CONCEPT OF A WALL BUILDING INDUSTRIAL ROBOTIC SYSTEM

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ABSTRACT: Up to now there are robots specializing in stationary industrial operations. The building industry is a highly diversified and dynamic branch and, therefore, robotic systems are not used on the construction site during the building process at all or in a very limited way to handle loads. There exist robotic wall building systems based on mobile machines that can make linear masonry structures (fence, wall). Because of the large dimensions and weight of these machines, however, they require a large working space and, therefore, they are not applicable for the construction of planar structures. The building industry lags behind the other sectors in the use of robotic systems, and due to a great number of human injuries and large volumes of loads moved by human power during the construction process the introduction of a wall building robotic system is an issue of utmost urgency. The paper deals with the concept and design of a self-acting wall building industrial robotic device for the construction of small to medium-sized structures using the dry wall and precision masonry technology.

Keywords: *Robotic System, Simulation, Wall, Building, Masonry Technology, Brick*

1. INTRODUCTION

Robots specialized mostly in stationary industrial tasks have been known so far. Building industry is a very variable and dynamic industrial branch and therefore the robot systems are usually not applied in constructing and/or their use is strictly limited to burden manipulation. There exist some robot brickwork systems constructed as mobile machines capable of line objects brick working (boundary walls, walls). Due to their large size and weight, the machines require enormous working space and are not applicable in building of flat objects. As concerns exploitation of the robot systems, the building industry falls behind the other branches. But due to frequent injuries and masses of human- force transported burdens during the building, introduction of the robot system in the building industry is urgent. The present paper deals with the concept and the design of the automated industrial brickwork robot suitable for building of small to medium-sized objects with exploitation of the technology of dry and precise masonry.

Concerning the use of robot systems, the building industry falls behind the other branches and because of numerous accidents and voluminous burdens transport by human force during the building, introduction of the robot system is urgently upcoming. The mentioned problems are substantially resolvable by the industrial robot brickwork system dealt with in this paper. What we talk about is a technological unit of a robot brickwork system exploitable in automatic brick working of flat constructions of small- to medium-sized building objects.

The paper describes the creation of a mathematical model in simulation software. The mathematical model of the brickwork robot system enables simulation of a complicated servo motor set, of the input signals and the outputs of the model. The simulation will serve for the estimation of technical parameters of the system and of time and energy consumption during the object construction.

The output of the mathematical model will also be a transformation matrix of motion of the system servo motors.

2. DEFINITION OF THE MODEL

The mathematical model is depicted in Fig. 1. It is composed of several parts. The first part of the system is the entrance data describing the technical parameters of the model: size and weight characteristics of the building components – bricks and form pieces. The calculation of the basic construction model of the building object is automatic. Then the system is being entered by the matrix of source values S (Source). The matrix describes the set of coordinates of bricks arrangement on the pallets. The target D (Destination) matrix describes the target coordinates of the building elements according to the construction drawings.

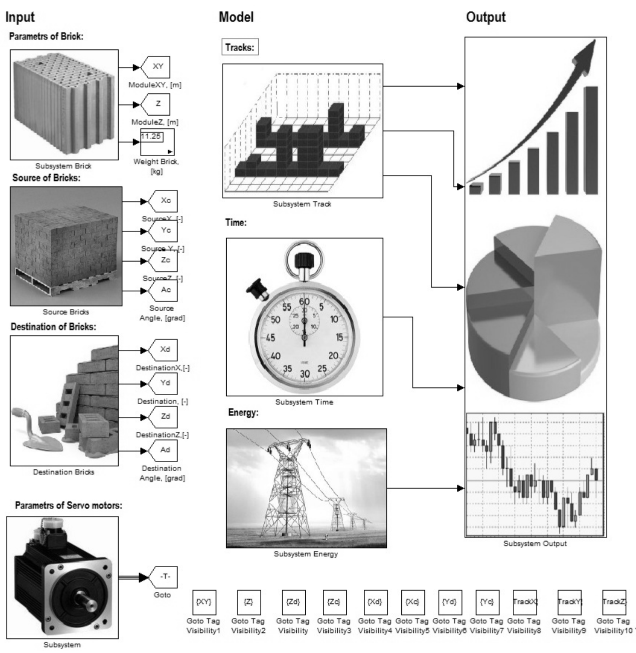

Fig. 1 The mathematical model of the brickwork robotic system.

$$S = \begin{vmatrix} x_1, & y_1, & z_1, & a_1 \\ & \vdots & & \\ x_i, & y_i, & z_i, & a_i \\ & \vdots & & \\ x_n, & y_n, & z_n, & a_n \end{vmatrix},$$

$$D = \begin{vmatrix} x_1, & y_1, & z_1, & a_1 \\ & \vdots & & \\ x_i, & y_i, & z_i, & a_i \\ & \vdots & & \\ x_n, & y_n, & z_n, & a_n \end{vmatrix},$$

$$T = \begin{vmatrix} t_{11}, & t_{12}, & t_{13}, & t_{14}, & t_{15} \\ & & \vdots & & \\ t_{i1}, & t_{i2}, & t_{i3}, & t_{i4}, & t_{i5} \\ & & \vdots & & \\ t_{n1}, & t_{n2}, & t_{n3}, & t_{n4}, & t_{n5} \end{vmatrix},$$

where X and Y describe the placement of the building elements in a plane, Z – height of placement of the construction elements, A – swing of the elements.

Furthermore, the system is entered by the technical parameters of 5 servo motors: minimum and maximum speed of the drive, efficiency and output of the unit, reliability etc.

Trajectories of the unit motion, time and energy consumption are calculated in the model. Also haphazard factors of delay and technical faults are considered.

The output shows the results of the simulation: final time of the building process, energy consumption, the resulting transformation matrix T (Transformation) containing the individual impulses of the servo motor start-up for each building component.

The basic principle of the brickwork robot functioning is depicted in Fig. 2.

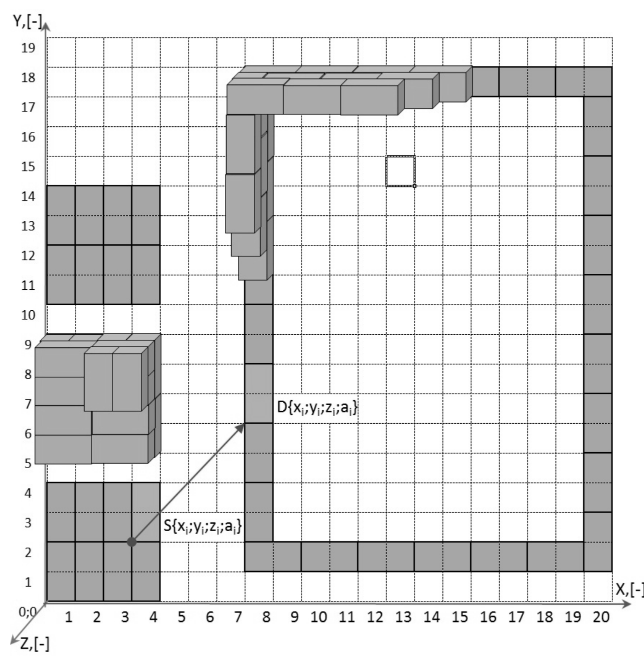

Fig. 2 Scheme of the brickwork robot system principle.

For an example simulation, four pellets of building components (bricks of 400 kg/m^3 volume mass and 300x600x250 mm in size) were used. For this building component, the basic building module XY was calculated as 30 cm. The basic building module Z for the present building component was calculated as 25 cm which corresponds to the height of one line of the bricks. Total amount of the bricks makes 128. The simulation software was applied to the simulation building of a windowless rectangular object. The input signals of S and D matrixes are cyclic in shape – see Figs. 3 and 4.

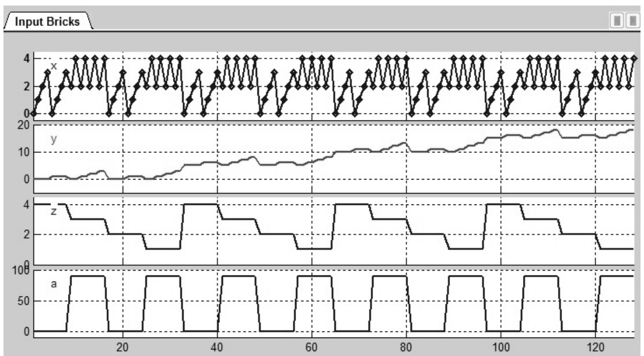

Fig. 3 Input simulated signal of the initial location of the building components.

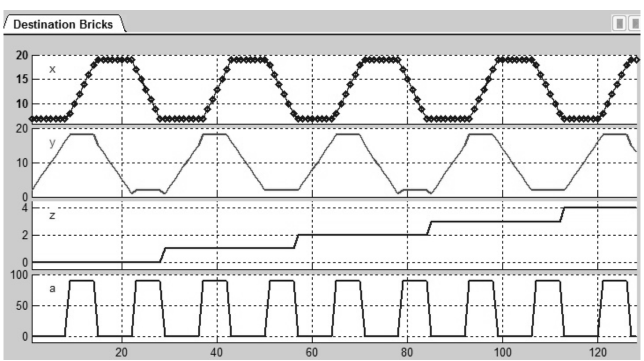

Fig. 4 Input simulated signal of the final location of the building components.

The following formulae were used for the calculation of the brickwork robot motion trajectories:

- in the Cartesian coordinate system, the distance between the two points S[x_i,y_i] and D[x_i,y_i] on a horizontal plane equates to the number:

$$SD_{xy} = \sqrt{(x_{di} - x_{ci})^2 + (y_{di} - y_{ci})^2}$$

- final position of D[x_i,y_i] point is determinable by means of the so-called polar coordinates. The transition between the Cartesian and the polar coordinates, if the pole is at the point S[x_i,y_i] and the polar semi-axis is situated in the plus part of axis x:

$$(x_{di} - x_{ci}) = \theta \cos\varphi,$$
$$(y_{di} - y_{ci}) = \theta \sin\varphi,$$
$$\theta = \sqrt{(x_{di} - x_{ci})^2 + (y_{di} - y_{ci})^2},$$
$$\varphi = arctg\frac{(y_{di} - y_{ci})}{(x_{di} - x_{ci})}$$

- calculation of the complete trajectories of the robot motion is as follows:

$$Track = 2\left(m_z(z_d - z_c + 2) + SD_{xy}\, m_{xy}\right)$$

- to determine one time cycle of the robot motion, the following formula was applied, see Figs. 5 and Fig. 6:

$$T = Time_{xy} + Time_z + Time_{rotation} + Time_{grip}$$

Within the simulation of 128 working cycles unexpected events (break-down, delay, material defects, various disrepairs) may occur. The model copes with such problems by enrollment of haphazard quantities based on the Monte Carlo method, which slow down the process of the object building, but, at the same time, bring the theoretical simulation model closer to the real process.

On the basis of predetermined servo motor technical parameters and calculated start/stop time impulses the program of all working cycles can be defined exactly and energy consumption of the whole robot system can be estimated.

The outputs of the brickwork robot model will show the transformation matrix of time impulses of the individual servo motors, calculation of the total time, motion trajectories and energy consumption of the robot system. The simulation outputs can be exported in the form of tables or diagrams – see Fig. 7 and Fig. 8.

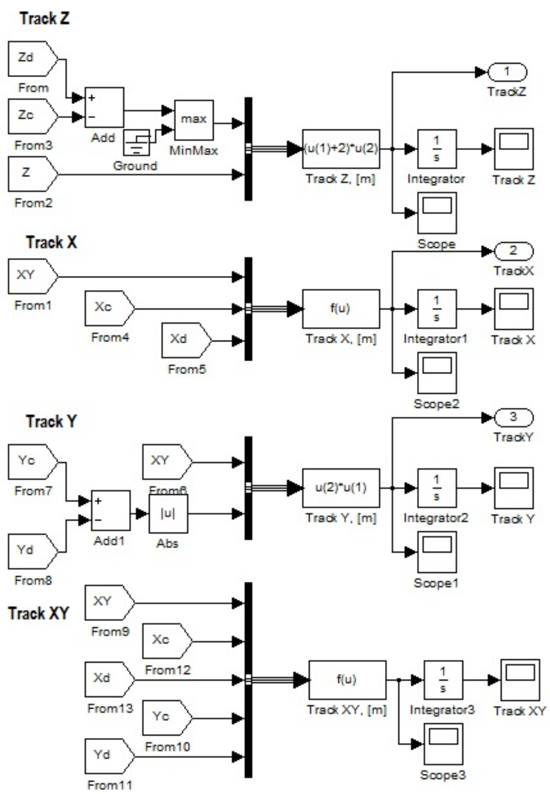

Fig. 5 Illustration of a calculation block of the track consumption.

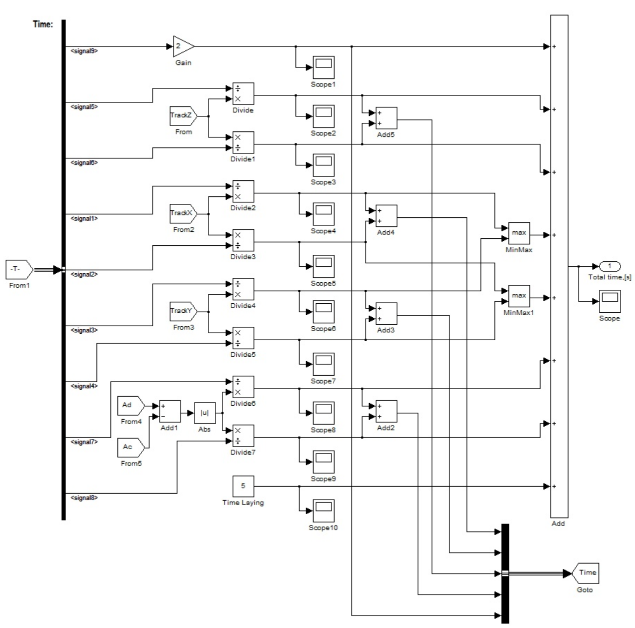

Fig. 6 Illustration of a calculation block of the time consumption.

Simulation time for brick working of 128 building components was estimated at ca. 3600 seconds (1 working hour of the system). This result substantially exceeds the speed of manual brick working of the building object. Further construction components (beams, window fillings, doors) can simply be enrolled into the system bringing the mathematical model closer to the real building object. Energy consumption of the robot system did not exceed 1.5 kW. The building process itself can be accelerated by rising the servo motor power.

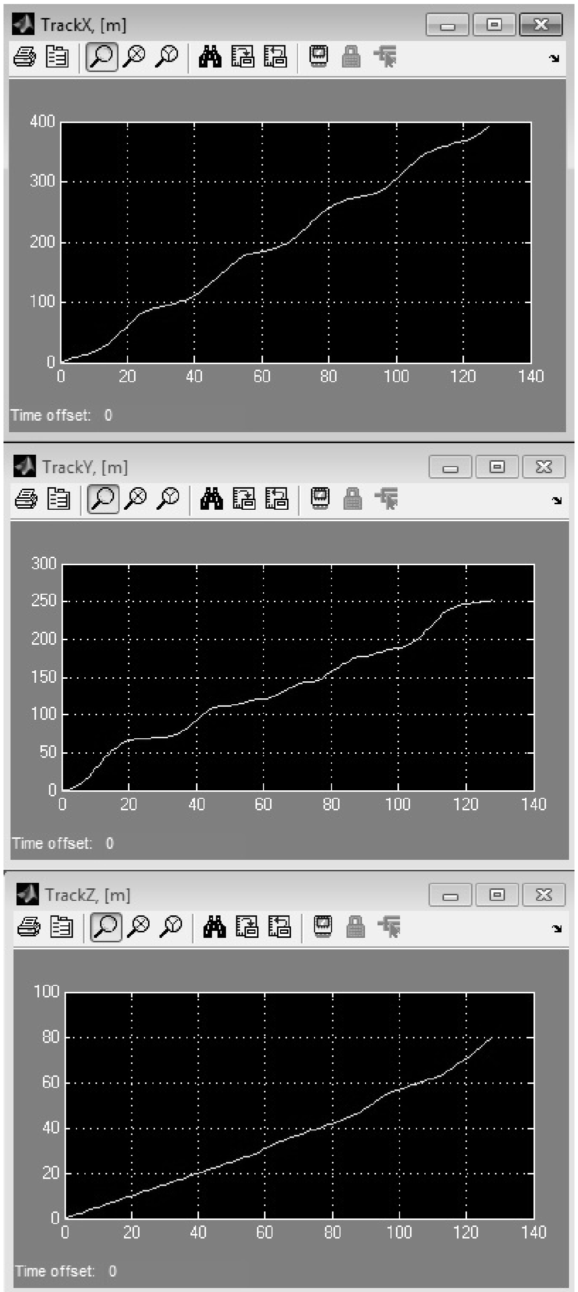

Fig. 7 Track outputs of the brickwork robot simulation model.

Of course, a control unit with feedback to the ongoing process must be developed. The control unit should be equipped with numerous sensors as well as video recorders watching a fluent course of the building process.

CONCLUSION

During the first phase of the brickwork robot design the following objectives were defined and fulfilled: simulation of the mathematical model of the robot motion and exact calculation of the technological process parameters using the simulation sw. The mathematical model showed the advantages of exploiting the robot system in the building industry.

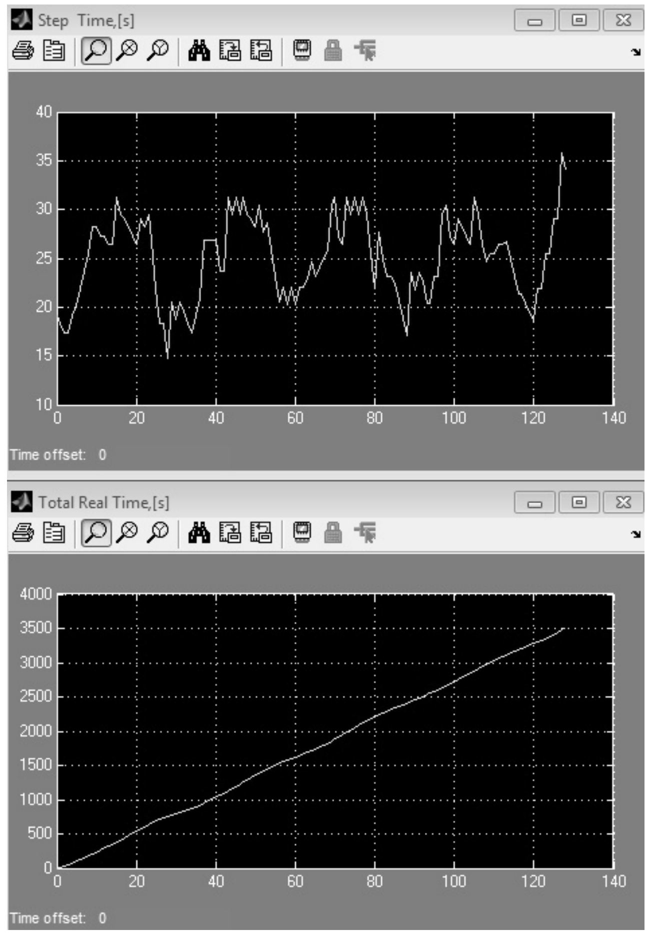

Fig. 8 Time outputs of the brickwork robot simulation model.

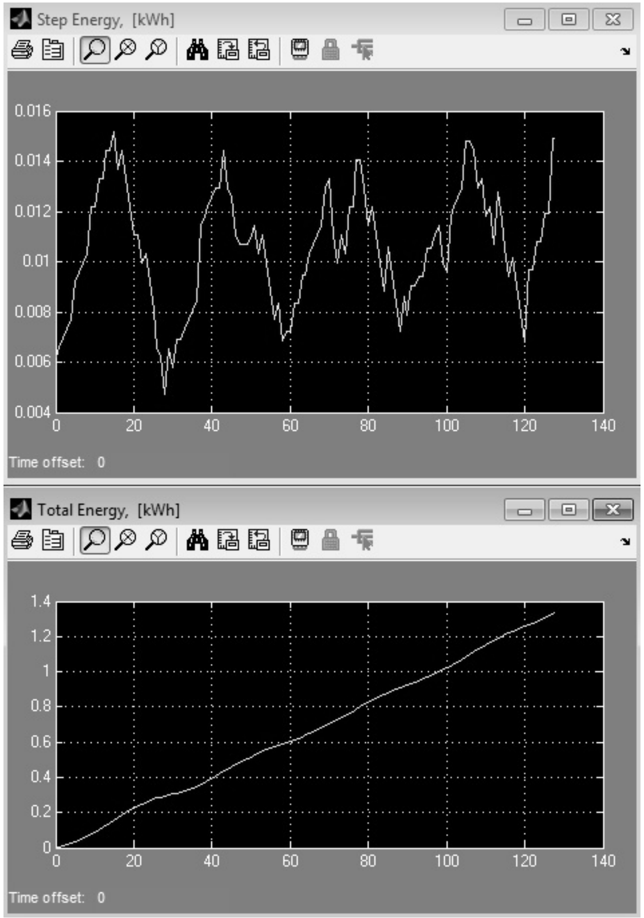

Fig. 9 Energy outputs of the brickwork robot simulation model.

The indisputable advantages are i.e. cut-down injuries at the working site, high speed of the building process, larger working extent of build ability as concerns time, climate, temperature and light, high preciseness of the object building, low energy demands, saved men power, possibility of remote-controlled building. The disadvantages, on the other hand, are the system complexity, need for higher qualification of the workers, programming of the building objects using appropriate software, higher failure rate of the system.

The second phase will be aimed at creation of a real miniaturized model of the brickwork robot and verification of the mathematical model and the calculated values at real conditions.

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