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Automation of Davidovits theory in construction using mobile laser robot

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Abstract

The truth behind the approach of building the Giza pyramids (Egypt) is still unknown. Many postulates were proposed. Noted in the past years the theory of Professor Joseph Davidovits indicating that the pyramids were “assembled” in place by heating the mud. This was proven by the identified amount of water found in the test of the nanoparticles. The advantage of such approach is bypassing the mobility and weight issues of the stones. In this paper we offer a simulation of the construction process using a multipurpose robotic manipulators. The role of this mechanism is to inject mud and heat it using LASER technology.

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1. Introduction

Construction is one of the aspects of social development. Evolution of the construction concepts and arts depends of the needs and prosperity of the society. Historically, human was relying on hunting for day-to-day living. The cave was enough to protect him from climatic conditions and risks. Acquired the knowledge of agriculture, human had to store goods and products in permanent settlements: tents were set up from animal bones and wood, huts from leaves.

In Mesopotamian period, clay, plain and glazed bricks were introduced in Chaldea. While Assyrians used bricks and stones, the Persians preferred limestone and timber to build their communal houses. The Egyptians continue the tradition of using natural products and masonry materials (basalt, granite, limestone). Greek used the marble, while their successor the Romans used concrete, which continued as primary building materials until the industrial age introducing steel and glass. With the development in nanotechnologies, engineers aim to achieve the hitherto difficult invention of long lasting [pp.158, 4; pp.66, 5], light (transportation) [pp.7, 6], and flexible building materials [pp. 57, 2; pp.80, 3].

The result appears in the 3D printing technology. These printers can create products starting from pens, guns or biological organs. With relation to construction, China is set to build in Dubai the first 3D office covering an area of 186 square meters using 6-meter tall printer. Already China is specializing in printing large buildings achieving recently 6-strory apartments occupying 1100 square meter area. It is estimated that a single house can be concrete printed in less then one day.

2. Mathematical model for laser glazing robot

In this paragraph, we will be describing the glazer robot, identify it mathematical model and control approach. The robot consists of two major parts, the CO_2 Laser generator lifted by a mobile cart. The generator part has 2 water-cooled electrodes between them high frequency stimulating the laser gas. Alongside with couples of mirrors, the two electrodes form the resonator. A concept of the CO_2 laser machine is illustrated in fig.1 [pp.18; 9].

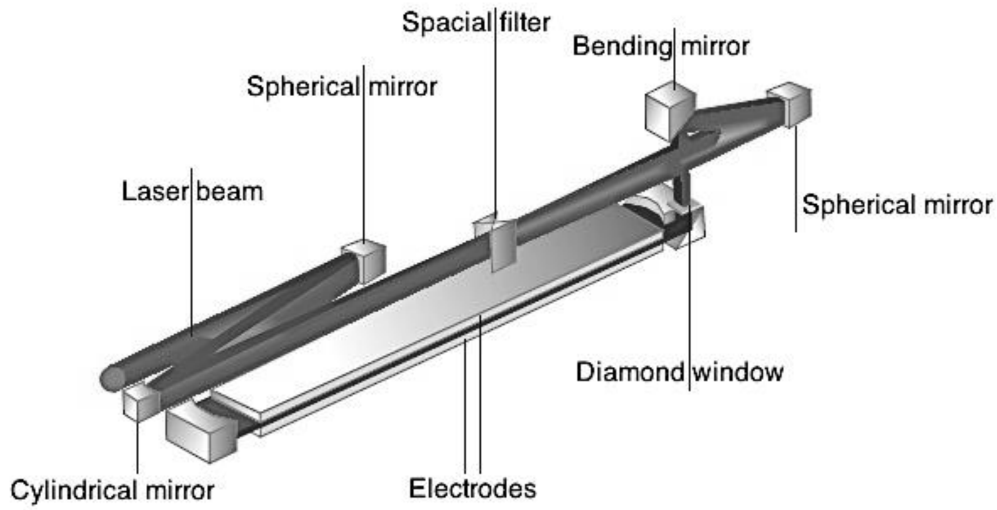

Fig.1. Concept of CO_2 laser machine

We aim to perform slab and walls concrete treatment. Hence the laser should reach different altitudes and corners. We can consider the cart and the lifting mechanism as a possible simulation for our case study. Therefore we will represent the setup as two-dimensional problem of an inverted pendulum moving in the vertical plane as shown in the fig.2. bellow. While the cart is moving, it applies force F on the lifting mechanism, which in its turn will tilt around the fixation point by an angle θ. Hence the control input is the force F and the control output is the angle θ and the horizontal movement of the cart x [pp.5 ,11; pp.25, 12].

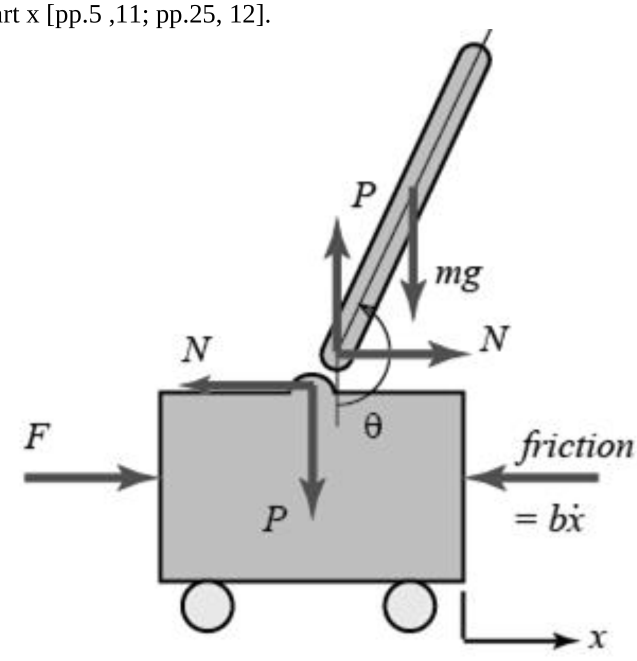

Fig.2. Two-dimensional inverted pendulum problem

In fig.7 are marked the forces applied to the body frame. Using Newton law of motion we can introduce the sum of the forces in the free-body diagram of the cart and pendulum in the horizontal direction:

$$M\ddot{x} + b\dot{x} + N = F; \tag{1}$$

$$N = m\ddot{x} + ml\ddot{\theta}cos\theta - ml\dot{\theta}^2 sin\theta; \tag{2}$$

where M and m are the mass of the cart and the lifting mechanism respectively; b is the coefficient of friction depending on the wheels and the floor type.
Substituting equation (2) in (1) we obtain the following equation

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\theta}cos\theta - ml\dot{\theta}^2 sin\theta = F; \tag{3}$$

Summing the force perpendicular to the pendulum we get the second equation of motion

$$Psin\theta + Ncos\theta - mg\sin\theta = ml\ddot{\theta} + m\ddot{x}cos\theta; \tag{4}$$

The terms of P and N can be found be summing the moments about the centroid of the pendulum. Hence we can write:

$$-Plsin\theta - NlPcos\theta = I\ddot{\theta}; \tag{5}$$

Combining equation (4) and (5) we obtain the second governing equation

$$(I + ml)\ddot{\theta} + mglsin\theta = -ml\ddot{x}cos\theta; \tag{6}$$

Using the trigonometry low of small angles, equation (3) and (6) can be written in the following simplified forms

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\Phi} = u; \tag{7}$$

$$(I + ml)\ddot{\Phi} + mglsin\Phi = -ml\ddot{x}; \tag{8}$$

Using u and Φ where replace the F value and small angle terms hereafter.

The next step consists in finding the transfer functions of the system. Therefore we need to introduce the Laplace transformation of the equations assuming zero initial conditions. The equations (7) and (8) can be written as follows

$$(M + m)X(p)p^2 + bX(p) + ml\ddot{\Phi}(p)p^2 = u(p); \tag{9}$$

$$(I + ml)\ddot{\Phi}(p)p^2 + mglsin\Phi(\mathrm{p}) = -mlX(p)p^2; \tag{10}$$

where p is the Laplace operator.

Taking into consideration that the transfer function is the relation between the form of single input and single output at one time and rearranging equations (7) and (8) using linearization method we obtain the following:

$$\frac{\Phi(\mathrm{p})}{u(p)} = \frac{\frac{ml}{K}p^2}{p^4 + \frac{b(I + ml^2)}{K}p^3 - \frac{(M + m)mgl}{K}p^2 - \frac{bmgl}{K}p}; \tag{11}$$

where $K = [(M + m)(I + ml^2) - (ml^2)]$; and $W(p) = \frac{\Phi(\mathrm{p})}{u(p)}$.

From the transfer function above we can clearly see that there is a pole and zero at the origin. Hence the transfer function can be rewritten using the following system of equations:

$$\frac{\Phi(\mathrm{p})}{u(p)}=\frac{\frac{ml}{K}p}{p^3+\frac{b(I+ml^2)}{K}p^2-\frac{(M+m)mgl}{K}p-\frac{bmgl}{K}}; \quad (12)$$

$$\frac{\mathrm{X(p)}}{u(p)}=\frac{\frac{(I+ml^2)p^2-gml}{K}}{p^4+\frac{b(I+ml^2)}{K}p^3-\frac{(M+m)mgl}{K}p^2-\frac{bmgl}{K}p}; \quad (13)$$

where $\frac{\Phi(\mathrm{p})}{u(p)}$ and $\frac{\mathrm{X(p)}}{u(p)}$ are the pendulum and cart transfer function respectively.

The whole system can be represented in matrix form using state space equation. Hence we can write the following:

$$\begin{bmatrix}\dot{x}\\ \ddot{x}\\ \dot{\theta}\\ \ddot{\theta}\end{bmatrix}=\begin{bmatrix}0&1&0&0\\0&q_1&q_2&0\\0&0&0&1\\0&q_3&q_4&0\end{bmatrix}\begin{bmatrix}x\\ \dot{x}\\ \theta\\ \dot{\theta}\end{bmatrix}+\begin{bmatrix}0\\q_5\\0\\q_6\end{bmatrix}; \quad (14)$$

where

$$q_1=\frac{-(I+ml^2)b}{I(M+m)+Ml^2};$$
$$q_2=\frac{m^2gl^2}{I(M+m)+Ml^2};$$
$$q_3=\frac{-mlb}{I(M+m)+Ml^2};$$
$$q_4=\frac{mgl(M+m)}{I(M+m)+Ml^2};$$
$$q_5=\frac{I+ml^2}{I(M+m)+Ml^2};$$
$$q_6=\frac{ml}{I(M+m)+Ml^2}.$$

The output of the system Y can be represented using the following equation

$$Y=\begin{bmatrix}1&0&0&0\\0&0&1&0\end{bmatrix}\begin{bmatrix}x\\ \dot{x}\\ \theta\\ \dot{\theta}\end{bmatrix}+\begin{bmatrix}0\\0\end{bmatrix}u; \quad (15)$$

The matrix $\begin{bmatrix}1&0&0&0\\0&0&1&0\end{bmatrix}$ has two rows representing the cart position and the pendulum movement.

For us, the most important is to control the movement of the pendulum as it represents the lifting effect and movement of the CO_2 laser beam. But still the cart has to reach the indicated area.

The figures 3 and 4 represent the simulation results of resolving two-dimensional inverted pendulum control problem. Figure 3 illustrates the horizontal movement of the cart as consequence to tracking force F. As it is seen the cart moved linearly smoothly.

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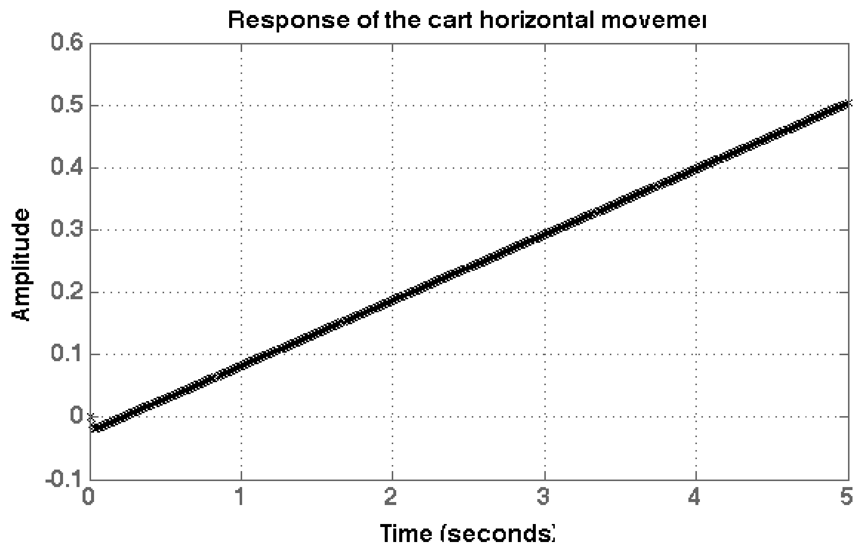

Fig.3. Cart movement from zero initial condition

On the other hand and following a sudden movement of the cart, the lifting mechanism curve has shown an overshoot then the working angle was stabilized.

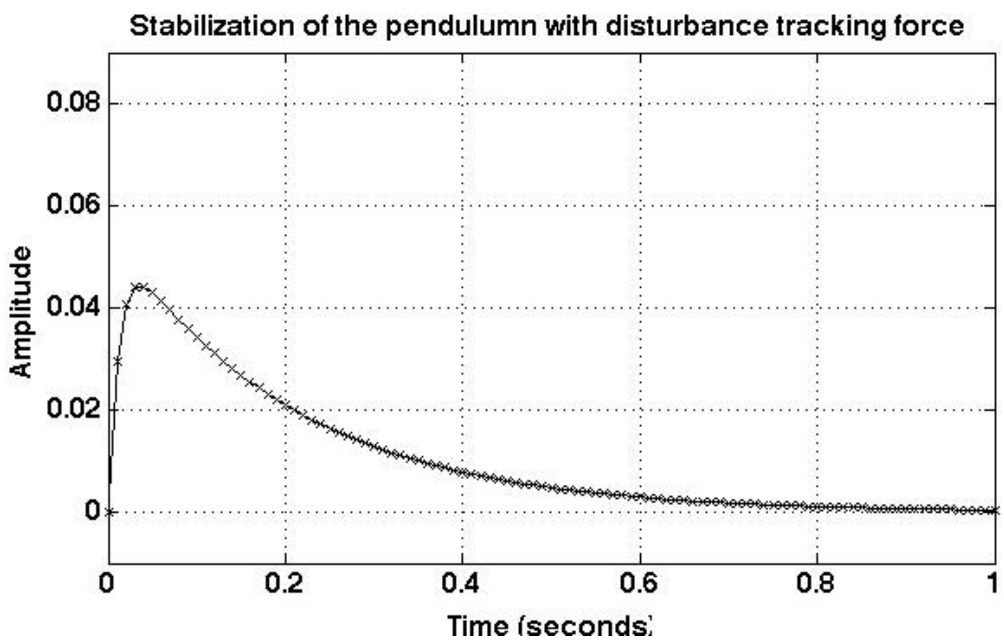

Fig.4. Lifting mechanism stabilization to desired position while the cart is moving

The successful control of the inverted pendulum consists of stabilizing the lifting mechanism while the cart is moving smoothly in the horizontal plan. Hence by implementing the control approach the shape of the curve representing (X) should be ascending, while the rotation of the pendulum (θ) should be consistent to a pre-assigned value representing the working angle or the reaching of the laser beam [pp.3,7 ; pp.5,8].

Conclusion

To wrap up, there are three points to recap. Firstly, it is about the idea of the glazing robot. We have saw the importance of treating the concrete in order to achieve better durability and minimize the wear range taking into consideration atmospheric and chemical factors. While the hydro-erosion offers good and cheap solution [pp.587, 1], laser glazing can be better alternative in terms of number of periodic preventive maintenance and technically in terms of improving the resistance of the concrete to detergents, minerals and acids causing multiple defects enumerated earlier. Secondly, in contradiction of the hydro-erosion technique, glazing does not depend on water availability and flow rate and pressure.

The second point is about the simulation of the glazing robot. As was discussed, the laser beam should reach the slab as well as walls. Hence lifting mechanism is supposed to orient the beams with reference to the vertical plan. We have selected the technical specifications of the cart and lifting mechanism in such way to be compared with the hydro-erosion robotic solution.

Later, the control task was formulated as two dimensional inverted pendulum problem. Assuming, that the cart is moving in a relatively smooth working site, the value of the friction coefficient between the wheels and the ground was chosen to be of minimal value. This coefficient plays important role in stabilizing the lifting mechanism as it can cause nonlinear curve form of the cart movement. Accordingly, the synchronization of the wheels rotation is an essential factor, which was not taken into consideration in our simulation [pp.14; 10]. In case all these factors needs to be considered, adaptive control system is recommended instead of the classic PID regulators offered in this paper.

We have also considered that the rotational movement of the lifting mechanism is achieved without friction around the pendulum centroid. The lifting arm is considered to be ideally rigid. As it can be seen, this is an idealized scenario, which cannot be considered in real practice when lifting the laser beams to six meters height.

Taking into consideration all the aforementioned constraints in the simulation phase, it is believed that the control task was resolved in terms of stabilizing the lifting mechanism while moving the carrying cart smoothly on working site.

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