. In the welding in 5G position, where the manipulator gravitates around of the pipe, all the welding positions are used, and the optimum parameters of positioning of the torch in relation to the welding pool as well as the electric parameters vary very. A fixed position of the torch for all the welding results in weak metallurgic results and weak productivity. This manipulator, although having four degrees of freedom, must be small and sufficiently light to fit in a portable mobile robot, and at the same time to be rigid and to have a work envelope compatible with the task.

The objective of this work is to develop a viable option of kinematics structure that are capable to easily fill the innumerable necessaries prerequisites and still to be capable to be manufactured with low cost. Also it is necessary to evaluate the easiness control of the mecatronic system, once that some systems have complex kinematics.

2. DESENVOLVIMENT

The robotics area has very developed at last years, enclosing new applications and increasing the performance. However, 72% of the industrial robots applications are destined to welding, and almost the totality of these robots have a serial configuration. Other configurations of manipulators normally are simpler, like cartesian, cylindrical and spherical, and with less degrees of freedom, like the ones shown in Figure 2. But nowadays more robots with parallel geometry appears, working successfully in operations of positioning, metal works and in flight simulators, filling the gap of performance and price that exists between the simplest robots and the sophisticated robots, like shown on the Figure 3.

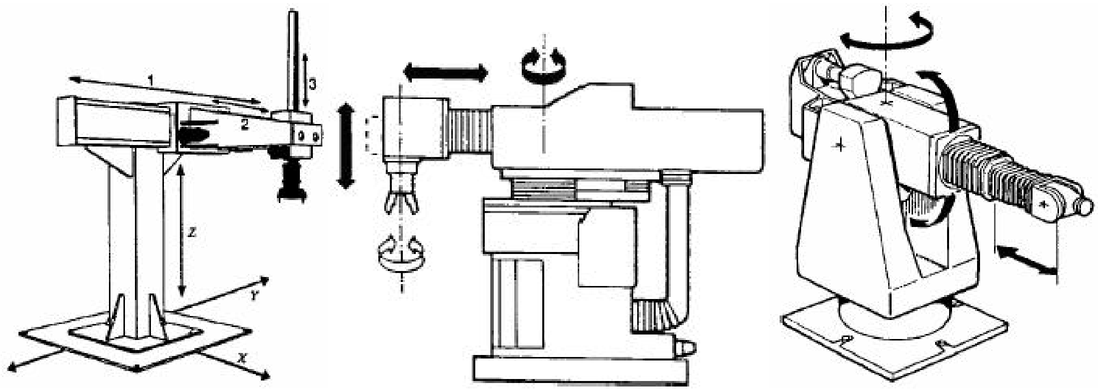

Figure 2: examples of simple serial robots with cartesian, cylindrical and spherical configurations (Eshed, 2001).

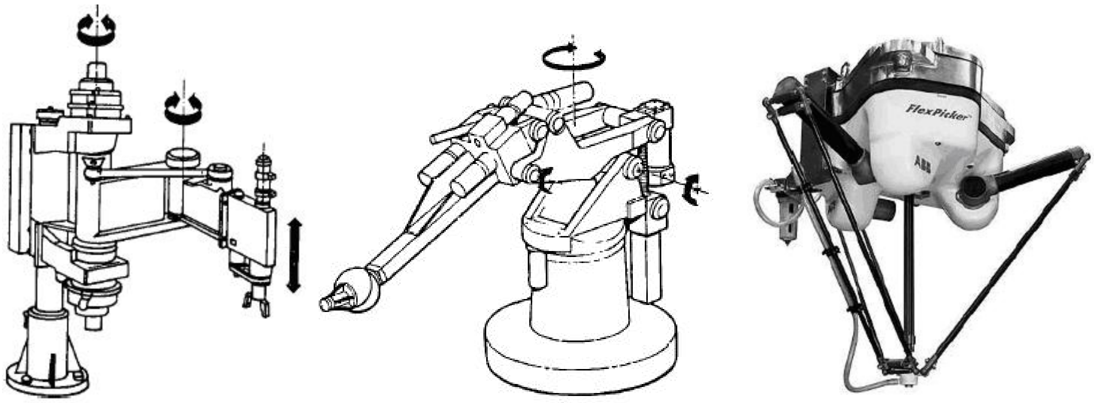

Figure 3: more complex robots, SCARA type, anthropomorphic (Eshed, 2001) and parallel DELTA type (Merlet, 2006).

Conventional industrial robots have become increasingly attractive by increasing the efficiency of production, but for industrial applications in fields such as welding of pipelines, the conventional robots are unable to operate effectively enough to justify the high cost of implementation. It is therefore necessary to create new systems that can fill the gap in conventional applications where the robots are not effective.

Lima II et al. (2005) shows the development of a dedicated robot for orbital welding of pipelines, as in Figure 4. The portable robotic system is able to walk around the pipe welded in all positions. A system for interfacing the computer with the welding machine changes the parameters according to the position, but the position of the torch must be modified for different positions of welding as well as to the appropriate placement of strips of solder later.

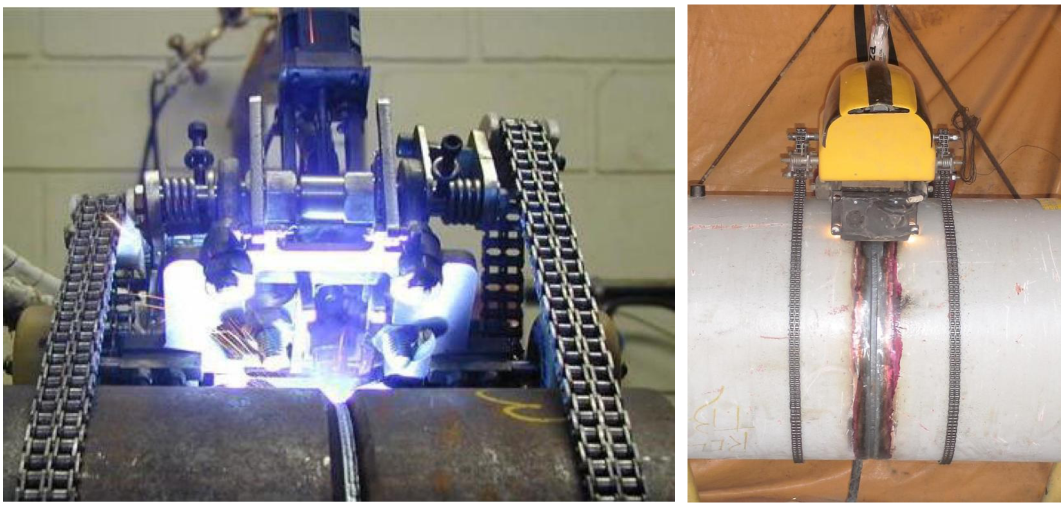

Figure 4: The first version test of the robot for orbital welding and
the second version, operating in Petrobras refinery.

A welding torch manipulator has been developed for the first version in 2003, followed by a new handler with an extended envelope that was introduced in 2005 in the second version of the robot. Both versions can be seen in Figure 5. These kinematics are capable only of adjusting the lateral and vertical positioning beyond the angle of attack in a Cartesian configuration.

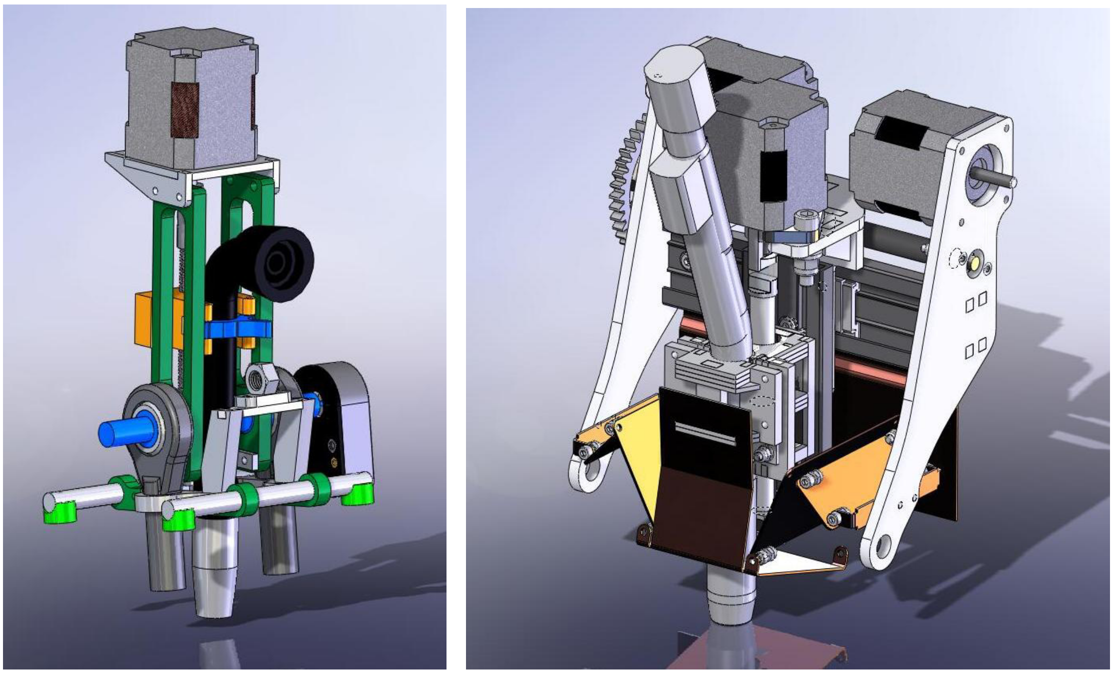

Figure 5: Two kinematics versions of the weld torch manipulator.

To insert the 4th degree of freedom (angle on the groove side) was necessary to place a motor in central position, very close to the heat of welding. This motor should have high torque, because of the weight of the cable and require very little flexibility, and therefore its implementation was not practical. Another decisive factor for the change in geometry was the size of the manipulator used in the second version, only to get a bigger work envelope, which was still limited. Therefore, a system that offered a large work envelope in relation to its size was very important.

3. RESULTS

To select the ideal manipulator to be designed, parallel robots have been analyzed from different settings and characteristics, compiled by Merlet (2006). The process of using the parallel robot in the welding was studied in all its potential and various options were considered in a process of selection and exclusion. The biggest problem is the fact

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that few parallel structures with 4 degrees of freedom have been developed since the parallel configuration is more efficient in more complex structures, with 6 degrees of freedom.

As none of the available kinematics was suitable to solve the studied problem, a new configuration was created specifically to meet the needs of the robot for orbital welding, among others:

- 4 degrees of freedom;
- Reduced size;
- Large work envelope for lateral movement and welding angle;
- Easy construction and maintenance;
- Standardized components;
- All components must be heat resistant.

Considering these prerequisites, we developed a parallel geometry as can be seen in Figure 6.

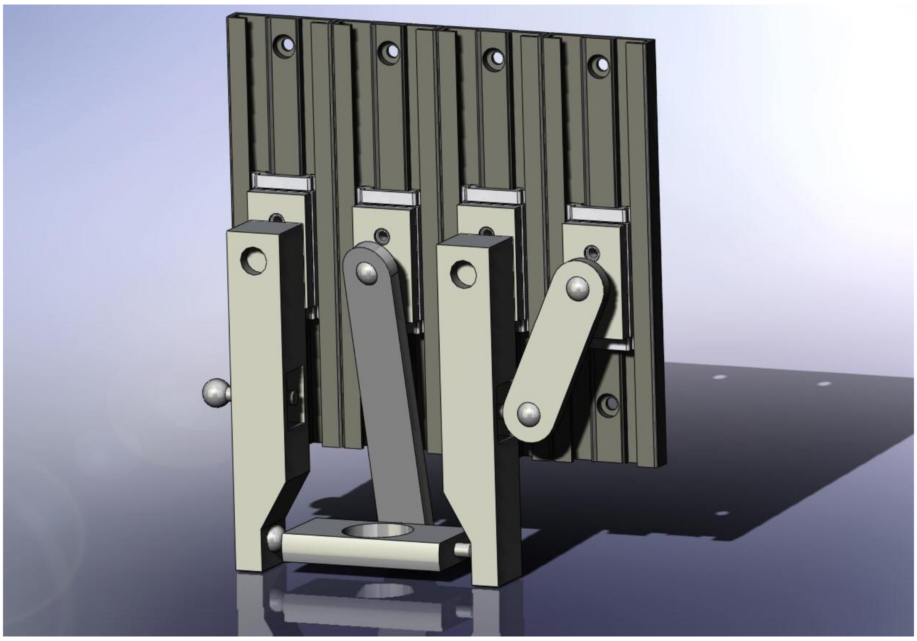

Figure 6: Design of a parallel structure to manipulate the welding torch.

Besides being a project that meets all the prerequisites described, it also has the advantage of requiring considerably lighter servo-motors, because the transmitions are not reversible and so the motors do not need to have a high static torque. The low weight of the system and the fact that each motor operates directly in the tool are also crucial factors to reduce the size of the manipulator, with a reduction of power required in the order of eight times compared to the first axis (angular motion) of the second version.

Another important factor of this configuration is its kinematic partially decoupled, allowing the calculation of direct and indirect kinematics to performed with ease. A coupled configuration, common to most parallel robots, brings some advantages such as increased rigidity, especially important in machine tools, but makes its kinematics model complicated, often requiring special techniques of numerical calculation. With the connection of an arm to another, instead of the plan, the system is partially decoupled and avoids the point of difficult solution.

To test the manipulator and before assembling it in the orbital system, it was mounted in a linear guide. This translation along the weld is the 5th degree of freedom and is completely decoupled from the kinematics of the system. Figure 7 shows this system.

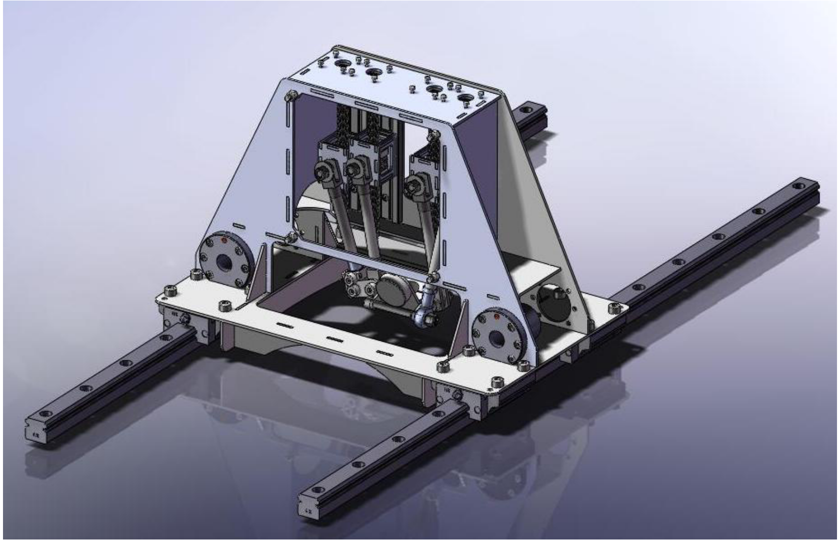

Figure 7: Handler on parallel axis 5.

The project was completely developed using rapid manufacturing techniques through the techniques presented in Ramalho Filho and Bracarense (2006, 2007) and Ramalho Filho (2007), using the Laminated Object Manufacturing (LOM) and laser cutting of thin metal sheets. The design was optimized with the technique of design for manufacture and assembly (DFMA), so all pieces are made of the same material, SAE1020, and a single thickness of sheet metal, laser cut and plug themselves to ensure good tolerances. The structure was united with autogenously GTAW. Parts of the main structure and the docking system can be seen in Figure 8.

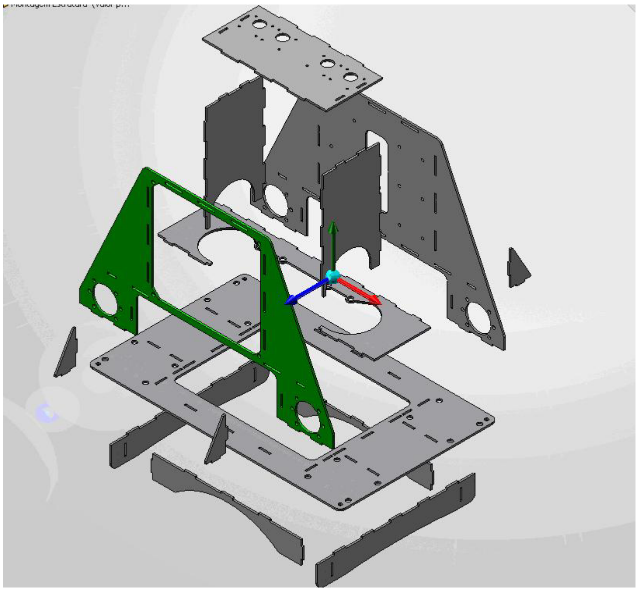

Figure 8: Proposed system optimized for rapid manufacturing.

The superiority of the system in ease of construction, reducing the number of components and standardization of the remaining parts are visible. The improvement in the size, weight and work envelope can be seen in Table 1.

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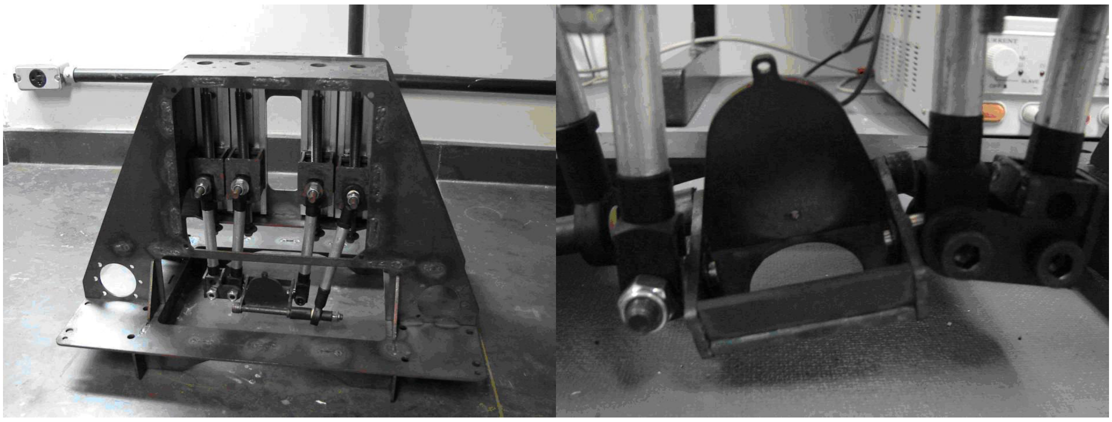
Table 1: Technical data of the 1st to 2nd manipulators of the original versions and parallel system.

	Approx weight	Width	Thickness	Height	Lateral Movement	Attack Angle	Vertical Movement	Side Angle
1ª. Version	1.2 Kg	120 mm	160 mm	180 mm	80 mm	+15°/ -20°	40 mm	-
2ª. Version	2.0 Kg	160 mm	200 mm	200 mm	85 mm	+30/ -50°	50 mm	-
Paralell	0.9 Kg	210 mm	75 mm	230 mm	200 mm	+70°/ -60°	70 mm	+45°/ -45°

The initial system prototype can be seen assembled in Figure 9. Techniques of calibration and measurement of their movements had to be taken to properly align the handler of the welding torch.



(a) (b)

Figure 9: Views of the prototype built. (a) prototype (b) manipulator.

4. DISCUSSION

The tests, although successful, showed some weaknesses in the project, including the fact that all arms are aligned in the same plane, resulting in a low stiffness when force perpendicularly applied to the plan.

Therefore, a similar but three-dimensional geometry would be able to obtain a global uniform stiffness across the work envelope. If the system has distributed the guides at the sides, instead of being aligned in the same plane, it would not only have the desired three-dimensional effect, as would also have space around the center of the envelope for the handling of the welding torch and its cable. Figure 10 shows the design of the new version that will be able to offset the shortcomings of the system and be the first candidate for use in orbital welding system.

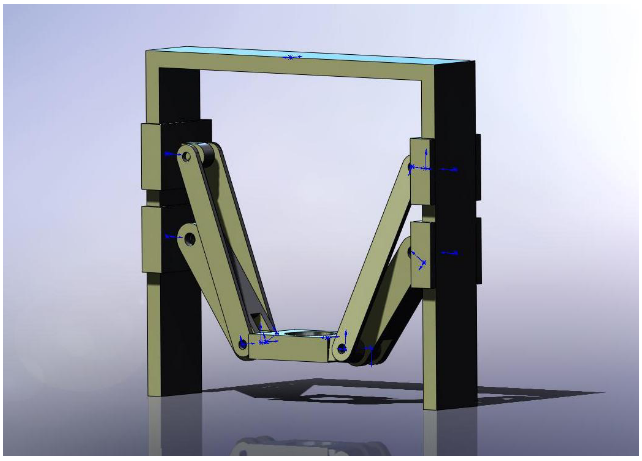


Figure 10: Parallel system with optimized distribution of actuators.

The new system not only solves the problems found, but also has only two tabs, instead of four, and further reduces the weight and thickness of the system. The envelope should remain the same, except the angle of attack to the side of the structure, which now is no longer limited by the collision with the structure.

5. CONCLUSION

It was noticed that the kinematic structure was faithful to the expected behavior, and the movement has shown a nearly linear trend, facilitating the controller program development and ensuring that the movements are very smooth, prerequisite during welding to avoid disturbance to the arc electric.

Another important factor is that the parallel structure, where each actuator acts directly on the tool, means that any error that may occur is restricted to the axis in which it occurred, and the errors do not add up, as in a conventional serial system. Therefore, the need for actuators of high precision is much lower for the parallel structure.

The extent and precision of movements is higher than in the conventional system, allowing superior repeatability, essential character when are welded parts of high responsibility as pipelines. Another advantage is that small shifts in the actuator allows large displacements of the tool, so that the system is fast enough to allow weaving, which until now were impossible with the conventional system.

The parallel robots, however, do not compete with anthropomorphic robot for industrial applications, but is more affordable and efficient than the Cartesian robots which are designed for simple applications or special applications such as welding in the field, and therefore should be considered especially for applications with three or more degrees of freedom.

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