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Restoration and PLC control of a material handling MP-9S industrial manipulator platform

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Abstract. In this project, a material handling MP-9S industrial manipulator was restored and put into operation. In its starting state, the only the manipulator itself was available, without a functioning controller. As a part of the restoration, the manipulator's mechanical structure was examined, the existing electrical connections and sensors were checked, its missing controller was replaced, and was later programmed to execute an example task. The control system was designed to flexible and able to accommodate a wide variety of controllers. In its currently realized state, the program can be observed and interacted with by the implementation of a Human-Machine Interface. These tasks and the necessary tests were completed at the robotics lab of University of Debrecen, Faculty of Engineering.

1. Introduction

At the „Cyber-Physical and Intelligent Robot Systems Laboratory” residing at University of Debrecen's building mechatronics research center, a laboratory showcasing new industrial solutions was created [1]. The new industrial robot cell makes it possible to emulate or simulate various industrial tasks [2]. Relevant data is available to those who participate in the research done in this laboratory, through its closed network [3]. Nowadays, mass production is considered an everyday phenomenon. This level of productivity can be most easily achieved by automated solutions. During modernizations, it's not uncommon to discard otherwise functional robots due to their obsolete controllers. As questions regarding sustainable development arise, with the desire of ever-higher profits still being present, reconstruction and modernization of an earlier discarded machine might be an option to consider. During this project, I have completed a similar restoration, during which my main goals were to restore the manipulator to its original (or near-original) state, and to replace the missing controller with a suitable, modern device. Keeping costs low was also an important consideration. The MP-9S manipulator making up a large part of this project was originally employed in a VAZ factory. Within the factory, they fulfilled material handling roles, more exactly, the handling of oriented half-done workpieces during hot-die manufacturing. Using these manipulators in pairs, the number of required workers reduced from six to just two [4].

2. Technical overview

2.1. The physical and technical structure

The manipulator's three degrees of freedom are given by one rotational axis (B), and two translational axes (A, C). Due to this, the manipulator is of TRT construction. The parameters defining the working



zone are the rotational angle, movement along X-axis, and movement along the Z axis. The manipulator has an open kinematic chain, which may be observed in figure 2. Apart from the three, degrees of freedom-giving movements, the manipulator can also move the gripper attached to it (D). The simplest possible gripper consists of two metal plates, which to be inserted into the gripper head's jaws. The actuators are all bistable construction, except the gripper, which is monostable (spring returned).

The movements of the manipulator happen from one end-state (limit) to the other, which are sensed by reed-sensors placed at every limit. The actuators have small permanent magnets built into them, which, after reaching the limit of movement, activate the sensors. The gripper does not have any sensors, as such they do not give feedback regarding their current position or state.



Figure 1. MP-9S manipulator

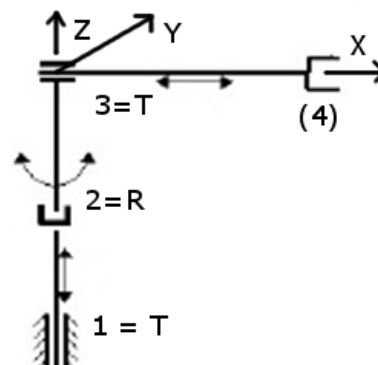


Figure 2. Kinematic chain based on [5].

The compressed air needed by the actuators is first moved through one of the previously mentioned, 3/2 monostable electro-pneumatic valves. The air supply must be connected to a connector found on the back panel of the manipulator. Their nominal voltage is 24[V], and their nominal pressure is 10 [bar]. The actuators require two valves each, except the gripper (which only needs one). As such, the manipulator's movements require a total of seven of these valves, leaving the eight one unused. The interior of the manipulator's housing can be accessed by lifting off the curved cover plate.

2.2. Electrical structure

Without a controller, the manipulator's electrical structure is limited to the wiring of the limit switches and electropneumatic valves. One of the connectors carry the signals send by the limit switches, why the other is responsible for controlling the valves. These valves, due to their electromagnets, generate a small backward current spike. To avoid damage from these spikes, diodes are connected parallel to them, on a separate component to which the valves' wires are connected to. In the manipulator, there are 17 separately numbered wires. Discovering the connections and purpose of these wires are one of the key tasks during the project.

3. Steps of restoration

3.1. Preparations

The restoration was preceded by preparations. First, the manipulator was cleaned, its outside surfaces received a new layer of paint. In addition, two aluminum profiles were fastened to the manipulator, which profiles were later equipped by wheels. This ensures the robot's increased mobility. Four threaded rods were added, serving as both a stand, and a way to move the manipulator along its Z axis, for finer positioning.

3.2. Re-examination and restoration of electrical connections

During this project, some of the main goals were to restore the equipment to a state where it may fulfill its original roles, and also achieve this by cost-effective methods. Due to this, keeping the existing wires and components (if they are safely functional) was justifiable. In the manipulator, most wires were already numbered, which numbering was extensively used during the restoration. Before reverse-

engineering said connections, the original connectors were removed: they were old, and partially damaged, finding an identical replacement was not feasible. Considering that only eight and nine pins were used per connector, it was more sensible to replace them with more modern parts. By using a continuity tester, tracing wires, and methodically activating limit-switches, the electrical connections of the manipulator were mapped. Later, DB-9 connectors were added as replacement connectors.

After finding the purpose of every wire, the valves' electromagnets had to be tested. Finding the value of electrical current required for the proper function of the electromagnets was found by using a bench power supply, by gradually increasing the current limit at 24 [V] voltage: the value was found to be between 500 and 600[mA].

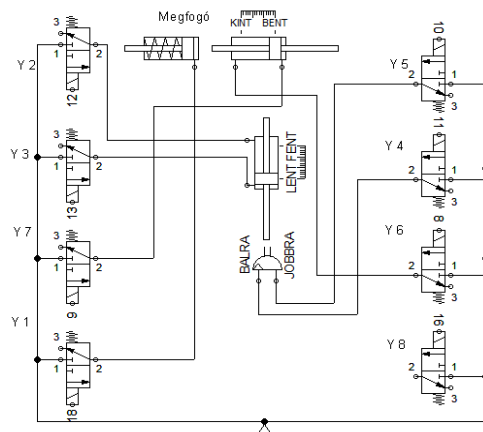


Figure 3. Pneumatic connections

3.3. Testing of pneumatics

Before the controllers' replacement, it was prudent to test the pneumatic components of the system. The manipulator was connected to a source of compressed air. The pressure value was chosen to be 2,5[bar], which is close to the minimum operational value. To complete the testing, the valves were tested using the bench power supply, one by one. The result of this test was satisfactory: all axes except axis "Z" functioned well. Initially, movement long axis "Z" could not reach its limit while lifting the arm. This was solved by finding the suitable pressure level, and repeated the movement of the mechanism.

4. Choosing the new controller

4.1. Parameters of the old control system

The ETsPU-6030 (ECPU-6030 / ЭЦПУ-6030) is a cyclical controller, designed especially to control machines consisting of two end-state actuators, and their technological processes [6]. This controller was able to operate machines using up to four axes, and six additional technological commands. Timers (delays) were also available, with time intervals of 0...0,7[s]. Each program could consist of a maximum of 30 steps, and four modes were available, which are as follows: manual (moving the actuators based on the moving axes), command (execution one part of the program), cycle (execution of one cycle), and automatic (the cycle repeats continuously).

While choosing the new controller, it was a critical condition, that the controller must have all original (and relevant) features, and if possible, it should be easy to use, and allow further improvements. These needs are all met by a modular PLC (with an amplifier stage). PLCs are wide-spread in industries, they are reliable, freely re-programmable, and physically meet all requirements set by an industrial environment.

4.2. Amplifier stage

Some controllers are unable to drive loads that they control, due to their construction. In such cases, a separate amplifier stage needs to be used, which can also fulfill other roles, such as separating incoming cables into wires within the device itself or provide additional protection by galvanic separation. During

my project, such a device was at my disposal. Its main components are the 12 TIP120 NPN darlington transistors, which, using the output signal of the PLCs are able to provide the necessary performance to the electropneumatic valves. The device has its own separate power supply. The transistors are cooled by a 12 [V] fan, driven by a "7812" voltage regulator IC. The manipulator's cables can be connected to the device by the connectors placed on the front face of it.

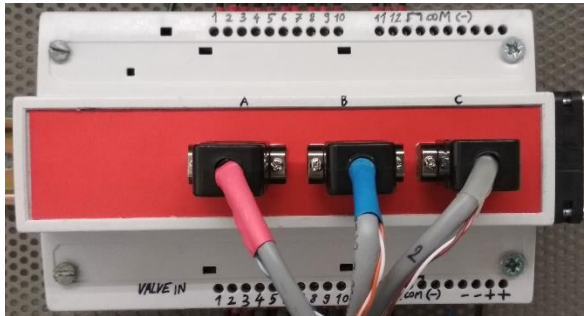


Figure 4. Amplifier stage device

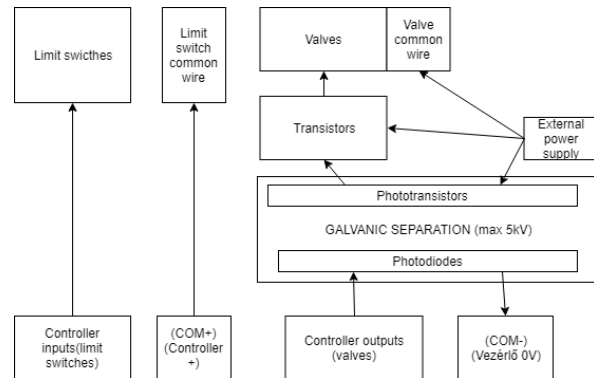


Figure 5. Amplifier's block diagram

The galvanic separation was later added in the form of 12 TLV-817 optocouplers, which offer complete galvanic separation up to voltages as high as 5[kV]. As the amplifier stage supports a wide range of controllers, initial tests were carried out using an Arduino Nano open source controller. Its low cost and ease of use make it ideal as an early testing device. The amplifier stage is usable both at the 5[V] output voltage of the Arduino, and the 24 [V] signals sent by the PLC. No other peripherals were used during this test, the manipulator executed the simple sequential program without error.

5. Final controller

The used device is a Schneider Electric Modicon M340. This modular PLC's 32 inputs and outputs (64 I/O total) can serve not only the following program's needs, but also enable us to connect additional devices, like pushbuttons or indicator lights, but may also pave the way to further improvements. The PLC has a separate power supply, connected via the rack.

The earlier mapped connections help during the programming. In the PLC program, the amplifier's inputs and outputs must be assigned to the variables found in the PLC program. In the program, sequential programming was used. During programming, it must be considered that at any time, only eight points from the manipulator's work area can be reached.

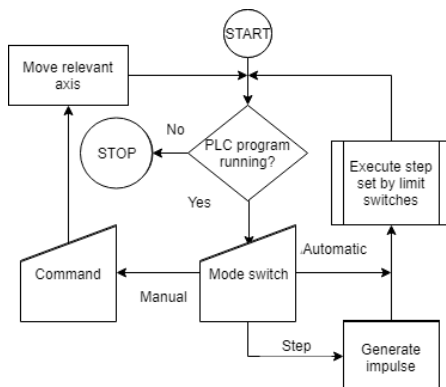


Figure 6. Simplified flowchart of the PLC program

The PLC program also contains the variables necessary for the different modes, and also sections responsible for communication with the HMI. After activating the main switch on the HMI, we can choose from three functions. In automatic, the movements repeat continuously, in manual-step mode, the manipulator only executes the next step of the program (the necessary impulse signal is created by

a TP timer). These two modes can be switched between freely, the program remembers the last executed step. In manual mode, the actuators can be operated separately. Upon deactivating the main switch, all actuators and internal variables are reset.

6. HMI

A Schneider Electric Magelis touchscreen HMI was used, programmed with Vijeo Designer. The HMI's interface consists of various pushbuttons that move separate axes or select modes. In the upper right corner of the interface, a progress bar showing the current step can be seen, with a model right under it, that visualizes the manipulator's position in real time, serving as visual feedback. With the addition of the HMI, the control system becomes complete.

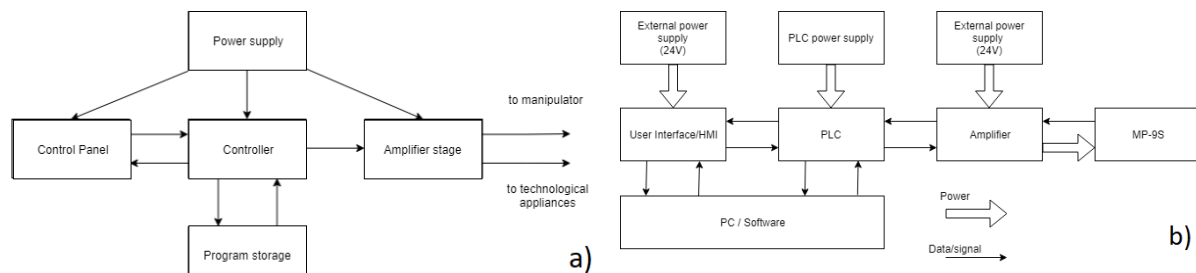


Figure 7. Block diagrams of the control system (original and new)

7. Conclusion

During this project, the restoration of the introduced MP-9S manipulator, and some steps ensuring its ease of use were completed. Its missing controller and user interface were replaced by up-to-date devices. During the project, most guidelines were successfully followed, the restored manipulator has retained all of its past functions, and even received new functionalities, thanks to its modern controller. To summarise, the restoration was a success, the previously non-functional device is now able to do material handling tasks and may also serve as a basis of the additional projects, such as a new gripper design.

Acknowledgment

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