Design and Novel Control Solution for a Modular Mechatronic Demonstrator with Video Feedback Used In Research and Education

Cristian MOLDOVAN, Valentin CIUPE, Valer DOLGA,
Erwin-Christian LOVASZ, Inocentiu MANIU
Universitatea Politehnica Timisoara, Facultatea de Mecanica, Departamentul de Mecatronica

ABSTRACT

This paper deals with design solutions for a modular mechatronic demonstrator with video feedback used in research and education. The Demonstrator allows the testing of control algorithms on various mechanical structures with multiple degrees of freedom (DOF). Although simple in mechanical design, our setup offers a large number of possibilities both in research and education. It is our aim, with this demonstrator to test model based and also model free control strategies comparable to human behaviour. For this paper we will construct a 2 DOF arm as the mechanical structure to be controlled. Our hypothesis is that a human does not require knowledge on its arm kinematics in order to perform tasks, thus we present in this paper an approach on determining the arm configuration to reach a target point without knowing the arm's elements lengths.

Keywords: mechatronics design, robotics, kinematic free positioning, machine vision.

1. INTRODUCTION

The starting point of this research is the insight that applications of mechatronic and robotic systems are becoming increasingly spread in the modern world. There is a shift and extension in focus from the "classic" industrial applications towards the use of robotic and mechatronic systems in not very well structured environments such as at home or in open spaces, as consequence, systems become increasingly sophisticated and control strategies must be adapted accordingly. Two impressive examples of highly sophisticated robotic systems that use state of the art mechanical and control systems are the DLR HaSy[1] and DLR C-Runner[2] and although they do not use visual feedback, at some point this can be included in the structure, both use classical Control to drive the system. In paper [3] a research group from Uni Udine presents a number of algorithms that could be used in conjunction with trajectory and path planning, and in [4] the same group presents aspects regarding the design of a robotic vision system.

Due to recent advances in artificial intelligence and computation power, there can be seen also a shift from model based towards model free controllers. In [5] the authors demonstrate a novel concept for kinematic-free control of a robot arm. It implements an encoderless robot controller that does not rely on any joint angle information or estimation and does not require any prior knowledge about the robot kinematics or dynamics. The approach works by generating actuation primitives and perceiving their effect on the robot's end-effector using an external camera, thereby building a local kinodynamic model of the robot. The experiments with this proof-of-concept controller show that it can successfully control the position of the robot. Although this proposal is similar to the Visual Servoing [6][7] approach as system architecture, especially the use of exteroception (external sensing - e.g. a camera) in order to observe the robot's motion, they are also different in the way information is processed. For visual servoing, camera information is used to calculate the desired velocity of the end-effector and then sent to a conventional velocity controller that still uses the joint encoders to execute the motion [6], [7].

Having such a great variety of possibilities for research we propose a modular mechatronic demonstrator as a test-bed for the control algorithms that we develop.

2. SYSTEM DESIGN

The main function of the proposed Mechatronic demonstrator is to be a platform for research and education in the areas of robotics, machine vision and artificial intelligence. To achieve this goal and in the same time to have great flexibility in the choice of the mechanical structures to be controlled, we propose a modular structure. A conceptual diagram is presented in Fig.1 with two variants, one in the horizontal plane designated Fig.1a and one in the vertical plane Fig. 1b.

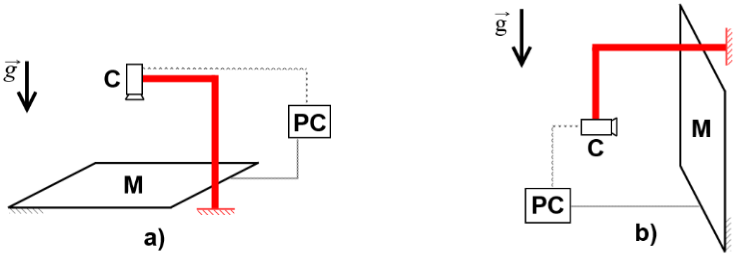


Figure.1 Mechatronic demonstrator conceptual diagram. (a – horizontal and b – vertical setup)

Because we want feedback control of the mechatronic system, the sensors used are of two types, proprioceptive sensors the ones built-in the servos and exteroceptive like the video sensor.

In Fig.1 there can be identified the following elements:

- "PC" in charge of image processing and inferring information such as Tool Centre Point (TCP) position, distance to target position, geometrical configuration of the system. The second function of the PC is to command the servos such that the goal is achieved, for example, the TCP should reach a goal position. In order to achieve this, the PC must also execute specific algorithms.
- "C" camera or video sensor has the function to take data about the environment and to deliver it to the "PC" for further processing in order to obtain useful information. In our case we used a Lenovo B920 video camera
- "M" is the mechanical system and also the modular part of the demonstrator. This part is conceived to be change-able and may be a robotic manipulator arm in various configurations to be controlled depending on the situation. It encompasses the servos with proprioceptive sensing capabilities. For the 2 DOF arm proposed in this paper we use 2 Dynamixel RX24F servos with an angular resolution of 0.29 degrees, rotational speed of 126 rpm and stall torque 2.6 Nm (at 12V, 2.4A) [8].
- "g" is the direction of gravitational field acting on the system. It is important because, when using passive joints, gravity direction has to be taken into consideration

As stated before, the modular part of the Mechatronic demonstrator is "M" which can be materialized through various structures. In Fig.2 and Fig.3 are presented structures with 2 DOF suitable for the horizontal and vertical position respectively.

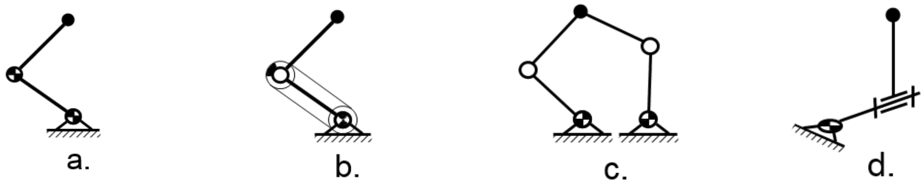


Figure 2 Mechanical structures in the horizontal plane setup

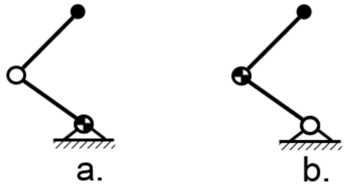


Figure 3 Mechanical structures in the vertical plane setup

The solution in Fig.2a is a serial manipulator with both joints actuated. By convention we mark the actuated joints as crossed and the TCP as a black dot at the end of the arm. In Fig.2b the arm has both actuators mounted on the base, motion being transmitted to the second joint through a wire or belt mechanism (ideally with transmission ratio of 1). Although mechanism a and b are similar, the control law is different and has to be determined separately. One future task is to develop a general control algorithm based on machine learning for the positioning of the TCP. In Fig.2c is used a five-bar linkage actuated at the fixed joints.

In comparison to all the mechanisms presented, the mechanism in Fig. 2d has only one actuated joint, the second joint being passive. This structure represents a rotary inverted pendulum, similar structures being developed by Quanser [9]

In the vertical setup presented in Fig. 3 we propose inverted pendulum type of structures with only one actuated joint. In Fig.3a the actuated joint is at the base and in Fig.3b the base joint is free, actuation being only on the second joint, thus resulting in an acrobat type of inverted pendulum studied extensively in the Acrobot project [10]

The presented structures are only some examples of structures that can be adapted to the mechatronic demonstrator, one way to generate other possibilities being the increase in the number of joints. Thus we can conclude that the demonstrator can provide great possibilities for research and education.

For this paper we propose a study on the configuration presented in Fig.2a and an objective to position the TCP without knowing the elements length of the 2DOF arm.

3. MECHANICAL SUB-SYSTEM DESIGN FOR THE SERIAL 2DOF ARM

For the scope of this study we designed a serial 2DOF robotic arm based on the kinematic structure presented in Fig.2a as a module for the Mechatronic demonstrator. For this we used CREO 5.0 CAD software, the resulting CAD model being shown in Fig. 4. For the manufacturing of the custom parts, a 3D printer was used – Symme3D.

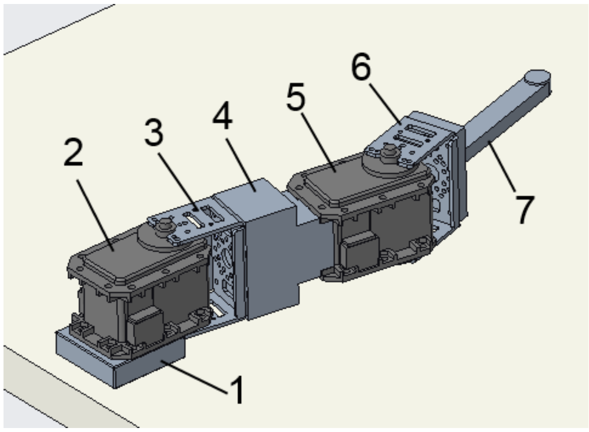


Fig. 4 CREO CAD model of the 2DOF arm

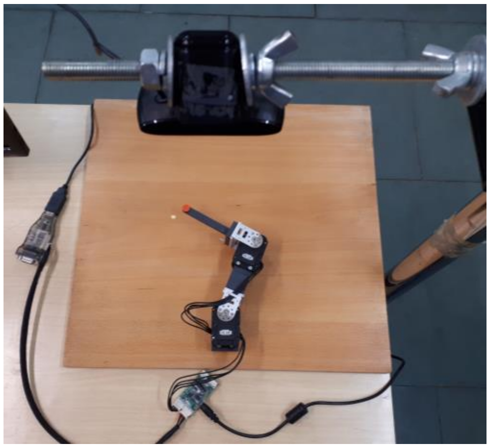


Fig.5 The obtained Mechatronic demonstrator

The arm is mounted on an exchangeable plate. The other components used are listed as follows:

1. custom part used to mount servo 2 on the exchangeable plate
2. First Dynamixel RX24F servo
3. Standard Mounting bracket provided by Dynamixel
4. custom part used to mount the second servo in the structure
5. Second Dynamixel RX24F servo
6. Standard Mounting bracket provided by Dynamixel
7. custom part designed to be the final element of the arm.

In Fig.5 is presented the final result, the 2 DOF arm integrated in the Mechatronic demonstrator together with the overlooking Video Sensor.

4. CONTROL STRATEGY

The control strategy implemented for our 2 DOF arm is different than the well-established kinematic based approaches. Our starting assumptions are that the robot does not have information on the element lengths, the only information from the environment being:

1. current position $P_C\left(x_{P_C}, y_{P_C}\right)$ of the TCP in the image
2. goal position $P_G\left(x_{P_G}, y_{P_G}\right)$ in the image
3. position of the fixed joint $O(x_O, y_O)$, called origin, determined in the image
4. angular values from the servo joints θ_1, θ_2

The information regarding the positions of the points is extracted from the image, angular values of the arm's elements are extracted from the servo joints, tough they could also be extracted from the image.

The objective for the robotic arm is to reach the goal point P_G from any starting position. A graphic representation of the problem to solve is represented in Fig. 6.

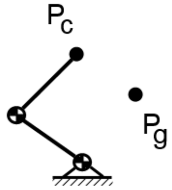


Fig.6 Simple positioning problem

We impose a coordinate system in the upper-left corner of the image. To solve this positioning problem we propose a two-step approach, in the first step, the robot moves through the workspace while for every considered position there is recorded the following data:

- x coordinate of the TCP in the current position in the image
- y coordinate of the TCP in the current position in the image
- θ_1 angle value in the current position for fixed joint
- θ_2 angle value in the current position for the second joint

The table can be generated either by specifying the angular step for each servo or by feeding them random values. One tuple example can be the following (Table 1)

Table 1 Recorded tuple example

x	y	θ_1	θ_2
144	342	284	782

We call this the "learning" phase, where the robot explores its workspace. In the learning phase the robot can store a number of n tuples with the correspondence between position of the TCP and angular configuration of the 2 DOF arm

In the second step, the robot has to position its TCP precisely, respecting an imposed threshold, at the goal position. The goal position can be specified as input from the keyboard, or through clicking on the image and recording the goal coordinates, obtaining point $P_G\left(x_{P_G}, y_{P_G}\right)$.

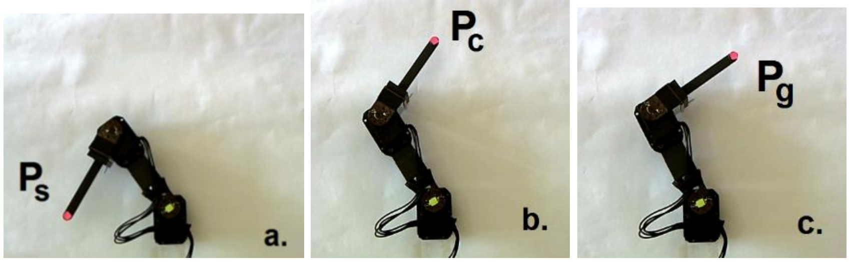


Fig. 7 Motion sequence of 2DOF arm from start to goal position

The robot starts in a random configuration – Fig.7a, then the controller performs a 1-Nearest Neighbours search in the tuple table. The search is conducted to find the nearest learned point to the goal point P_G based on the (x,y) coordinates. When a solution is found, the controller reads the corresponding (θ_1, θ_2) values from the table and moves the arm in that configuration. We designate this position as $P_C\left(x_{P_C}, y_{P_C}\right)$ shown in Fig.7b, this point being close to the goal point. Now we need to move the TCP to the goal location – Fig.7c, thus we propose the following algorithm based on the schema in Fig.8 where the controller imposes a rotation about joint A with $\Delta\theta_1$ and a second rotation about joint O with $\Delta\theta_2$.

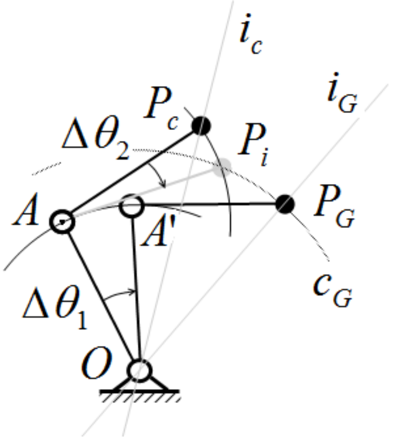


Fig.8 Transition schema for the 2DOF arm from the current position to the final position

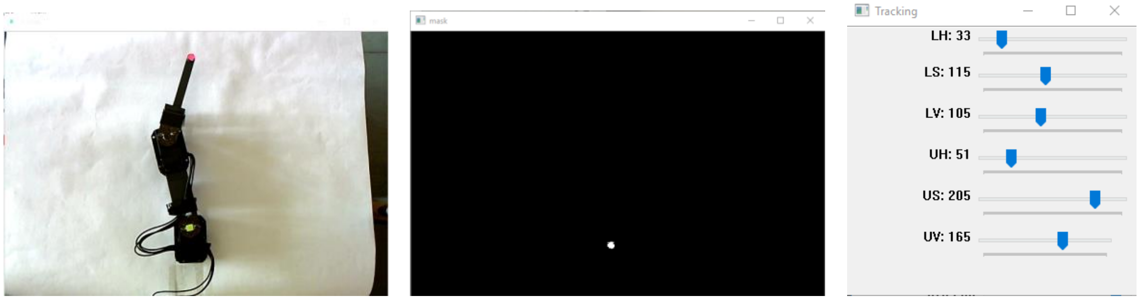
To determine the exact values of rotation, we proceed as follows, the current configuration OAP_c is known, $P_C\left(x_{P_C}, y_{P_C}\right)$ and the corresponding (θ_1, θ_2) are read from the n-tuple table. We also determine the current position of the origin O in the image using image processing library OpenCV and Python from the image. The point $O(x_O, y_O)$ coordinates are extracted from the image as shown in Fig.9. On the first joint O we positioned a yellow marker, and constructed a procedure to track the marker in the image, specifying that the contour area should be greater than a threshold value in order to suppress noise. We will be using the same procedure to determine the position of the TCP, but with other color settings since the color of the TCP is red.

With the coordinates $P_C\left(x_{P_C}, y_{P_C}\right)$ and $O(x_O, y_O)$ line i_c can be drawn and the distance between the two points computed using (1)

$$OP_C = \sqrt{\left(x_O - x_{P_C}\right)^2 + \left(y_O - y_{P_C}\right)^2} \tag{1}$$

Similarly we compute the distance from $P_G\left(x_{P_G}, y_{P_G}\right)$ to $O(x_O, y_O)$ using (2)

$$OP_G = \sqrt{\left(x_O - x_{P_G}\right)^2 + \left(y_O - y_{P_G}\right)^2} \tag{2}$$



LH: 33
LS: 115
LV: 105
UH: 51
US: 205
UV: 165

Fig. 9. Determining the position of the marker in the image

Since the two points are relatively close to each other, the geometric aberrations in the image are neglected.

In the next step we compare the lengths OP_G with OP_C , if OP_C is bigger than OP_G we reduce incrementally the length of OP_C until it is equal within a threshold to OP_G by actuating joint A; similarly the other way. To actually perform this action, OP_C is computed at each incremental motion from the image in a similar manner to the procedure presented in Fig.9. At the end of this step, the arm is in intermediary position P_i and on circle c_G .

To reach P_G we maintain joint A unactuated and actuate only joint O incrementally, permanently measuring the Euclidean distance between the TCP and the target position P_G in the image.

The procedure stops when the TCP is positioned over the target position within a specified threshold.

1. CONCLUSION

We have presented our work on the development of a modular mechatronic demonstrator that uses video feedback. The proposed demonstrator can adopt many mechanical structures to be controlled using either classical or novel control approaches. For this paper we developed a simple 2 DOF robotic arm. A novel strategy was developed to position the TCP, where the kinematic models of the arm, especially the elements lengths were not specified. The strategy relies on visual information on the arm's TCP and fixed joint position based on markers and also on element's angle values from the servos. Finally we managed to position the TCP within a specified threshold limit to the goal position.

ACKNOWLEDGMENT

This work was supported by research grant GNaC2018 - ARUT, no. 1364/01.02.2019, financed by Politehnica University of Timisoara

REFERENCES

[1] M. Grebenstein, A. Albu-Schäffer, "The DLR Hand Arm System", IEEE International Conference on Robotics and Automation, Shanghai, China, 2011

[2] F. Loeffl, A. Werner, A. Albu-Schäffer et al., "The DLR C-Runner: Concept, Design and Experiments", IEEE-RAS 16th International Conference on Humanoid Robots, Cancun, Mexico, 2016

[3] A. Gasparetto, P. Boscariol, A. Lanzutti, R. Vidoni "Path Planning and Trajectory Planning Algorithms: A General Overview" Motion and Operation Planning of Robotic Systems. Mechanisms and Machine Science, vol 29. Springer, 2015 pp. 3-27.

[4] A. Biason, G. Boschetti, A. Gasparetto, A. Puppatti, V. Zanotto, “Design of a Robotic Vision System”, AMST’05 Advanced Manufacturing Systems and Technology, Springer, 2005

[5] P. Kormushev, Y. Demiris, D. G. Caldwell, “Kinematic-free position control of a 2-DOF planar robot arm”, 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Hamburg, 2015

[6] F. Chaumette, S. Hutchinson. Visual servo control, Part I: Basic approaches. IEEE Robotics and Automation Magazine, 13(4):82-90, Décembre 2006.

[7] F. Chaumette, S. Hutchinson. Visual Servo Control, Part II: Advanced Approaches. IEEE Robotics and Automation Magazine, 14(1):109-118, March 2007

[8] Dynamixel RX24F E-manual, http://emanual.robotis.com/docs/en/dxl /rx/rx-24f/ accessed 20.07.2019

[9] Rotary Inverted Pendulum, Quanser Website accessed 20.07.2019 www.quanser.com/products/rotary-inverted-pendulum/

[10] Scott C. Brown, Kevin M. Passino - Intelligent Control for an Acrobot, Journal of Intelligent and Robotic Systems, Volume 18, Issue 3, pp 209–248, March 1997