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About the development of a technological complex with a manipulator for an unmanned underwater vehicle

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Abstract. This paper presents solution of underwater manipulator tasks providing interaction with environment to perform tasks. Underwater manipulator is a part of unmanned underwater vehicle used to perform operations on ordered depth. Technological system based on standard and available elements is explored. Main research avenue is a remote control of modular system elements using Programmable Logic Controller. This paper describes the design and implementation of algorithms for controlling the manipulator or its hardware platform. Software architecture to control using standard programming tools is shown. Additionally, compute resources necessity depending on control system structure has been reviewed.

1. Introduction

Robotic manipulation technology is widely used by the ocean development industry including offshore gas industry to perform intervention operations on subsea infrastructure by remotely operated vehicles (ROVs). The robotic manipulators found on intervention capable ROVs typically rely on hydraulic or electric actuators to achieve motion and are controlled by operators through remote control.

Recent researches in underwater objects handling technologies area are dedicated to developing a new class of underwater robotic manipulator that achieves high power density. Additional features include modular actuators and housings and quick access Marman clamps for rapid manipulator assembly/disassembly. Onboard equipment also includes tools for operation area visualization, manipulator position control system, pressure, temperature, and humidity sensors.

High performances can be obtained by means of lightweight parallel-drive or delta-like kinematics, whose advantages in terms of reduced moving masses and inertias are well-known. In most cases, these architectures management is created on hardware platforms based on Personal Computers (PC). Such solution reduces software development costs, but it is necessary to have some design features to protect of harsh industrial environments, so cost outcome increases significantly.

Programmable Logic Controllers (PLCs) are playing a dominant role in industrial automation, thanks to their robustness, reasonable cost and ease of use. Electronic components inside PLCs are selected for their reliability and solid presence on the market, rather than for their performance. For this reasons, PLCs are commonly considered as low-level systems, whose main purpose is to control simple Boolean signals (i.e. discrete control and sequencing). However, modern PLCs have most of the times sufficient computational bandwidth to execute also complex mathematical calculations, which could be successfully used for robot control. Despite on the existence of a PC compatible software with user



modification ability, PLC-based control systems for robot manipulators are quite rare and, in general, limited to simple Cartesian structures.

A modern robot arm is the combination of links and joints in the form of a chain where one end is fixed while the other end is free. The joints are driven by actuators. In order to move the free end, also called the end effector all of the joints are to be moved. The task assigned to the robot arms can be performed repeatedly with high accuracy and with precise movements of joint angles. In doing so it is necessary to solve the inverse kinematics equation. In the case of redundant manipulator, inverse kinematics is much more difficult when compared to a non-redundant manipulator whose kinematics is not so complicated. There are traditional methods such as algebraic solutions, geometric solutions and iterative solutions in order to solve the inverse kinematics problem. Deriving the best possible inverse kinematic solution for end effector is challenging and difficult, solution of such problem by single manipulator example is shown below.

2. Research objective

Initial design data for research are given below:

- 5 DoF (The configuration design of the manipulator is given on figure 1);
- Dimensions of the manipulator stowed position are 600x600 mm.;
- Loading weight is not more than 5 kg.;
- Loading transport speed is not more than 0.5 m/s.;
- Depth rating is not more than 1000 m.;

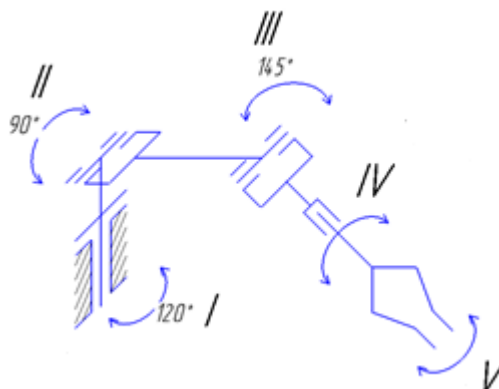


Figure 1. The configuration design of the manipulator.

3. Manipulator design

The initial manipulator concept architecture consisted of a modular, 5 DoF design incorporating distributed motor controllers and brushless motors. The kinematic layout of the manipulator features a 1 DoF shoulder with 3 linked roll-pitch elbow pairs. The same actuator size and gearing is used on every manipulator joint.

Each elbow is connected through a static roll pitch adapter housing. The kinematic layout of the manipulator allows dexterous manipulation of elements in the manipulator's workspace. A modular approach was taken in designing the manipulator allowing the ability to swap sub-assemblies in the field for rapid repair or reconfiguration. Each assembly is held on with a Marman clamp on each end allowing the quick removal of a subassembly.

Power and communication pass inside the manipulator. At each roll pitch adapter housing, connections are routed through a sealed bulkhead allowing modular, independently sealed volumes. This provides the protection of the manipulator in the event that one section of the manipulator sealing is

compromised. The shoulder housing has an output to an underwater bulkhead connector for connecting the manipulator power and communication to ground support equipment via a tether.

To facilitate a variety of manipulations a few canonical arm poses are defined (figure 2). There is a starting configuration for completion of tasks with the gripper axis. These tasks include such things as turning a valve or grabbing a handle.

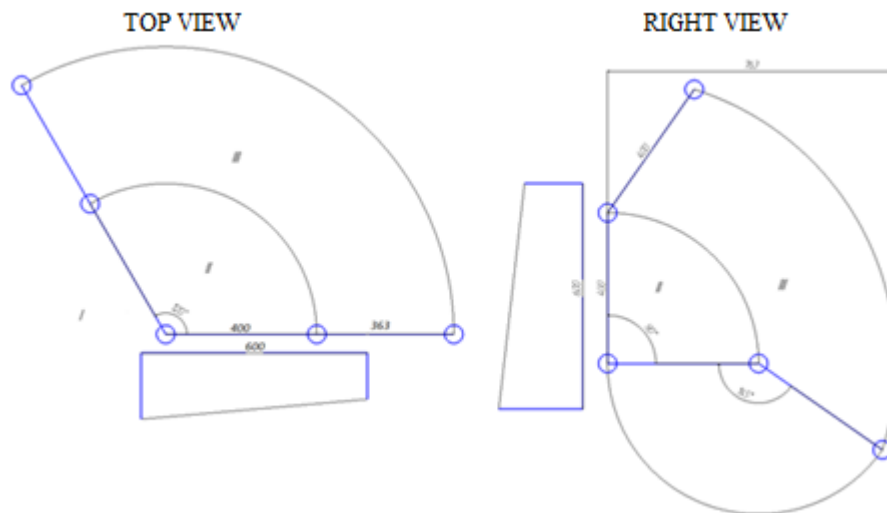


Figure 2. Manipulator parts motion diagram.

As the manipulator is design for pick and place application, the manipulator pick up the part and place it in relative positions such as good part position or bad part or rejection area according to the sensory data. So the states finding for the robot manipulator is finite. The arm has its work space and it can reach to those positions by different paths.

The initial state for the robot manipulator could be any state depending on the signal send by the sensors to the arm, but at the start of the program the manipulator always go to the home or nesting position.

The manipulator action depends on the signal received from the sensors (camera, part detect sensor, etc.). The manipulator takes action after the signal send to the controller by sensors and controller decides the movement of arm. So manipulator moves toward the destination area by avoiding the obstacles in the path as well as within the time limit and with respective speed. To reach to the goal or object manipulator has to find out the best possible path with minimal joint angle movement within its work space. The end effector will try to reach the object as soon as X and Y coordinates are calculated. There are also some other actions such as for open and close the gripper, take snap shot of parts, start/stop the conveyor, start/stop the motor etc.

4. The transition model development

The transition model for the manipulator is depending on the action taken. At the start the manipulator returns to the homing position. So we will consider the initial state as the homing position.

To achieve the goal of the application, the position trajectories calculation of robot manipulator is the most difficult task, as it has to avoid the obstacle and reach to the product picking. For this robot manipulator there are lots of possible path to reach object. Among those paths, the best path will have the minimal joint movements and shortest distance within its workspace. There are lots of algorithms and techniques have been developed for finding the inverse kinematics of the manipulator. The complexity of finding the kinematics solution increases with number of joints or Degree Of Freedom (DOF). The robot manipulator position, path planning and motion control in 3 dimensional workspace become a key factor for control system design engineers and robot manufacturers. The typical task for robot arm in industry is to move its end effector from initial position to some desired position in working

environment with least residual vibration, minimal torque, obstacle avoidance and collision free kinematics, shortest time interval and/or distance of a desired path.

The principal advantage of using position-based control is the chance of defining tasks in a standard Cartesian frame. On the contrary, the image-based control is less sensitive to calibration errors; however, it is required the online calculation of the image Jacobian, that is, a quantity depending on the distance between the target and the camera which is difficult to evaluate.

For finding solution of DFK (Direct Forward Kinematics) in VAW (Vector Algebra Widening) operators system it is easy to organize special cycle operator for sequence turns or all vectors extensions of selected vector object (fixed vectors array of its kinematic layout). PSV operator is example of such DFK:

“Vector system rotation”:

$$PSV(nv, M0[], mo, O[mo], U[mo], M[])$$

where: mo – DoF axis amount (=5); nv – amount of 3D-vectors in vectors system (=15); $M0[]$ – 2-D array of 3-nv parts, tilt axis and grab reference axis; $O[mo]$ – axes vector numbers array of массив object DoF; $U[mo]$ – axial angles array (= [120°, 90°, 145°, 360°, 40°]); $M[]$ – 2-D array of tilted parts position vectors and manipulator axis.

Sequence accessing to “tail” rotation operator of DoF vectors PSVK is performed in PSV operator – “End vector system rotation”:

$$PSVK(nv, M[], m, u)$$

Operator turns about an m-axis an angle of u all remaining 2D-array $M[nv,3]$ vectors, from m+1 to nv by access cycle to PVV.

$$\begin{aligned} &PSVK(nv, M[], m, u \\ &\{For(i = m + 1; i \leq nv, i = i + 1) \\ &M[i,3] = PVV(M[i,3], M[m,3], u); \} \end{aligned}$$

Initial Cartesian positions of the end of gripper fingers and directional cosine situate on 4 last line of vectors axis $M[]$.

5. Conclusion

In this paper we have described a fully electric underwater robotic manipulator capable of robust interactions with an underwater work at depth of 1000m. The design is modular. Device efficiency is achieved due to the more serviceability with high power density provided by brushless DC motors. Algorithms for intervention operations of manipulator set on unmanned underwater vehicle are developed. In this paper we proposed algorithms for trajectory planning for industrial robot manipulator using the Position based algorithm. The proposed combination algorithm reduces the computation time and positioning error for finding the target in real time.

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