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Robot base with holonomic drive

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***Abstract*— This paper gives introspection to the concept of the Ethon – holonomic drive based mobile robot. Nowadays the mobile robots are widely spread at the industrial and the service sectors as well. It is a facing problem in the view of development cost and time that the mobile robots are redesigned for every different application, despite most of the mobile robots are move on wheels. Our mobile robot base development gives a solution for the movement of mobile robot applications whit its modularity, holonomic movement, high load and work time capacity. The robot base has 3 DoFs according to the holonomic wheels and it can move, handle or even drive different superstructures. [1]**

Keywords—omnidirectional; holonomic; mobile robot;

I. INTRODUCTION

Nowadays, more and more industrial and service problems demand mobile robot solutions. At the industrial sector mobile robots are usually used for raw material or assembly parts transportation between production sells or lines, and the automated warehouse. At the service sector [2 - 5] robots are usually used for cleaning, grass cutting, etc. The most common way to the movement of the indoor industrial and service robots also is the rolling on wheels. It requires less energy, development time and price than walking or flying. At an indoor environment the rough terrain do not causes any problems at the movement, and most of the houses and industrial factories or warehouses are usually rolling on wheel compatible except the stairs and the doorsteps, but one robot usually works on one floor and the doorsteps can be easily modified. At a mobile robot development in most of the cases the half of the long time demanding development is the movement of the robot so the mechanical design of the drive system, the design of the embedded system(s), the design of the power electronics, the implementation of the odometry calculations, interpolation, inverse kinematics and the power management. With the Ethon concept (fig. 1) the whole robot base can be used for different applications with different superstructures. The mechanics of the robot is designed up to 25 kg load capacity, 1,5 m/s velocity, holonomic movement and up to 4 hours working time without any charge or battery change.

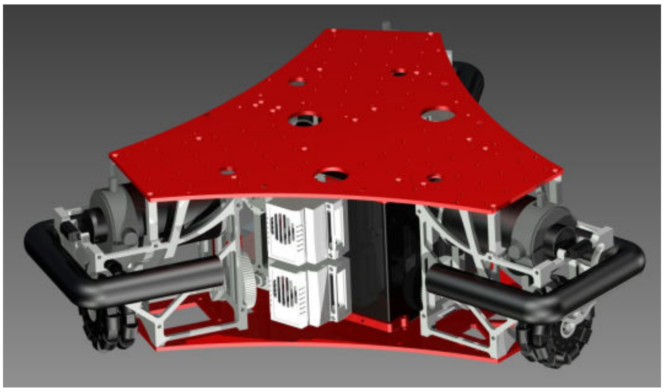

Fig. 1. The rendered image of the robot base

II. MECHANICAL SOLUTIONS

A. About the kiwi drive

The robot has 3 DoFs on the ground floor according to the omni whels. Omni wheels (fig. 2) or poly wheels, similar to Mecanum wheels, are wheels with small discs around the circumference which are perpendicular to the rolling direction. With this mechanical solution the wheels can roll with full force, but also can slide perpendicular to the rolling direction. This platform has employs three omni wheels in a triangular form, what is generally called kiwi drive.

Fig. 2. The omni wheel

B. Inverse kinematics

The kinematics of the robot can be calculated from the mechanical arrangement of the structure. At the software development of the inverse kinematics and the transformation between the robot coordinate system and the world coordinate system (fig. 3) we implemented equations 2.1-2.10.

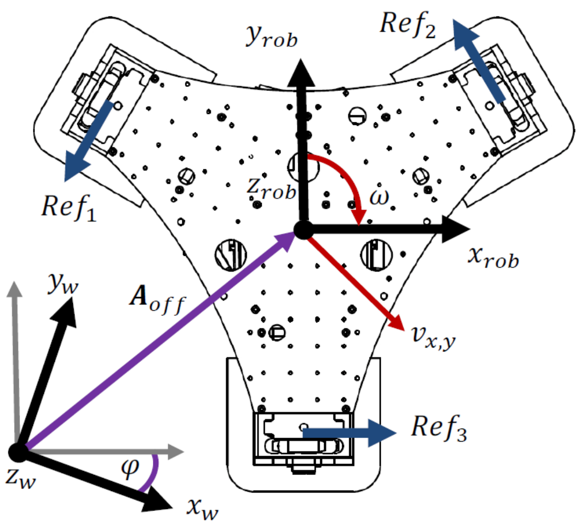

Fig. 3. The variables of the equations

The transformation between the robot coordinate system and the world coordinate system can be described as equation 2.1.

$$T_{R\to W}: \Re^3 \xrightarrow{Rot(z,\varphi)\cdot Trans(x,\Delta x)\cdot Trans(y,\Delta y)} \Re^3 \quad (2.1)$$

The transformation world between the coordinate system and the robot coordinate system can be described as equation 2.2.

$$T_{W\to R}: \Re^3 \xrightarrow{Rot(z,\varphi)^T\cdot Trans(x,\Delta x)^{-1}\cdot Trans(y,\Delta y)^{-1}} \Re^3 \quad (2.2)$$

The transformation of a point from robot coordinate system to world coordinate system can be expressed at the easiest way as equation 2.3.

$$P_W = P_R \cdot Rot(z,\varphi) + \boldsymbol{A}_{offset} \quad (2.3)$$

The transformation of a point from world coordinate system to robot coordinate system can be expressed at the easiest way as equation 2.4.

$$P_R = (P_W - \boldsymbol{A}_{offset}) \cdot Rot(z,\varphi)^{-1} \quad (2.4)$$

Where the offset can be expressed as equation 2.5.

$$\boldsymbol{A}_{offset} = \begin{bmatrix} \Delta x \\ \Delta y \\ 0 \end{bmatrix} \quad (2.5)$$

The rotation around the z axis can be expressed as equation 2.6.

$$Rot(z,\varphi) = \begin{bmatrix} cos\varphi & -sin\varphi & 0 \\ sin\varphi & cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (2.6)$$

The inverse of the rotation at the z axis can be expressed as equation 2.7.

$$Rot(z,\varphi)^{-1} = \begin{bmatrix} cos\varphi & sin\varphi & 0 \\ -sin\varphi & cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (2.7)$$

At the implementation of the inverse kinematics we used dimensionless values and calibrated contants to compensate the geometrical dimension of the robot and the differences in the dimensions. The references of the wheels can be expressed from the robot references as equation 2.8-2.10, where K is a constant to get real units.

$$Ref_1 = K\left(C \cdot \omega - v_x \cdot \sin 30^\circ - v_y \cdot \cos 30^\circ\right) \quad (2.8)$$

$$Ref_2 = K\left(C \cdot \omega - v_x \cdot \sin 30^\circ + v_y \cdot \cos 30^\circ\right) \quad (2.9)$$

$$Ref_3 = K(C \cdot \omega + v_x \cdot 2) \quad (2.10)$$

C. Mechanical design

The mechanical design (fig. 4) is optimized trough different versions for the less manufacturing with the highest design and load capacity solutions. The robot drive is designed with three 120 W DC servos, 1:7 gear belts. The elements of the structure are made from aluminum plates with water cutting and eloxed in different colors. The 24 Ah battery of the robot is in the center of the gravity and it fills out most of the robot volume from the top to the bottom cover plates, so the standard sized battery defined the height of the structure. The top plate has several holes in a raster for cables, screws and peripheries. The bottom plate has windows to the ground for additional sensors, like a laser odometry sensor, a line following sensor, or even mechanical elements.

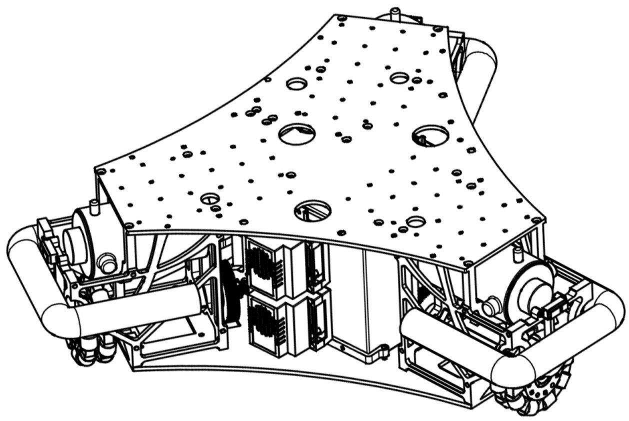

Fig. 4. The mechanics of the robot

D. Superstructure example

We made our first superstructure (fig. 5) for the service sector. The Comparative Ethology Research Grup (MTA 01 031) develops artificial intelligence models in the social robotics topic with our mobile robots. The superstructure has a mini ITX motherboard based PC, 1 DoF arm, 2 DoF Kinect, loud speakers, stereo microphone, RC servo controller, gyroscope, compass, acceleration sensor etc. The 2 DoFs camera is driven by an additional servo amplifier module, what can drive up to 2 DC servos with interpolation and ramp velocity profile. For the RC servo controller and the power management of the superstructure we designed a power module with E-stop, fuses, main power switch and a 5 V power source what can produce up to 30 A.

Fig. 5. Service robot examples

E. Docking bay mechanics

The robot can work for 4 hours without any charge or battery change but it should go work 8 hours, what is the time of a normal work day. At the time when the machine is between two missions it can be on charge but it is impossible at an office or a warehouse for the workers to care with the charging of the robot as "part time job". The docking bay (fig. 6) is designed for the robot base with adjustable parts to compensate the errors from the bumper and the position, orientation problems. The charging of the system (so the power on the connectors) starts only in case of successful docking. The solution is provided by end switches, relays on the robot and the docking bay.

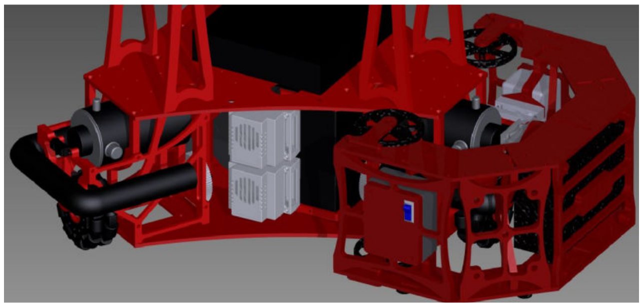

Fig. 6. The docking bay

III. ELECTRONICAL SOLUTIONS

A. Block diagram

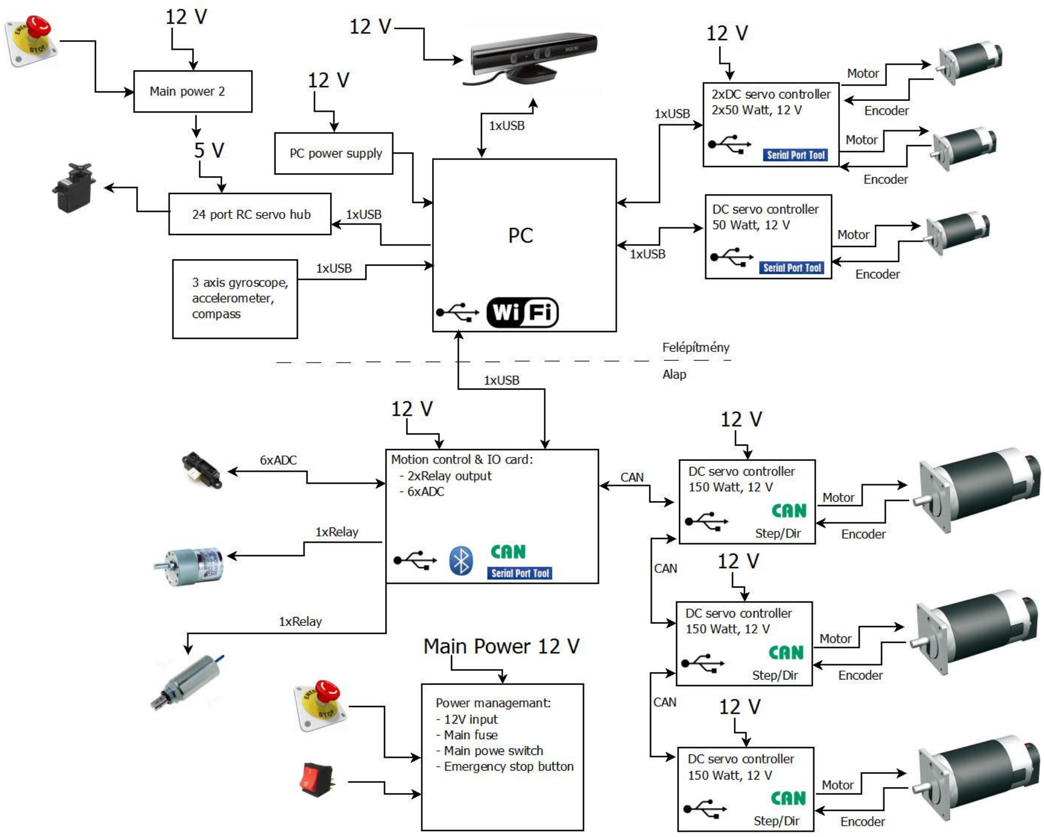

Fig. 7. The block diagram of the service robot example

The block diagram of the robot can be seen on (fig. 7). [6, 7] The center of the robot base is the central controller (motion control and IO card). The center of the whole robot in this service robot case is the PC, what deals with the artificial intelligence model. The servo amplifiers of the robot base are connected to the central controller via CAN bus. The servo amplifiers can be tuned and configured via USB from a PC with a graphical user interface. The central controller has 6 ADC ports and two relay outputs for direct peripheral handling. The 6 distance sensors are connected to these ADC ports, and two digital IO peripheries are connected to the relay outputs. The robot base, the servo amplifiers of the superstructure, the RC servo controller, the Kinect, and the sensor card are connected to the PC via USB. The whole system runs on 12 V except the RC servos, what runs from the 5 V 30 A power supply. The emergency stop button switches down the power of all the servo peripheries, but it allows to run the PC and the central motion control card. The main power switch of the robot base disconnects everything from the battery. All of the blocks are designed by our research except the RC servo hub and the sensor card.

B. *Servo amplifiers*

The DC servo amplifiers, what we designed for the robot base as it mentioned above are connected to the central motion controller via CAN bus. The amplifiers can get position, speed and torque (current) references via isolated CAN, Step/Dir, or USB ports. In this case the USB ports can be used for the tune of the PID controller, the configuration of the encoder, the CAN address, the Step/Rotation, etc. At the graphical user interface (fig. 8) the time function of the step response, the follow error, the current sign, the PWM, the current position and the reference position can be monitorized.

The controller algorithms can be P, PD, PI, and PID, where velocity feed forward and anti windup can be also used. The amplifier has active cooling and it can run DC servo motors up to 400 W power and 100 V DC bus. The power and the control parts of the amplifier can be separated for two cards. At the end of the development we reached the calculation throughput of the control card so the second version will be able to deal with Ethernet based communications and more sophisticated current, position and velocity control loops.

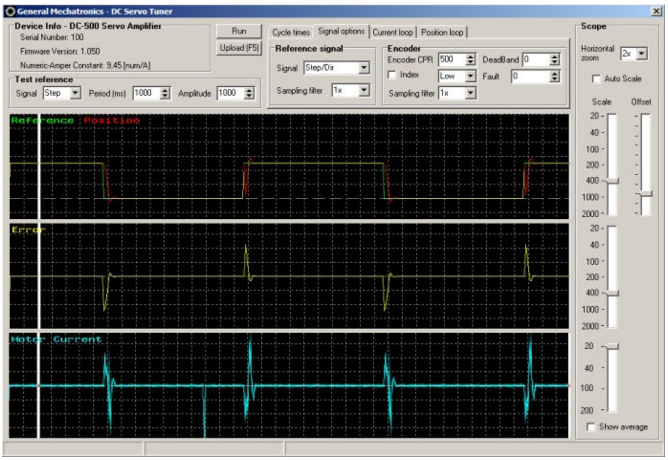

Fig. 8. The user interface of the DC servo tuner program

C. *Central controller*

The center of the robot base is an ASIC (Application Specified Integrated Circuit) [8, 9]. The block diagram of this system can be seen on (fig. 9). This embedded system is responsible for all realtime tasks, like robot kinematics, interpolations, power management, odometry calculations, sensor data handling, charging control, follow errors, etc. The card has CAN, Uart, Bluetooth, and USB communications. The CAN is specified for the DC servo amplifiers, and the other communications are responsible for the references between the robot and the controller, and for further data communication. As it mentioned above the robot has IR distance sensors, IR docking sensor, and laser odometry sensor by navigation and safety considerations, like obstacle avoidance [10, 11]. The servo diagnostics can detect and handle follow error, over current, or under voltage lockout problems. The main task of the controller is the navigation, what deals with the interpolation, docking bay detection, docking navigation, ramp generation for the robot and the references of the servo amplifiers [12]. The firmware update is also possible via an USB bootloader. All of the communication protocols have checksums, and acknowledge counters at the end of the frames by data handling considerations.

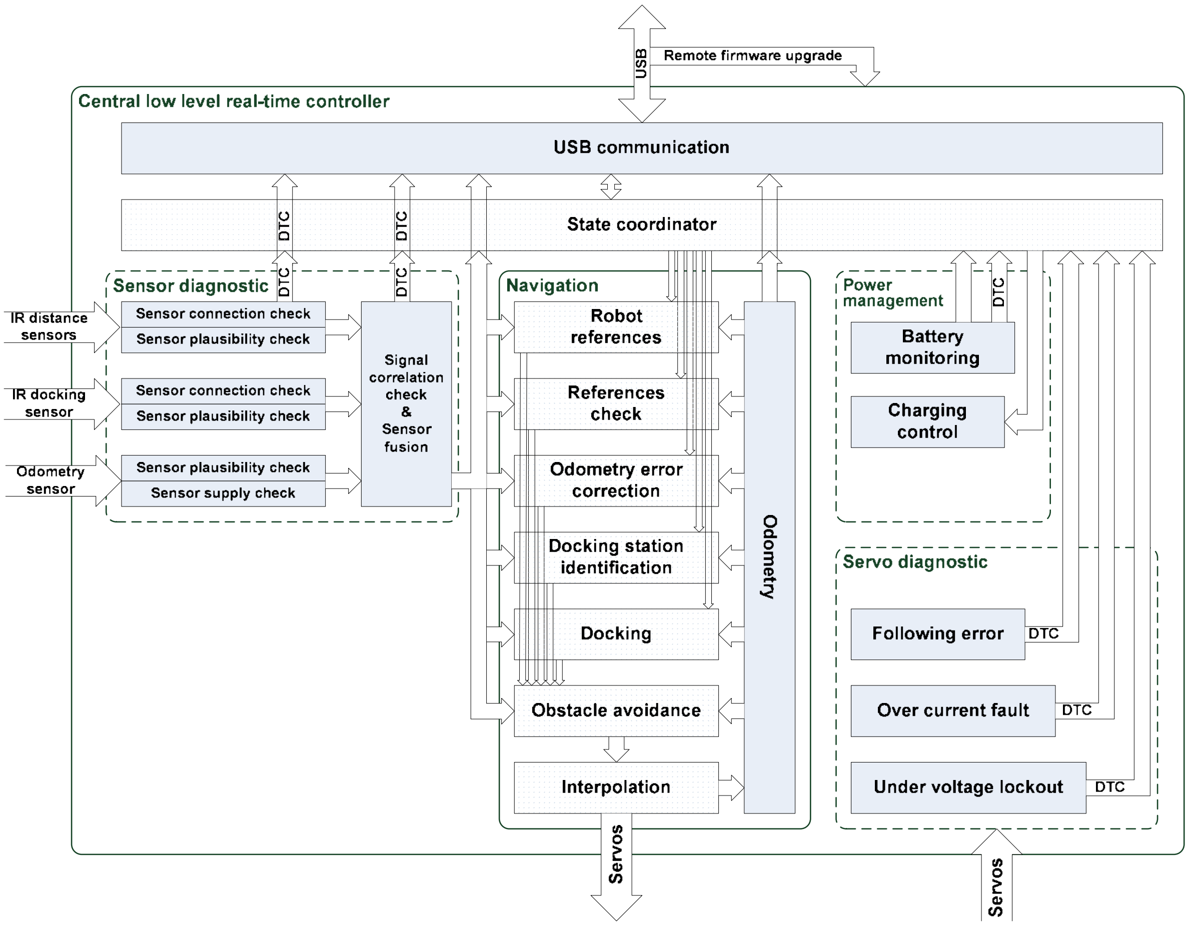

Fig. 9. The block diagram of the implemented algorithm

D. Docking bay electronics

A serviceable mobile robot has to be able to connect to a power pole automatically for self charging batteries. Nowadays, there is no such solution that is able to navigate and connect to electronic charging equipment autonomously and charge the batteries of the robot automatically. There are solutions those using distributed sensor network and computing like external camera vision systems or positioning systems. But the artificial intelligent and sensors of a navigation system should be placed only into the robot for practical implementation. This gives the availability to use robots in different unknown environments without developing external agents for helping the control. The task is to track the relative position and orientation of docking bay during the docking procedure, and control the robot's drive system. During a successful docking procedure, the robot moves in the shortest path between the docking bay and its original position. A new type of specialized vision system introduced, by using infrared light wavelength selective spot configuration detection. A new camera based infra vision sensor helps the navigation system to locate an infrared spot formation. Cost effectively, the docking bay is marked by three infrared LED markers in a specified arrangement (fig. 10). If the markers are in the viewing angle of the camera, the vision processing algorithm can calculate the relative position of the docking bay. The infra point sensor is able to sense up to four infrared spots and gives information about the planar coordinates of the points on the captured picture, the size of the points, and the brightness. With three different points and with geometric mathematical equations we can calculate the robot position and orientation according to the marked docking bay.

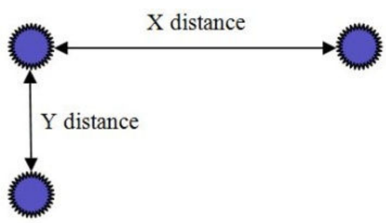

Fig. 10. The arrangement of the IR leds

On the plane of the capture screen, the Y distance is proportional to the distance between the robot and the infrared markers. Angle between robot and markers can be calculated using distance X corrected by distance Y. Furthermore, it is possible to define other different objects as well for the robot with different infrared LED arrangements (fig. 11).

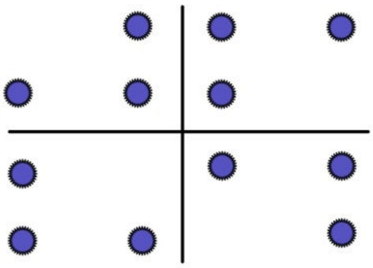

Fig. 11. Further IR led arrangements

Because of the introduced special camera sensor solution and with the novel methodology, the whole navigation solution can be implemented into an embedded system placed on the mobile robot platform. Hence the higher level PC-based robot control do not have to deal with the complicated docking procedure.

IV. DISCUSSION

The Ethon robot base concept can be used for the movement at the most common mobile robot applications according to its raster holed top plate, high load and work time capacity, and different PC and microcontroller based communication protocols. With the use of the same robot base at different service or industrial mobile robot applications can save the highest development time and development cost. In line with the save at the development if we use the same robot base at different applications it can produced in large numbers, what means less costs at each manufactured product. As in Japan the robot industry market is projected through 2035 (fig. 12) the service robot sector will be wider than the industrial one. Most of the service robot applications are based on mobile robotics, so the innovation of this market will be a facing problem in some years and the industry must prepare for these needs.

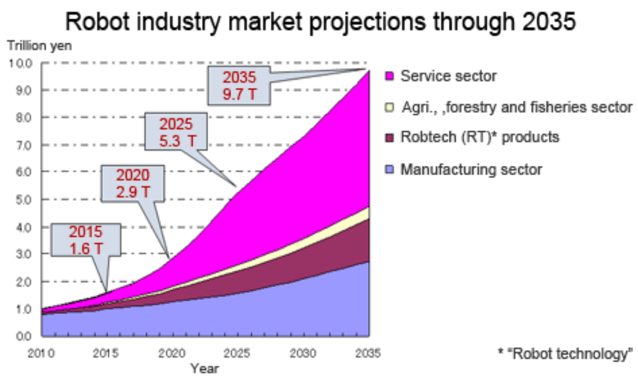

Fig. 12. The projections of the robot industr market

V. CONCLUSION

The development finished successfully, and the MTA research group tests our robots since January. According to their feedback we could implement some software developments at the communication protocols and the motion control. The second version of the servo amplifiers will make significant differences only at an industrial application, but in the industrial sector the change of the DC servos for BLDC or PMSM motors should be considered and of course is also requires the change of the servo amplifiers. We will investigate these developments in the view of costs, development time, and estimated work time, what depends on the application.

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