

Robotic Arm for an autonomous Rescue Robot

Andreas Poelzleithner and Raimund Edlinger

Abstract—Rescue robots replace humans for exploring disaster areas with the duty of acquiring information, detecting victims and retrieve dangerous situation. Therefore the robot has to be equipped with many sensors such as cameras and microphones and gyro-sensors. To explore even hard accessible areas of the disaster the robot is equipped with an robotic arm which carries cameras and sensors. This paper describes mechanical design and the kinematic model of the robotic arm.

I. INTRODUCTION

This paper describes a robotic arm. This robotic arm is attached to a autonomous robot for rescue and security applications. It is supposed to carry sensors and cameras at the very end of the arm. This is required to give the robot a better view of the environment for finding victims, detecting dangerous situations and orientation. A picture of the robot including the arm is shown in figure 1.

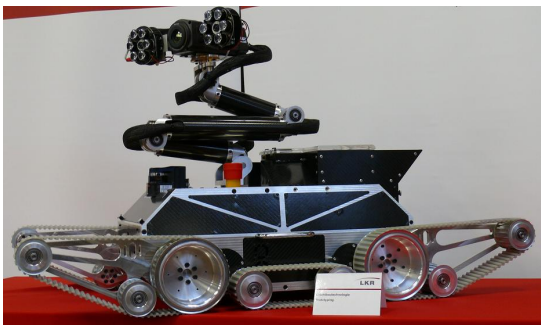


Fig. 1. Picture of the rescue robot with the robotic arm

A. Requirements

The requirements are based on the application as an rescue robot. The main requirements are the working range and low power consumption. The working range was set to approximately one meter radius. In order to keep the power consumption low a lightweight construction and appropriate drives are required. The arm is supposed to carry a payload of at least 2kg. Furthermore the links and the joints are designed to as modular systems so the configuration of the arm can be changed easily without any changes to the joints. Since the whole robot drives over uneven underground the arm needs to stand vibrations and dynamic forces caused by the motion.

A. Poelzleithner and R. Edlinger are with the Robo Rescue Team which is a reseearch & developement department with resarch focus on autonomous robot systems, University of Applied Sciences Upper Austria, Stelzhamerstrasse 23, 4600 Wels / Austria. 04103032@fh-wels.at, raimund.edlinger@fh-wels.at

II. FUNCTIONAL DESIGN

The robotic arm consists of an baseplate, five rigid links, the end effector at the very end and a flange to mount the payload. The links are connected to a kinematic chain via six joints which are all rotary. This gives six degrees of freedom. Figure 2 shows a schematic drawing of the robotic arm. The first degree of freedom allows the whole robotic arm to turn around an vertical axis. The following three degrees of freedom are around vertical axis and connect the links that are actually lifting the payload. The two last axis are carried out like a human wrist.

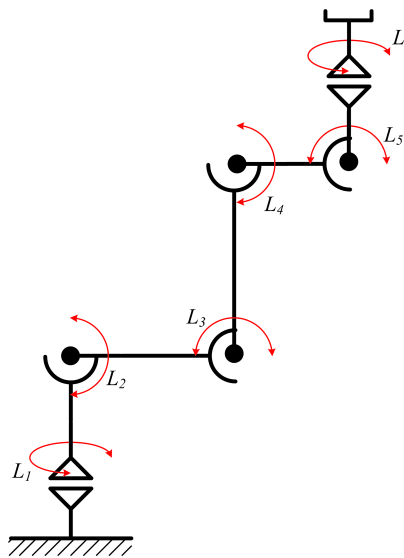


Fig. 2. Schematic of the kinmatic chain

III. MECHANICAL DESIGN

The whole robotic arm is designed using the CAD program CATIA from DASSAULT SYSTEMS which allows to draw a three dimensional model. The drawings can be exported for simulation and machining. The arm is assembled out of custom made aluminum and magnesium parts, standard parts such as ball bearings and carbon fiber tubes.

1) *Links and Joints:* As mentioned the arm is connected to the robot by a baseplate. The second link is U-shaped and is between the first and the second axis. The main links consist of carbon fiber tubes with pivot elements on both sides which are made out the aluminum alloy *EN AW 7075*. An pivot axis is mounted on the fixed part of the pivot which is rotative supported by ball bearings in the opposite part of the pivot. The driving motors are located inside of the tubes and drive the joints via a worm gear. Aluminum inserts are

glued into both ends of the tubes to mount the pivot parts. As mentioned the hinges are designed to achieve a modular system. This is realized by using the same hinge type for each joint. Figure 3 shows an explosion drawing of the joint.

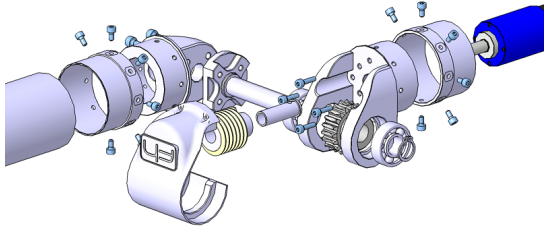


Fig. 3. Explosion drawing of the main joint

This type of hinge is applied for every joint except for the first and the last. The very last link is very complex because function is similar to the function human wrist. The last axis is orthogonal to the second last which allows the end effector to yaw and pitch. In order to reduce weight, the fifth link is made out of magnesium. An explosion drawing of the last two links is shown in figure 4.

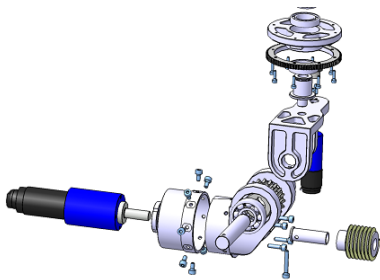


Fig. 4. Explosion drawing of the last two links

2) *Driving systems:* For driving the joints DC-motors with a planetary gear head and magnetic encoder are used. Except the last all joints are driven via worm gears so there is no power consumption in the static state. The last joint is driven via bevel gears. Encoders which are mounted on the rear side of the motors are used to measure the angular position of each joint. These encoders are also used to get feedback for the discrete negative feedback controller of the motor driver units. Since the encoder does not provide absolute values, opto-coupler is used to acquire a reference angle. The encoders have a resolution of 16 steps per revolution. Due to a transition ratio of 1 : 575 the angular accuracy is 0.039° per step.

3) *Finite element simulation:* To ensure that all parts are designed properly the robotic arm is simulated with the finite element simulation program ANSYS. For the simulation the CAD drawings are used. The simulation gives information of stress and pressure in the materials. Furthermore the deformation by its own weight and an additional payload is computed. The made it possible to assign the appropriate material to each part.

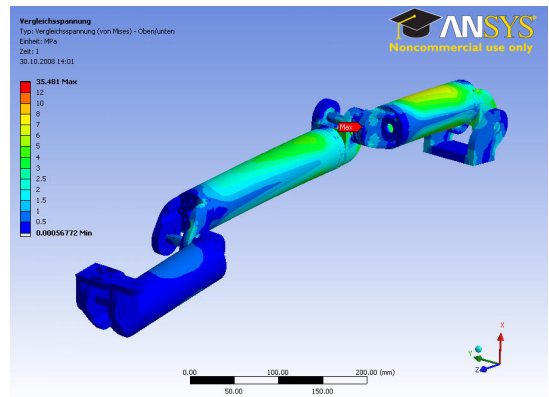


Fig. 5. Simulation of the robotic arm using ANSYS

4) *Machining:* All the custom parts are machined by CNC¹ mills at the LKR[2] which is a research center with the focus on lightweight constructions. To ensure high accuracy it is very important to produce very precise parts with low play.

IV. POWER DRIVES FOR THE DC MOTORS

Each motors is powered and controlled by a digital servo controllers. This controller consists of an DSP² and a H-bridge which provides up to 15 Ampere. The controllers are connected via a CAN bus to the main controller board. This distributed architecture brings the advantage of a good maintainability and scalability. A negative feedback controller is implemented and runs on the DSP.

V. KINEMATIC MODEL

A kinematic model is calculated do determine the position and orientation of the end effector out of the axis variables which are the angular position of each joint. To set up the forward kinematic model vector spaces and transformation equations are used. Therefore a homogeneous coordinate system is assigned to each link which are all considered as rigid. This assigned coordinate systems are named frames and define the orientation and position of each link in respect to the former.

A. Denavit-Hartenberg Notation

A convention, developed by J. Denavit and R. S. Hartenberg, defines a method to assign the frames to the links in a useful way. This method is introduced in [1]. The assigned frames are the transformation matrices end are generally denoted as in equation 1. A matrix describes how to get from the i th to the $i + 1$ th frame from the former to the latter in respect to the i th frame.

$${}_{i+1}T_i = \begin{pmatrix} \cos\theta_i & -\lambda_i \sin\theta_i & \mu_i \sin\theta_i & a_i \cos\theta_i \\ \sin\theta_i & \lambda_i \cos\theta_i & -\mu_i \cos\theta_i & a_i \sin\theta_i \\ 0 & \mu_i & \lambda_i \theta_i & b_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

¹Computer Numerical Controlled

²Digital Signal Processor

The variables a_i , b_i , μ_i and λ_i are the "Denavit-Hartenberg parameters" which depend on the mechanical construction of the respective link and the axis orientation. The variable θ_i is the axis variable and represents the actual angular position of the respective joint.

In this case six transformation matrices are assigned. The position and orientation of the end effector in respect to the first frame can be computed by multiplying the transformation matrices.

$${}^1_e T = {}^1_2 T \cdot {}^2_3 T \cdot {}^3_4 T \cdot {}^4_5 T \cdot {}^5_6 T \cdot {}^6_e T \quad (2)$$

In this way the orientation and the position of the end effector can be calculated by the controller.

VI. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

The robotic arm satisfied all the expectations. All the links and joints work properly without play and deformation. Specially the carbon fiber tubes and bonding to the aluminum inserts better than expected. Also the payload is higher as laid-out. The only weak point is that the arm can not be full outstretched into horizontal position. This causes too much torque in the second joint and may damage the gear head of the motor. Hence this state is not required it is not a disadvantage.

B. Future Works

The next step is to implement a test software in LabView that controls the DC-motors. The aim for the future is to calculate an inverse kinematic model. Furthermore a software for trajectory planning and collision avoidance will be developed.

In order to reduce weight or increase torque the DC motors may be replaced by brushless motors.

VII. ACKNOWLEDGMENTS

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