DEVELOPMENT OF A COLLABORATIVE ROBOT - VIETCOBOT

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Abstract: In this paper, the development progress of a collaborative robot is presented in industrial fields: namely Vietcobot. The cobot actuator is designed as an integrated joint of hollow style which is a key part of the cobot development. The optimization of force/torque sensor on cross beam structure is studied to make a better dynamic performmence that can apply to the cobot effectively. This sensor makes the cobot sensitive to its surrounding, especially to human. This design produces a cobot which is lighter, mobility and easy to handle. The scheme of the integrated development environment is built to connect to a simulation environment via API and control the cobot in realtime via Twincat Ethercat communication interface for critical tasks of this field. The kinematics of the cobot is examination, and a neural network dynamic controller is simulated to show the effectiveness of the online estimation of unknown nonlinear dynamics. The cobot control system is implemented which can interface to Industry 4.0 architecture in factory in the future applications.

Keywords: collaborative robot, joint actuator.

I. INTRODUCTION

Cobot, an abbreviation of collaborative robot, has been increasingly enriched thesedays. Today, cobots are not only revolutionising the manufacturing industry, they are also being used in conjunction with current technologies to innovate service industries that add real value and to our lives.

Traditional industrial robots are mainly used in large manufacturing industries such as automobiles, which tend to be large, long in installation and programming and expensive in price.

The previous large load and high rigidity industrial robots have not been adapted to the human-robot collaborative working environment. On the other hand, a security barrier is badly needed when working of industrial robots, and it show the highly ineffective safeguards. In the manufacturing fields, when the robot can cooperate with the human, many processes become more efficient [1].

Moreover, the big opportunities for robotic development are in fields that have not yet become automated with robots, such as lower-volume food production, lower-volume and more-complex assembly tasks, more customized welding. Low volume applications are the common thread because it’s in these areas where industrial robot integration was previously deemed too costly to adopt. But things have changed considerably by collaborative robots.

Collaborative robots are lightweight and adaptable; so, this technology can meet the demands in the general manufacturing and the small and medium-sized enterprises (SMEs) totally [2], [3]. There are several reasons for the rapid development of collaborative robots [1]:

1. Industrial robots have already relatively saturated in the automobile industry and need other challenges: electronics, pharmacy, food and other industries.

2. Traditional industrial robots designed for the automotive industry have been imported into general manufacturing automation, but the results show sign of less effectiveness as expected.

3. Human-robot collaboration is more efficient and safer.

4. Collaborative robots can aplied to the fields which is out side of the factory such as services, multimedia, medical surgery, educations.

5. Low-price collaborative robots will activate the SMEs market.

In this paper, the development progress of 6-dof cobot is presented: joint actuator integrating, force/torque sensor designing, cobot mechanical structure developing, a dynamic controller designing. The modelling and simulations are performed during the design process to show the posibility from theory proposals to the practice which can be applied to build the initial Vietcobot platform for the further comprehensive development. In addition, an eco-system of cobot is considered in Industry 4.0 architechture as well.

II. COLLABORATIVE ROBOT DESIGN

A. Joint Actuator Design

The key point of the cobot is the integrated robot joint design which function as an actuator. The actuator is composed of a hollow harmonic driver, a hollow framless motor, a hollow shaft, a brack, a hollow encoder. These make a hollow line from the end-effector to the base of the cobot, and the joints can be installed and controlled easily without any professional traning. First, cobot joints embody different reflective loads and inertia in accordance with position. Utilizing a gear reduction

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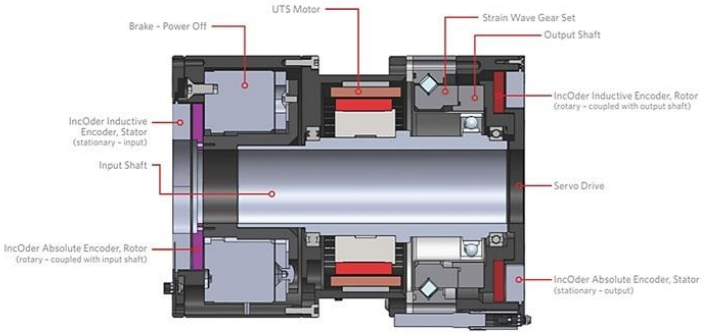
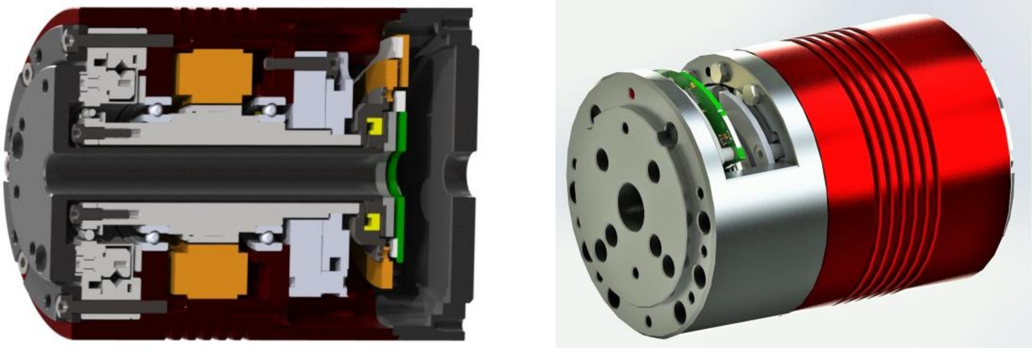
augments output torque, mitigates the servo tuning consequences of a large change in inertia with position, and permits the utilization of smaller motors that require lower power and promote efficiency. The motor drive was integrated at the end of the joint, this design is convenient for the wiring, on the other hand, the power of the busbar is low and safe. The joint also comprises an encoder that provides high resolution and precision on the output, in addition to a medium-resolution encoder on the rear of the motor. This assembly comprises an electromechanical brake for holding when the power is off. The reference design of actuator is shown in Fig. 1(a) and the modified joint actuator for Vietcobot, in Fig. 1(b).



(a) Reference design



(b) Vietcobot design

Figure 1. Joint actuator design

The function block of the joint actuator is shown in Fig. 2. Two printed circuit boards are used for the total joint actuator: a main control board and an encoder board. The reference design of motor driver is refered to [4] with several modifiers for Vietcobot. Main control board includes a motor driver based on STM32H7 Dual-Core MCU and a DRV8323 Bridge Driver which drives 6 N-channel TPH2R506PL 30V MOSFETs with 175ºC temperature limit, refers to Fig. 3-(1). The bottom PCB has Ethercat intereface for cobot controller communications, refers to Fig. 3-(2). This board is responsible for running the low-level motor commutation and PID controllers for separate position, velocity, and torque control at 10 kHz. The encoder board is a 20-bit encoder reader which senses the change in magnetic field from a diametrically polarized magnet ring connected which is from RLS supplier (Fig. 4).

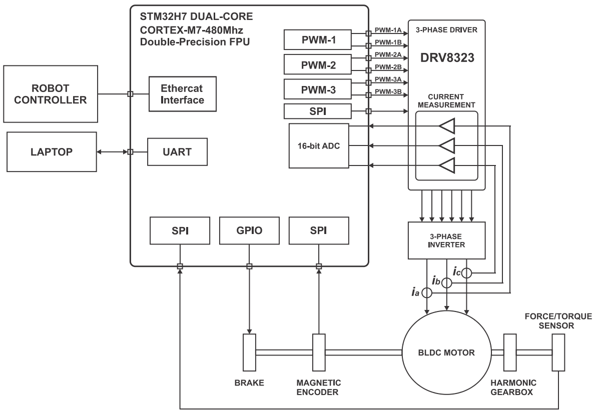
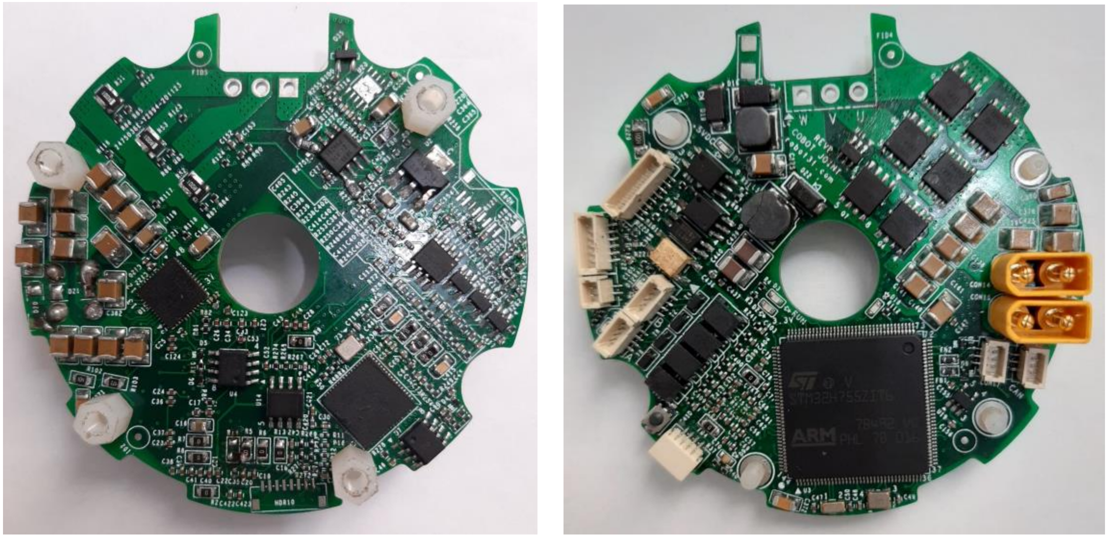


Figure 2. Function block of the joint actuator driver



(a) Servo driver (top side) *(b) MCU with Ethercat communications interface (bottom side)*

Figure 3. Joint actuator driver

Figure 4. Integrated magnetic encoder from RLS [5]

The motor controller is a cascaded style position, velocity and current control loop, as per the diagram below (Fig. 5). When the control mode is set to position control, the whole loop runs. When running in velocity control mode, the position control part is removed and the velocity command is fed directly in to the second stage input. In torque control mode, only the current controller is used. Each stage of the control loop is a variation on a PID controller with the following algorithms:

The position controller is a P loop with a single proportional gain:

pos_error = pos_setpoint - pos_feedback

vel_cmd = pos_error * pos_gain + vel_feedforward

The velocity controller is a PI loop:

vel_error = vel_cmd – vel_feedback

*current_integral += vel_error * vel_integrator_gain*

*current_cmd = vel_error * vel_gain + current_integral + current_feedforward*

The current controller is a PI loop:

current_error = current_cmd – current_fb

*voltage_integral += current_error * current_integrator_gain*

*voltage_cmd = current_error * current_gain + voltage_integral (+ voltage_feedforward when we have motor model)*

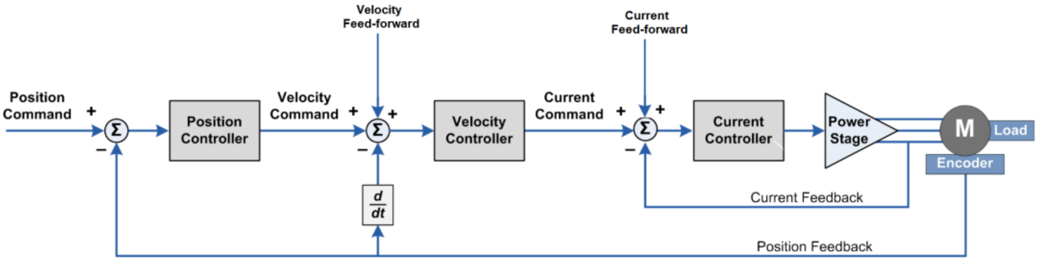


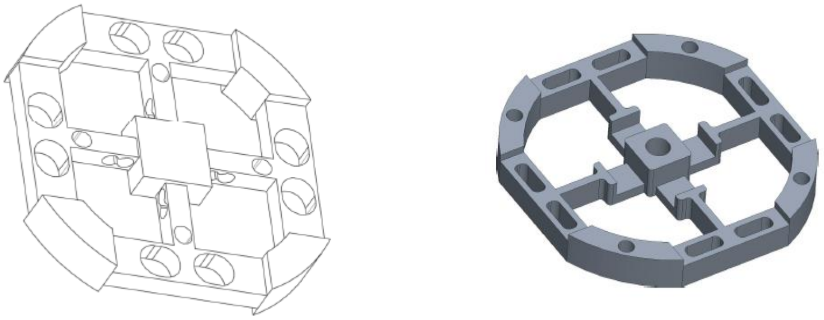
Figure 5: PID control scheme of BLDC motor

B. Force/Torque Sensor Design for Joint Actuator

The six-axis F/T sensor is one of the most important sensors of the robot which can simultaneously detect the full information of three-dimensional space. When F/T sensor is used to sense the collision between robot and environment, it is necessary to detect the size and direction of the dynamic collision force. As a detecting element in the force reflection control system, it should respond quickly to the load, namely, having excellent dynamic characteristics [6].

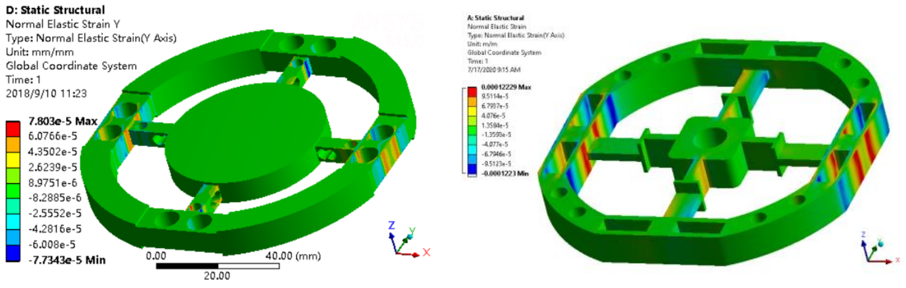
The performance of the strain sensor depends mainly on the design of elastomer. The core requirements of sensor elastomer design are high sensitivity, good dynamic performance and uncoupled output. However, the contradiction between sensitivity and dynamic performance is always a difficulty in elastomer design [7]. That is to say, the lager the deformation of the place pasted strain gauges, the better sensitive, and the width and the height of the main beam should as small as possible. Meanwhile, the smaller the sizes, the worse dynamic performance of the sensor, which creates a contradiction between static performance and dynamic performance

There are several researches on elastomer [7], [8], [9], [10]. The design of crossbeam elastomer is shown in Fig. 6. It comprises of four crossbeams, four compliant beams, a central platform, and four rims, which are characterized by a compliant beam flexible link at the connection between a crossbeam and two rims. The sensor of this design is a modification of the work [7] for better performance which can be applied to Vietcobot. The design is focused on crossbeam elastomer that show high symmetry, compact structure, large rigidity, easy to machine, simplified mechanical model due to a flexible link. The simulation of the deform under the force-torque changes which is compared to the model of Yong Wang [7] are shown in Fig.7.

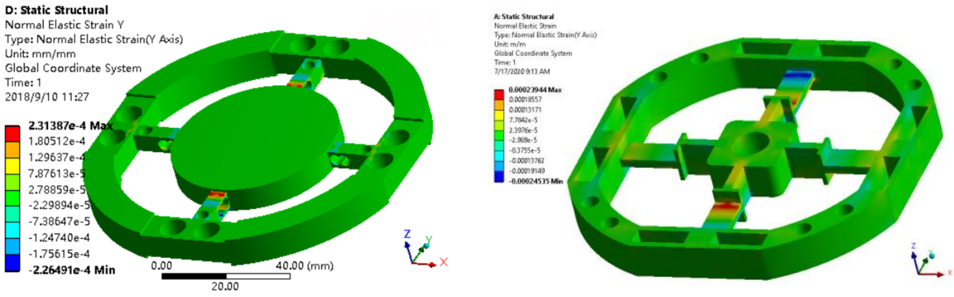


(a) The design of Young Wang (2018) [7] *(b) Design for Vietcobot.*

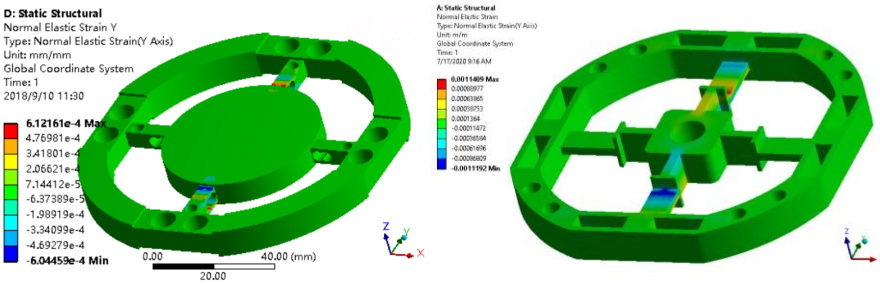
Figure 6: The design of crossbeam elastomer



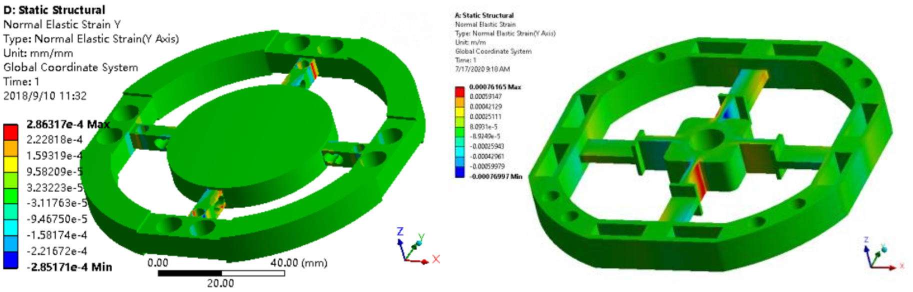
(a) Strain under $F_X = 50N$



(b) Strain under $F_Z = 50N$



(c) Strain under $M_X = 2.5Nm$



(d) Strain under $M_Z = 2.5Nm$

Figure 7. Simulation and compared between the design elastomer with Young Wang (2018)

Table I. The simulation results of the design elastomer on sensitive and dynamics factors

No.	Model	$F_X = 50N$	$F_Z = 50N$	$M_X = 2.5Nm$	$M_Z = 2.5Nm$
1	Yong Wang	7.803e-5	2.313e-4	6.122e-4	2.863e-4
2	Design	1.223e-4	2.394e-4	1.141e-3	7.617e-4

Mode	Mode Shape	Yong Wang (Hz)	Design (Hz)
1	Translation along X-axis	5910.9	4413.6
2	Translation along Y-axis	5911.1	4416.1
3	Translation along Z-axis	3742.5	3036.2
4	Rotation around X-axis	11185.0	6983.1
5	Rotation around Y-axis	11185.0	6987.9
6	Rotation around Z-axis	11107.0	7388.7

Figure 8. DAQ board for sensor's data acquisition with Ethercat communication

The acquisition of the dynamic characteristics of the six-axis F/T sensor is based on the dynamic calibration experiment. The dynamic calibration of a six-axis F/T sensor is to obtain the relationship between the input and output of the sensor when performing varied six-axis forces. This study will be presented in another research.

C. Cobot Structure Design

The structure model of Vietcobot is shown in Fig. 9. The 7 frames $O_iX_1Y_1Z_1$ (i=0-6) are represented with parameter. θ_i, d_i, b_i, a_i, α_i represent the link rotation, link offset, shift, link length, and link twist respectively. The Extended Denavit and Hartenberg parameters of the cobot is given in Table II.

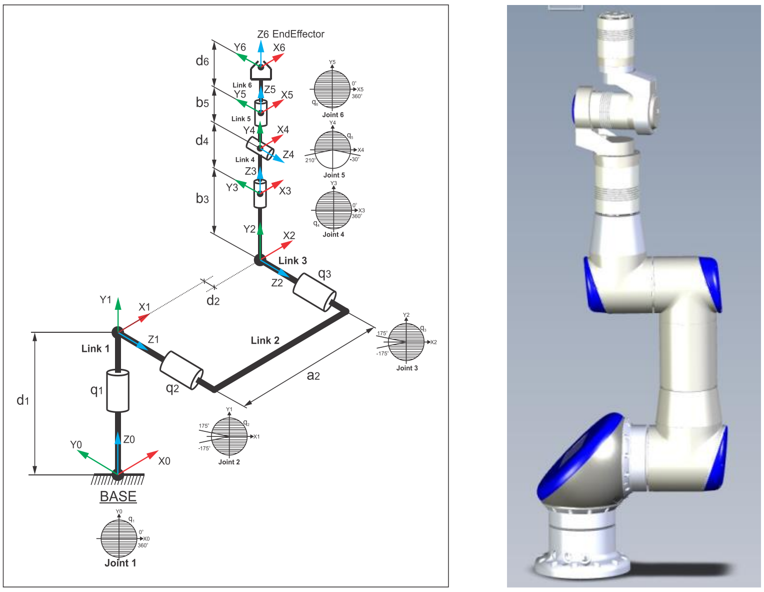


Figure 9. Structure model of the Vietcobot and the 3D design

TABLE II. D-H Parameters

Frame	Theta (rad)	di (m)	bi (m)	ai (m)	alpha (rad)
1	0	0.130	0	0	Pi/2
2	0	0.032	0	0.396	0
3	0	0	0.200	0	-Pi/2
4	0	0.650	0	0	Pi/2
5	0	0	0.141	0	-Pi/2
6	0	0.100	0	0	0

It is assumed that the joint space coordinate is described by the vector $Q=[q_1,q_2,q_3,q_4,q_5,q_6]^T$. The relative position matrices $A_{i-1,i}$ is the following:

$$A_{i-1,i} = ROT(z_{i-1},\theta_i)TRAS(z_{i-1},d_i)TRAS(x_{i-1},a_i)TRAS(y_{i-1},b_i)ROT(x_{i-1},\alpha_i)$$

$$A_{i-1,i} = \left[\begin{array}{ccc|c} \cos(\theta+q_i) & -\sin(\theta+q_i)\cos(\alpha_i) & \sin(\theta+q_i)\sin(\alpha_i) & a_i\cos(\theta+q_i)-b_i\sin(\theta+q_i) \\ \sin(\theta+q_i) & \cos(\theta+q_i)\cos(\alpha_i) & -\cos(\theta+q_i)\sin(\alpha_i) & a_i\sin(\theta+q_i)+b_i\cos(\theta+q_i) \\ 0 & \sin(\alpha_i) & \cos(\alpha_i) & d_i \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

and the matrices that describe the relative position matrices of the links are

$$A_{0,1}, A_{1,2}, A_{2,3}, A_{3,4}, A_{4,5}, A_{5,6}$$

The angular and linear velocity of a body with respect to a reference frame can be represented by the velocity matrix W:

$$W = \left[\begin{array}{ccc|c} 0 & -\omega_z & \omega_y & v_x \\ \omega_z & 0 & -\omega_x & v_y \\ -\omega_y & \omega_x & 0 & v_z \\ \hline 0 & 0 & 0 & 0 \end{array}\right] = \left[\begin{array}{c|c} \underline{\omega} & v_0 \\ \hline 0\ 0\ 0 & 0 \end{array}\right]$$

where $\underline{\omega}$ indicates the angular velocity of the body and v_0 is the velocity of the point, considered belonging to the body (called the pole) that in a considered instant is passingthrough the origin of the reference frame.

Similarly, the relative acceleration of a body with respect to a reference frame may be indicated by the acceleration matrix **H**, as follows:

$$H = \dot{W} + W^2 = \left[\begin{array}{ccc:c} & G & & a_0 \\ \hdashline 0 & 0 & 0 & 0 \end{array}\right]$$

where the 3x3 submatrix ***G*** is given by: $G = \dot{\underline{\omega}} + \omega^2$ and a_0 is the acceleration of the pole with respect to the reference frame.

Then a simple algorithm for them are developed for numerical applications with ease. The results of the kinematics paremeters are used for designing dynamics controllers in the next section.

Step 1: Declaration of the variables and the input data phase:

TABLE III. Data file of the cobot's parameters

Parameters	Data.csv
Number of Link	6
Link 1	
- Joint Type	…
- Denavit and Hartenberg parameters	…
- Mass of the first link	…
- Inertia moments jxx, jxy, jxz	…
- Inertia moments jyy, jyz	…
- Inertia moments jzz [kg.m^2]	…
- Center of Mass coordinates Xg, Yg, Zg	…
Link 2	
…	…
Link n-1	
…	…
Link n (End-Effector)	
…	…
External Action	
- Gravity components in BASE frame (0)	0 0 -9.8
- External forces + torques on End-effector	0 0 0 0 0 0

1. Input data describing the geometrical structure of the manipulator

- The number of links constituting the robot

- For each link (i):

- The joint type

- Five parameters to describe the position of the Frame (i), fixed on Link (i), with respect to the Frame (i-1), fixed on Link (i-1), according to an extension to Denavit and Hartenberg approach

2. Input data describing the dynamic parameters of the manipulator

- For each Link (i):

- The mass

- The six barycentral inertial moments

- The coordinates of the center of mass referred to the local Frame (i)

3. Input data describing the external actions on cobot

- The three components of gravity acceleration referred to the base frame

- The actions (the components of force and the components of torque) applied on the end-effector of the robot referred to the local frame of the gripper;

4. Input data describing the motions of the actuators

For each link (i) and for each instant: the relative position, speed and acceleration of Frame (i) with respect to Frame (i-1);

TABLE IV. Motion data file of the cobot's joints

Motion	Motion.csv
dt (Sampling time)	0.1
Point 1	
- Position, speed and acceleration joint 1	…
- Position, speed and acceleration joint 2	…
- Position, speed and acceleration joint 3	…
- Position, speed and acceleration joint 4	…
- Position, speed and acceleration joint 5	…
- Position, speed and acceleration joint 6	…
Point 2	
…	…
Point n-1	
…	…
Point n	
…	…

Step 2: Reads the joints motion (step 2), builds relative position matrices **A** (step 3) and the relative velocity and acceleration matrices by means **L** matrix (step 4)

- Evaluates the absolute position **M0** of each link (according to D-H. method) using the formula

$$M0_{0,i} = M0_{0,i-1} A_{i-1,i}$$

- Transforms the relative velocity and acceleration matrices from local to the absolute frame (0) (step 6-7)

$$W_{i-1,i(0)} = M0_{0,i-1} W_{i-1,i} M0_{0,i-1}^{-1}$$

$$H_{i-1,i(0)} = M0_{0,i-1} H_{i-1,i} M0_{0,i-1}^{-1}$$

- Evaluates the absolute speed of each link by summing the drag and the relative speed of each link (step 8)

$$W_{0,i} = W_{0,i-1} + W_{i-1,i(0)}$$

- Evaluates of the absolute acceleration of each link by means the Coriolis' theorem (step 9)

$$H_{0,i} = H_{0,i-1} + H_{i-1,i(0)} + 2W_{0,i-1} W_{i-1,i(0)}$$

For computer implementation, the kinematics algorithm consisting of a simple loop performing the following iterative operations, as shown in Fig. 10. In addition, the cobot development environment, Cobot IDE, is also built to evaluate the kinematics algorithm, matrix data structure implement, matrix transformation library, so on, as shown in Fig. 11. The results of the kinematics are used for the dynamics tracking controller design in the next topic such as adaptive control, sliding mode control, neural network control, robust control, etc. The Visual studio C# is used in this case to ensure the realtime control to the cobot via realtime Ethercat using Twincat interface in the future works. The overview of the simulation and control system is given in Fig. 11.

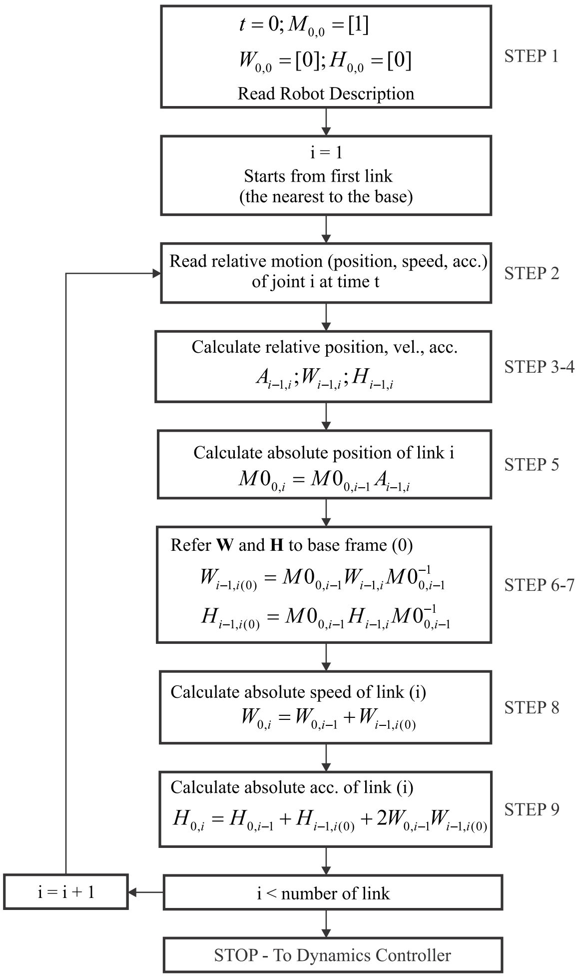
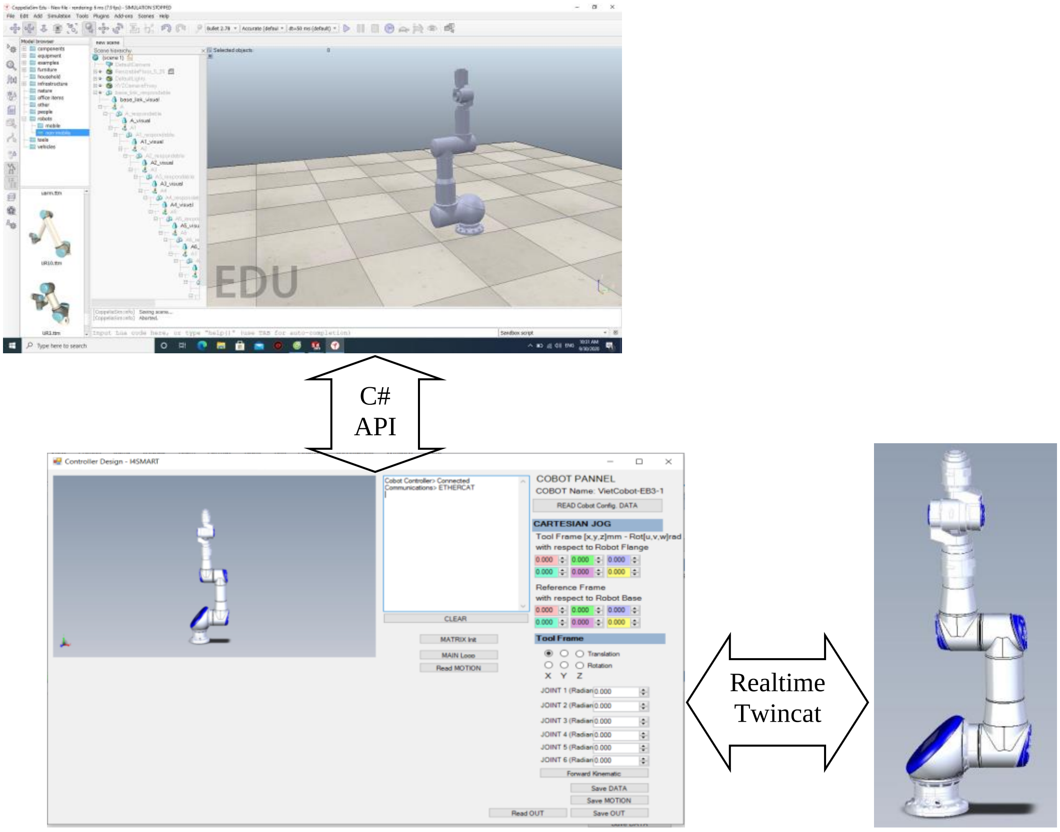


Figure 10. Simple kinematics algorithm for numerical computation



Cobot Controller> Connected
Communications> ETHERCAT

Figure 11. The Cobot IDE for simulation and realtime control in practice

III. DYNAMICS CONTROLLER DESIGN

Neural network, with their strong learning capability, have proven to be a suitable tool for controlling complex nonlinear dynamics system. The basic idea behind neural network-based control is to use a neural network estimator to identify the unknown nonlinear dynamics and compensate it. Also, the NeuralNetwork-based approach can deal with the control of nonlinear system that may not be linearly parameterizable, that required in the adaptive control.

In this study, a neural network controller is considered for the joint-space position control. The controller output is composed of a classical PID control and a neural network compensation term. The compensation term is used for online estimation of unknown nonlinear dynamics caused by parameter uncertainty and disturbances. The control scheme is capable of disturbance-rejection in the presence of unknown bounded disturbances [22]. This controller is designed based on [23] to show the ability of the simulation function in the cobot IDE. The proof of the neural network controller is presented in the work of [23]. The dynamics equation of the cobot as follows:

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + F + \tau_d = \tau_a \qquad (1)$$

where

q : generalized coordinate vector of the joint

$\dot{q}, \ddot{q}$: velocity and acceleration of each joint

$F = g(q) + \tau_f$: gravitational and friction force vector

τ_d : disturbance torque, τ_a : sum of all joint torques

Let us define the robot tracking error and its derivative as

$$e = q_d - q \, ; \dot{e} = \dot{q}_d - \dot{q}$$

and the filtered tracking error as $r = \dot{e} + ke$, where $k = k^T > 0$

From [23], *Gaussian functions* defined as

$$h_i(x) = \exp\left(\frac{-\left\| x - c_i \right\|^2}{\sigma_i^2} \right), i = 1, 2, .., n \qquad (2)$$

where

x is the input pattern to the neural network defined as

$$x = \left\{ e^T \quad r^T \quad q_d^T \quad \dot{q}_d^T \quad \ddot{q}_d^T \right\}$$

c_i is center, and σ_i is width, which are all chosen a priori and kept fixed throughout for simplicity. Therefore, only the weights W is adjustable during the learning process. The estimates of $\hat{\psi}$ is given by

$$\hat{\psi} = \hat{W}^T h(x) \qquad (3)$$

By choosing the control laws for (1) as [23]

$$\tau_a = k_p r + \hat{\psi} \qquad (4)$$

where the weight updating law for the neural network as

$$\dot{\hat{W}} = \beta h r^T - \mu \beta \left\| r \right\| \hat{W} \qquad (5)$$

where

$k > 0$: control gain

β : positive constants representing the learning rates of the neural network

μ : small positive design parameter

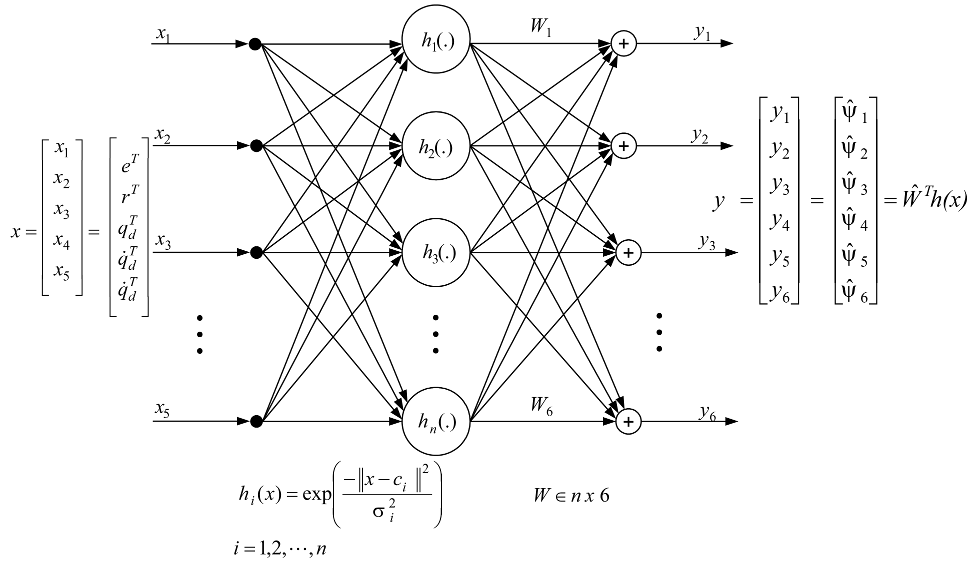


Figure 12. Neural network for the controller

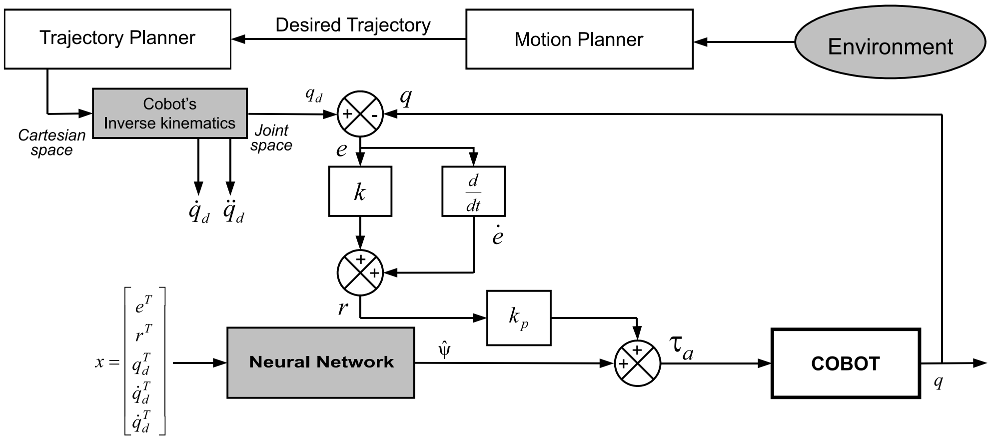


Figure 13. Neural network controller design

To verify the effectiveness of the controller, the simulations have been done with controller Eq. (4) using Cobot IDE in C# and Gnuplot 4. The reference trajectory are planned with sinusoid trajectory for joint 1 to joint 6 with the frequency of $0.8f, 0.9f, f, 1.1f, 1.2f$ and $1.3f$ $(F = 0.3125Hz)$ as shown in Fig. 14. The estimated value for the manipulator $\hat{\psi}$ is given in Figs. 16 and 17. The output of the Gaussian function for the controller is given in Fig. 18. The joint torque is shown in Fig. 19.

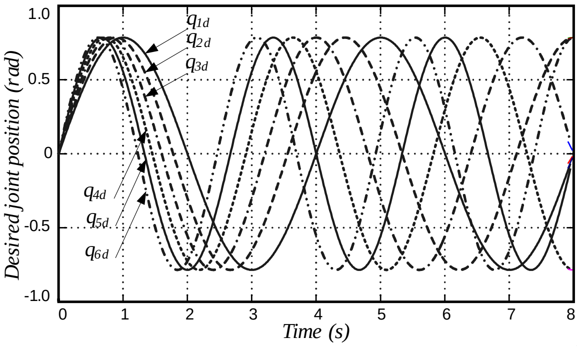


Figure 14. Joint reference trajectory

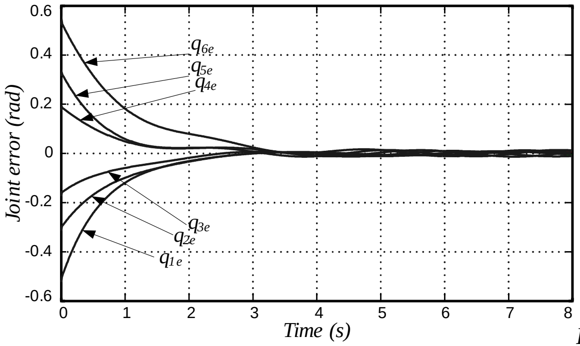


Figure 15. Joint position error

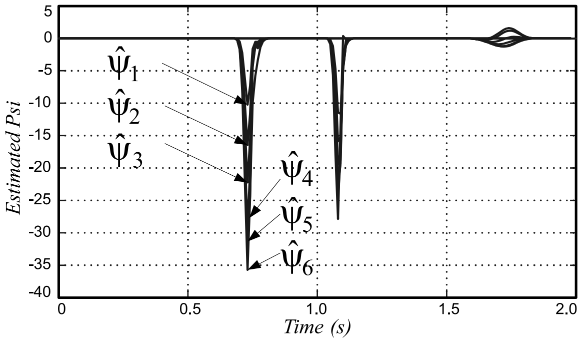


Figure 16. Estimated $\hat{\psi}$ of manipulator for 0-2s

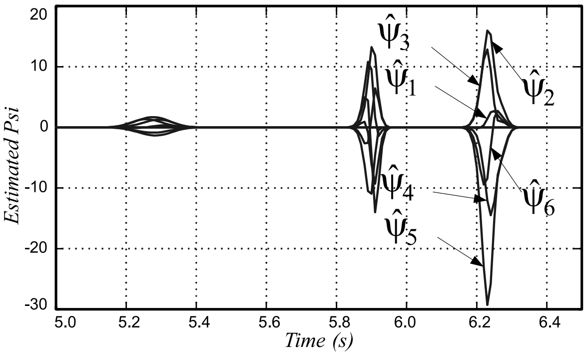


Figure 17. Estimated $\hat{\psi}$ of manipulator for 5-6.5s

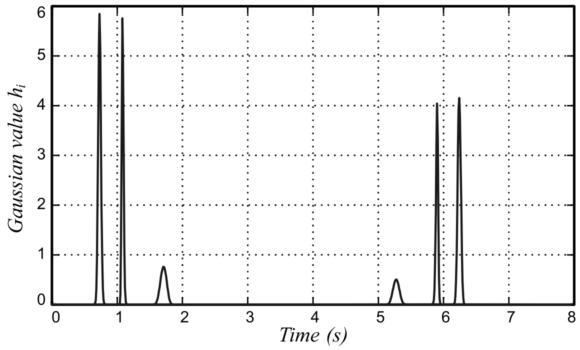


Figure 18. Gaussian value of hidden layer function

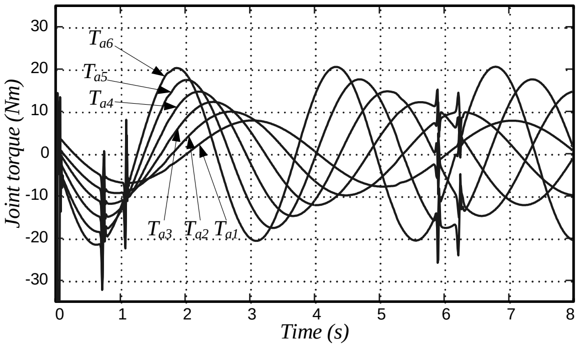


Figure 19. Joint torque τ_a

IV. CONTROL SYSTEM IMPLEMENTATION

The system brings the cobot platform to researchers and engineers for their applications and studies. The control system is PC-based control with master Ethercat interface, this configuration shows the best specification in fieldbus communication for robotics: simple, robust, flexible topology, affordability and realtime. The PC is developed with the functions as high-level control: dynamics controller algorithm, computer vision, collision detection, path planning for the cobot; and the actuators perform functions as low-level joint control with slave Ethercat interface. The diagram of the control system is shown in Fig. 6.1. The cobot integrated development environment (Cobot IDE) is developed using Visual Studio C# which is known a flexible environment for programming. The Cobot IDE interface to the actuators using Twincat2 from Beckhoff. So, all the controls and feedbacks on the cobot are performed via Ethercat communications in realtime. Many dynamic controllers can be designed and implemented such as adaptive control, sliding mode control, robust control to modern control such as neural network control, fuzzy control and AI technology as well.

What's more, the cobot IDE integrated 3DVision tool to make it possible for cobot vision which play an important role in cobots; for example, the cobot can detect 3D objects in the assembly lines for the bin-picking tasks in factories. The cobot and this tool become simple in hardware and software totally. In addition, the cobot is ready to cooperate other devices in manufacturing of Industrial 4.0. The IDE has API of OPC UA Client to connect to OPC UA Server (I/O Server) which is connected to the upper layer SCADA/HMI such as Alarm client, History client, Trends client. Their data are achieved from MES (Manufacturing Enterprise System). The cobot communications in Industry 4.0 architechture is shown in Fig. 20.

It can be seen the inpact of 5G on the cobot in factory automation on the Fig. 20. Mature 5G technology will enhance industrial automation effectively. Every automated industry will set up its own private 5G wireless network for addressing bandwidth needs and connecting industrial devices over the network. And the cobot with advanced features could only be managed with a mature 5G Local Area Network (LAN) [20]. Since mature 5G networks should be able to support the real-time control of hundreds of thousands of devices within every square kilometer, manufacturing has a dramatic potential to become more efficient and significantly increase production. Interestingly, implementing 5G in industrial automation will not require any significant alterations to the current infrastructure.

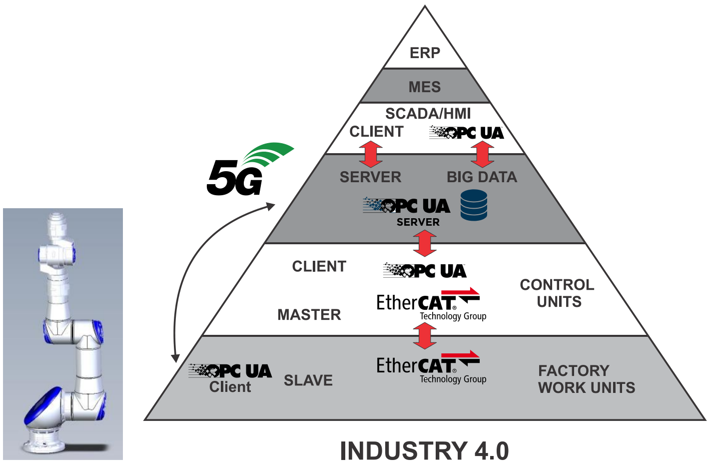


Figure 20. The cobot communications in Industry 4.0 architechture

V. CONCLUSIONS

This paper presents the research of the development of Vietcobot. The joint actuator is designed which is a combination of several engineering majors: joint actuator design, F/T sensor design, structure cobot design, cobot IDE implementation, and so on. With the joint actuator, this cobot has the advantages of the small structure, high reliability, small power consumption, easy to handle, and low price. These features make the cobot effective for broadly applying to many industries.

In addition, the structure model of the cobot is developed. The Extended Denavit and Hartenberg parameters is designed for deriving the kinematics of the cobot. The physical data, motion data, data structures, kinematics algorithm, dynamics controller development are defined for numerical computing on C# with ease. The results of the kinematics are used for dynamics controller design of neural network, to demonstrate simulation function of the tool cobot IDE. This tool can control the cobot via Ethercat interface in realtime as well. In addition, the control system of the cobot is considered in the context of Industry 4.0 for the future works.

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NGHIÊN CỨU PHÁT TRIỂN MỘT ROBOT CỘNG TÁC - VIETCOBOT

Tóm tắt: Bài báo này trình bày quá trình nghiên cứu phát triển một robot cộng tác dùng trong lĩnh vực công nghiệp, tên là Vietcobot. Cơ cấu chấp hành của cobot được thiết kế như là một khớp tích hợp kiểu trục rỗng là một bộ phận chính trong việc phát triển cobot. Nghiên cứu tối ưu hóa cảm biến lực bằng cấu trúc các thanh dầm giao nhau để có kết quả đáp ứng hiệu suất động học tốt hơn áp dụng được cho cobot một cách hiệu quả. Cảm biến này có tác dụng làm cho cobot nhạy cảm với môi trường xung quanh, đặc biệt là với con người. Thiết kế này tạo ra một cobot nhẹ hơn, dễ vận chuyển và dễ điều hành. Một môi trường phát triển cho cobot được xây dựng để kết nối với một phần mềm mô phỏng thông qua các giao tiếp API và thực hiện điều khiển cobot thông qua truyền thông Ethercat theo thời gian thực cho các nhiệm vụ thực nghiệm nghiêm ngặt trong lĩnh vực này. Động học của cobot được khảo sát, và một bộ điều khiển Neural network được mô phỏng tương ứng cho thấy sự hiệu quả của việc thiết kế bộ điều khiển ước lượng các thông số động lực học của cobot. Hệ thống điều khiển của cobot cũng được thực hiện có thể giao tiếp với kiến trúc Industrial 4.0 trong nhà máy cho cobot trong các ứng dụng tương lai.

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