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CONCATENATION OF THE MOVEMENTS OF THE MANIPULATOR AND THE CAMERA OF THE ROV

Alexandre Silva de Lima
Mechanical Engineering Program – PEM/COPPE/UFRJ
alexandre.silva.lima@gmail.com

Max Suell Dutra
Mechanical Engineering Program – PEM/COPPE/UFRJ
max@mecanica.coppe.ufrj.br

Luciano Santos Constantin Raptopoulos
Mechanical Engineering Program – PEM/COPPE/UFRJ
luciano@mecanica.coppe.ufrj.br

Fabrício Lopes e Silva
Mechanical Engineering Program – PEM/COPPE/UFRJ
fabricio@ufrj.br

Abstract. *Remote Operated vehicles (ROVs) are widely used in the world for submarine interventions in installation and maintenance of systems for oil exploration and production in deep water. This equipment is used for interventions in environments that do not allow divers to work. These vehicles are remotely operated from the surface, making the use of a camera of vital importance for the visualization of its workspace. The synchronism between the movement of the camera and the operation of the manipulator by the operator is a complex task, which in many cases is made manually. This paper presents a study that relates the workspace of the manipulator with the camera field of vision, and based in this study, considers the concatenation of the movements of the camera and the manipulator through an electro hydraulic solution. The proposed solution uses sensors of position (potentiometers) installed in the joints of the manipulator as references for the control of the hydraulical actuators that put the camera in motion, allowing either the grip or the tip of the manipulator to be in the camera field of vision, and thus, in the operator field of vision.*

Keywords*: ROV, underwater robotics, manipulator, positioning control*

1. Introduction

The maintenance and installation of systems of submarine exploration of oil are carried through by ROV's equipped with manipulator and camera remotely operated. The manipulator of the ROV and the movement of the camera are controlled from the surface (Romano, 2002). To try to minimize the synchronism problem between the movement of the manipulator and of the camera, these tasks must be executed by the same operator (Reis and Messina, 1988).

A lot of works used sensors of position based on stereoscopic vision (Bellin, Maddalena and Visentin, 1990)(Chen and Lee, 2000). These systems are well complex and its main objective being to assist the navigation of the ROV, but they could also be used for the automation of the movement of the ROV’s camera.

In this work a less complex system that concatenates the camera to the manipulator through the interconnection of the electric signals of the potentiometers of the five first hydraulical actuators of the manipulator to the valves proportional directional of the two actuators of the camera, is presented. Making possible the movement of the camera from the movement of the manipulator, as it is shown in Fig. 1.

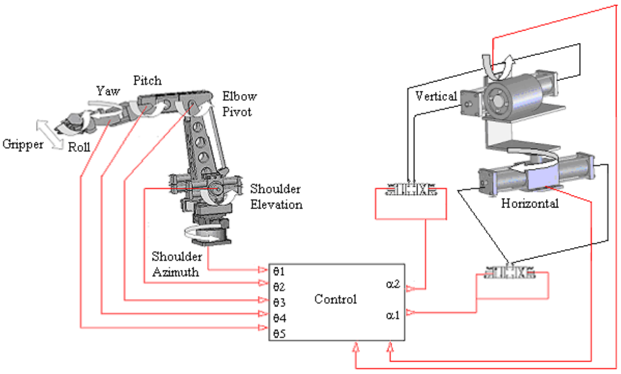

Figure 1. Project of the objective.

The system of movement of the camera has two degrees of freedom (horizontal-vertical or pan-tilt) and the manipulator has six degrees of freedom. The sixth degree is not being used in this interconnection with the camera, which had not to intervene with the trajectory of the arm.

2. Manipulator

This study used a typical ROV manipulator that is defined as a general purpose hydraulical system, master-slave, tele-operated, projected to execute tasks in submarine environments or any another hostile environment, of the antropomorphus type with pulse RPY (Roll, Pitch, Yaw), also call of pulse of Euler (Holobut, 2003). In Figure 2 a drawing of the arm with the identification of the degrees of freedom is presented.

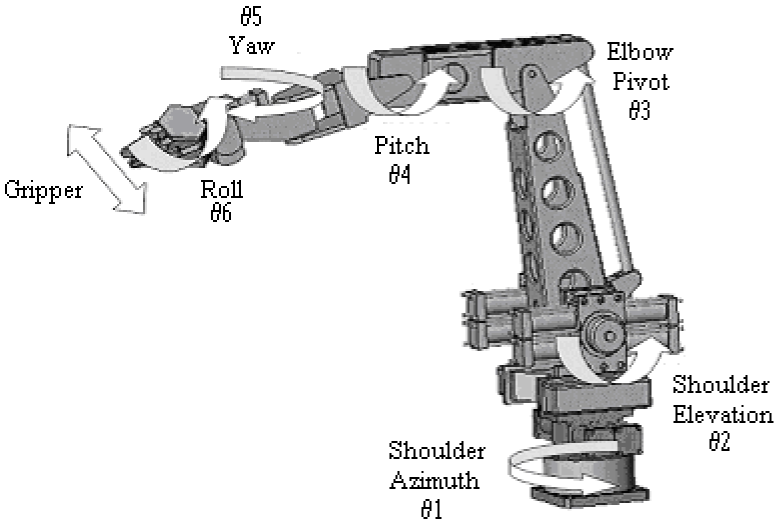

Figure 2. Manipulator.

In Table 1 the maximum angular displacement for each joint of the manipulator is shown.

Table 1. Joints versus angular displacement.

Joints	Angular displacement
Shoulder Azimuth	180 º
Shoulder Elevation	120 º
Elbow Pivot	110 º
Pitch	100 º
Yaw	105 º
Roll	180 º

The manipulator joint has a potentiometer that supplies the angular position to the control system (Merritt,1967).

3. Pan and Tilt System

The pan and tilt system is a remote operated device projected to assist the submarine tasks of the ROVs. The system used in this study is compound by a rotary hydraulical actuator with a nut rack mechanism. This one acts moving each degree of freedom of the system, that are controlled by hydraulic proportional valves (AU,1994). The measurement of angular position in each joint is made toward potentiometers. The Figure 3 presents the system scheme.

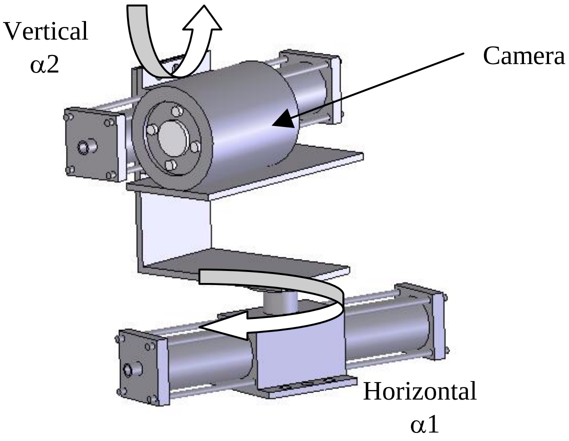

Figure 3. Pan and Tilt System

These systems present angular restrictions imposed from constructive characteristics, and are presented in Tab. 2.

Table 2. Pan and tilt's angular displacement.

Vertical angular displacement	120 º
Horizontal angular displacement	270 º

4. Modeling

In the presented modeling the dynamics was ignored due to low speed requirements.

4.1. Manipulator

The kinematic study of the arm is presented through the transformation matrices (rotation and translation) of the base until the tip of the gipper, where the lengths of the links are represented by *Li* and the angles by θi , where *i = 1, …, 6*. At the matrices presentation was used *S* to *Sine* and *C* to *Cossine* (Sciavicco and Sicilliano, 1999).

The study was divided in two parts. In the first, the modeling of the antropomorphus arm was made, whose transformed matrix final, *M30*, showed in Eq.(1).

$$M30 = \begin{bmatrix} C1.C23 & -S1 & C1.S23 & C1(L2.C2 + L3.C23) \\ C23.S1 & C1 & S1.S23 & (L2C2 + L3C23)S1 \\ -S23 & 0 & C23 & L1 - L2.S2 - L3.S23 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

In the second part we have the transformed matrix final of the pulse, *M63*, in the Eq. (2).

$$M63 = \begin{bmatrix} C4.C5 & -C4.C6.S5 + S4.S6 & C6.S4 + C4.S5.S6 & C4(L4 + (L5 + L6)C5) \\ S5 & C5.C6 & -C5.S6 & (L5 + L6)S5 \\ -C5.S4 & C6.S4.S5 + C4.S6 & C4.C6 - S4.S5.S6 & -(L4 + (L5 + L6)C5)S4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

In the Equation (3) the transformed matrix total of the system, *M60,* is shown.

$$M60 = M30.M63 = \begin{bmatrix} M60_{11} & M60_{12} & M60_{13} & M60_{14} \\ M60_{21} & M60_{22} & M60_{23} & M60_{24} \\ M60_{31} & M60_{32} & M60_{33} & M60_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The last column of the *M60* matrix represents the position (X, Y, Z) of the system. These elements are shown in the Eqs. (4), (5), (6).

$$M60_{14} = C1(L2C2 + L3C23 + C234(L4 + (L5 + L6)C5)) - (L5 + L6)S1.S5 \tag{4}$$

$$M60_{24} = (L2.C2 + L3.C23 + C234(L4 + (L5 + L6)C5))S1 + (L5 + L6)C1.S5 \tag{5}$$

$$M60_{34} = L1 - L2.S2 - L3.S23 - (L4 + (L5 + L6)C5)S234 \tag{6}$$

4.2. Pan and Tilt

In this part of the study, the modelling of the pan and tilt system was related to the modeling of the manipulator. For this is presented the position of reference for pan and tilt (refcam) in the Eq. (7), based on manipulator´s reference.

$$refcam = \{Xrc, Yrc, Zrc\} \tag{7}$$

The position of the camera (poscam) was determined from Eqs. (4), (5) e (6) and is presented in the Eq.(8).

$$poscam = posmanip - refcam =$$

$$\begin{bmatrix} C1(L2.C2 + L3.C23 + C234(L4 + (L5 + L6)C5)) - (L5 + L6)S1.S5 - Xrc \\ (L2.C2 + L3.C23 + C234(L4 + (L5 + L6)C5))S1 + (L5 + L6)C1.S5 - Yrc \\ L1 - (L2 + L3.C3)S2 - L3.C2.S3 + (L4 + (L5 + L6)C5)(-C4.S23 - C23.S4) - Zrc \end{bmatrix} \tag{8}$$

4.3. Manipulator with Pan and Tilt

Using the two models presented in sections 4.1 and 4.2 the relation between the angular positions of the pan and tilt (*α1, α2*) and the angular position of the manipulator (*θ1, θ2, θ3, θ4, θ5*), considering the length of links (*L1, L2, L3, L4, L5, L6*) is shown in Eqs. (9) e (10).

$$\alpha 1 = ArcCot\left\{\frac{Xrc - C1(L2.C2 + L3.C23 + C234(L4 + (L5 + L6)C5)) + (L5 + L6)S1.S5}{-Yrc + (L2.C2 + L3.C23 + C234(L4 + (L5 + L6)C5))S1 + (L5 + L6)C1.S5}\right\} \tag{9}$$

$$\begin{aligned} &\alpha 2 = ArcTan\{(L1 - Zrc - L2.S2 - L3.C3.S2 - L3.C2.S3 + (L4.C4 + L5.C4.C5 + L6.C4.C5) \\ &(-C3.S2 - C2.S3) + (C2.C3 - S2.S3)(-L4.S4 - L5.C5.S4 - L6.C5.S4)) / \\ &[(-Yrc + L2.C2.S1 + L3.C2.C3.S1 - L3.S1.S2.S3 + (L4.C4 + L5.C4.C5 + L6.C4.C5)(C2.C3.S1 - S1.S2.S3) + \\ &(C3.S1.S2 + C2.S1.S3)(-L4.S4 - L5.C5.S4 - L6.C5.S4) + C1(L5.S5 + L6.S5))^2 \\ &+(-Xrc + L2.C1.C2 - L3.C1.C2.C3 - L3.C1.S2.S3 + (L4.C4 + L5.C4.C5 + L6.C4.C5) \\ &(C1.C2.C3 - C1.S2.S3) + (C1.C3.S2 + C1.C2.S3)(-L4.S4 - L5.C5.S4 - L6.C5.S4) - \\ &S1(L5.S5 + L6.S5))^2]^{\frac{1}{2}} \end{aligned} \tag{10}$$

4.4. Proportional Valves

The system proposed in this work uses a four-way proportional valve for each joint of the pan and tilt mechanism.Its actuation is made by two proportional solenoids, one in each side of the spool (Fig. 4).

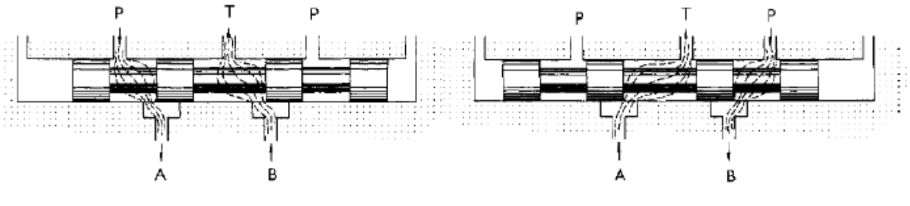

Figure 4. Ways proportional valve.

A first order solution for this mechanism is presented in Eq. (11), as a satisfactory practical model (Clegg,1994).

$$\frac{x_c}{i(S)} = \frac{K_i}{\tau_i S + 1} \tag{11}$$

where x_c is spool displacement, i is input current, K_i is the gain and τ_i is time constant.

The flow through the valve (Q) can be calculated with the Eq.(12)

$$Q = K_q.x_c - K_c.P_m \tag{12}$$

where:

$$P_m = P_1 - P_2 \tag{13}$$

K_q is flow gain and K_c pressure gain.

Equations (14) and (15) can be found applying Bernoulli's equation (De Negri, 2001).

$$Q_A = \mathrm{sgn}(\Delta P_A) K_v \left|x_c\right| \sqrt{2\left|\Delta P_A\right|} \tag{14}$$

$$Q_B = \mathrm{sgn}(\Delta P_B) K_v \left|x_c\right| \sqrt{2\left|\Delta P_B\right|} \tag{15}$$

where ΔP_A e ΔP_B are presented in Eqs.(16) e (17).

$$\begin{aligned} \Delta P_A = {} & P_S - P_1 \quad se\ xc \geq 0 \\ & P_e - P_1, \quad se\ xc < 0 \end{aligned} \tag{16}$$

$$\begin{aligned} \Delta P_B = {} & P_e - P_2, \quad se\ xc \geq 0 \\ & P_S - P_2, \quad se\ xc < 0 \end{aligned} \tag{17}$$

where P_s is the input pressure, P_e the output pressure and K_v is shown in Eq. (18)

$$K_v = 2.\pi.R.x_{c\max} \tag{18}$$

where R is the spool radius and x_{cmax} is equal to 1.

In this presented modeling had not been considered leaks in proportional valve and it is had critical center.

For the pursuing control modeling of the manipulator trajectory for the camera, the linear zone of operation of proportional valve was considered, as it is shown in Fig 5.

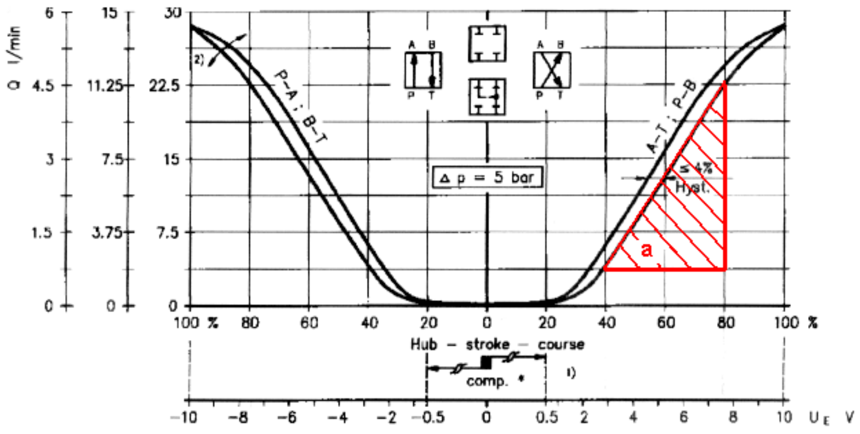

Figure 5. Proportional valve's graph (Bosch, 2001).

Where the calculated proportional constant (K_1), through the red triangle, is presented in the Eq. (19).

$$K_1 = tg(a) = \frac{6.25}{4.8} = 1.30\frac{m^3}{s}.\frac{1}{V} \tag{19}$$

4.5.Actuator

The according with Fig. 6 is presented the actuator's modeling, where q is flow, A_P is piston area, X is rack displacement, R is piston radius and α is angular displacement.

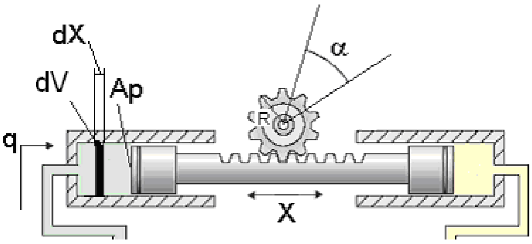

Figure 6. Actuator.

The flow through the actuator (q) can be calculated with the Eq.(20)

$$q = \frac{dV}{dt} \tag{20}$$

where dV is presented in Eq.(21).

$$dV = A_p.dX \tag{21}$$

In Eq. 22 is presented the substitution Eq. 20 in Eq. 21.

$$q = \frac{A_p.dX}{dt} \tag{22}$$

where X is presented in Eq.(23), and it is a relation between piston radius (R) and the angular displacement (α).

$$X = R.\alpha \tag{23}$$

In Eq. 24 is presented the substitution Eq. 23 in Eq. 22.

$$q = A_p.\frac{d(R.\alpha)}{dt} = A_p.R.\dot{\alpha} \tag{24}$$

Using Laplace:

$$Q(s) = A_p.R(s.\alpha(s)) \tag{25}$$

$$\alpha(s) = \frac{Q(s)}{s.A_p.R} \tag{26}$$

The proporcional Constant (K_2) is presented in Eq. 27.

$$K_2 = \frac{1}{A_p.R} \tag{27}$$

where A_p=11,37 x 10^{-4} m^2 and R=0,022 m to actuator used.

5. Control

In the Fig. 7 is presented the feedforward block diagram control, implemented using SIMULINK® where the plant gain (K_a) is the product between K_1 and K_2, α is the output angle, α_d is desired angle, the function transfer is presented in Eq. (28) and the control signal is presented in Eq. (29).

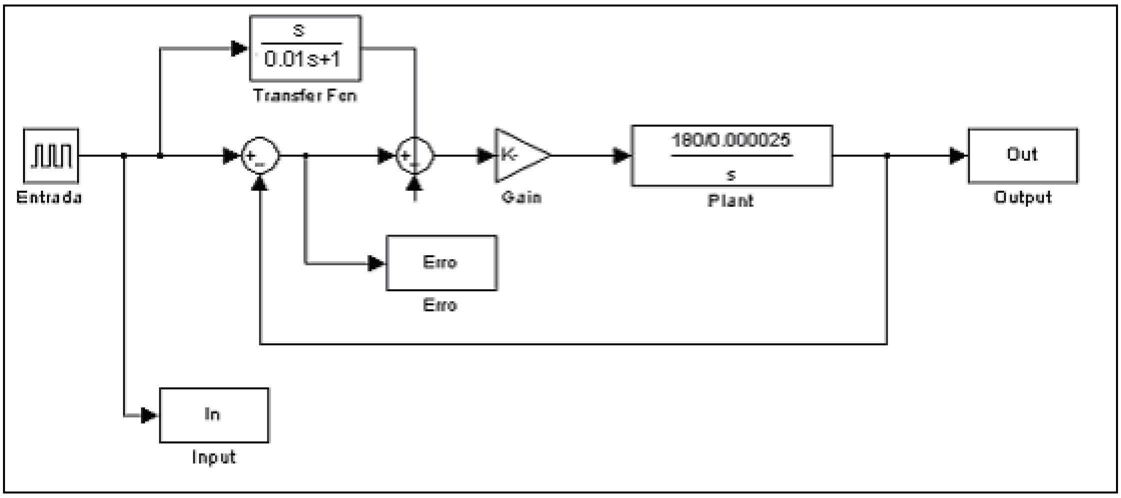

Figure 7. Control Block Diagram

$$\frac{s}{0.01s+1} \tag{28}$$

$$u = K\left[(\alpha_d - \alpha) + \dot{\alpha}_d\right] \tag{29}$$

This control with feedforward was used to approach to an ideal derivator. The modification of the theoretical derivative element (s) was carried through because in the real system it is impossible to implement a derivator. The difficulty in this implementation must it impossibility be foreseen, in a real system, the reference signal. Thus, this element is divided by the polynomial 0.01+1 (Eq. (28)).

In the Fig. (8) is presented the error and response signals from the input signal sine.

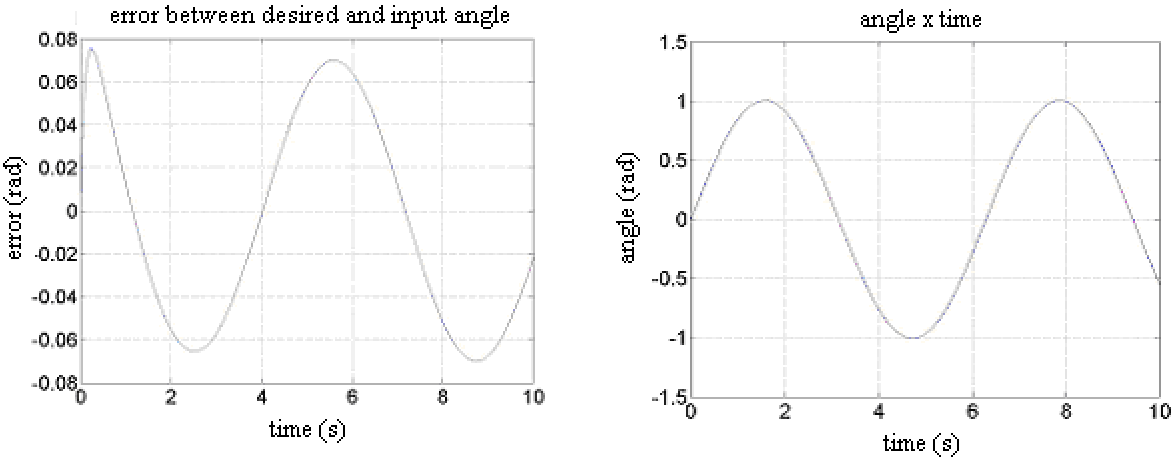

Figure 8. Sine signal input.a)error x time. b)output angle x time.

6.Conclusion

In this work was presented a possible solution for the manual control of camera positioning. Nowadays two operators are necessary, one to control the manipulator and another one to point the camera to the gripper. This paper proposed the synchronization of the manipulator movements with the camera movements interconnecting toward electric signals from manipulator joints with proportional valves of the pan and tilt system of the camera.

A linear signal can be formed for a lot sine signals like Fourier´s law. The sum of these sine signals represents the original linear signal, thus, can be concluded making the pursuing of each sine signal is obtained the control of the original linear signal thus, if can obtains the pursuing of the trajectory of this signal. As can be observed in Fig. (7) and (8), the proposed control system presents use sine signal instead of slope and step signals.

It is observed that the error has the same characteristics of the reference entrance therefore it varies of sine form as desired, in view of the error has that to constantly compensate the variations of the input. It can be concluded that for the sine input, the control feedforward obtained that the output angle followed the reference angle. The analysis of the input signal of the sine type is very important, therefore this manifest the variacional character of any reference input that is the characteristic of the pursuing of the trajectory, where the displacement of the manipulator is unexpected.

7. Acknowledgements

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