MODELING AND MEASUREMENT OF H-BOT KINEMATIC SYSTEMS

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INTRODUCTION

Due to the ever increasing demand for high productivity which implies high dynamics at reduced costs additional efforts are required in the search for alternative structural designs. This leads to the permanent investigation of alternative machine concepts for the application in fields, where standard, serial concepts have been used so far. Even if alternative kinematics are already used as is the case of 3D pick and place applications, other parallel structures have to be studied in order to improve the system's overall capabilities. In this paper a parallel kinematic structure called H-Bot has been investigated [1] and realized comprising modeling and measurement. The results of both areas of investigation are shown and discussed.

THE H-BOT CONCEPT

This H-Bot concept represents the interaction of two rotary drives which are connected by a single H-shaped circumferential timing belt around two staggered linear axes in a gantry-type like configuration, see figure 1. The kinematics of the H-Bot mechanism formulated in (1), where x and y are the TCP- and q_1 and q_2 are the drive-coordinates in radians and r_d is the drive's pulleys radius:

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = r_d \begin{bmatrix} -1 & 1 \\ -1 & -1 \end{bmatrix} \begin{Bmatrix} q_1 \\ q_2 \end{Bmatrix} \qquad (1)$$

Due to the fact that the drives do not have to be moved the achievable dynamic values can be quite high. Another aspect of this concept in contrast to delta-robot like kinematics is that the weight of the work load is carried by the linear guideways and not by the drives. Also, the working envelope, the required transformations and the uniformity of the distribution of properties are far easier to handle for industrial use than the often odd shaped working envelopes, complex kinematics and the strongly nonlinear property distribution of alternative concepts.

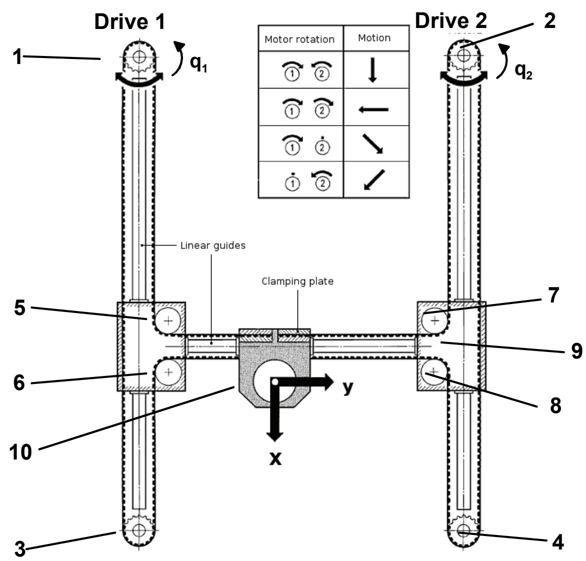

FIGURE 1. Schematic of the H-Bot configuration and the kinematic [3], numbering of bodies.

MEASUREMENT RESULTS

On a first prototype a series of measurements covering geometric properties could be carried-out. Figure 2 shows exemplarily the results of a circle test. As opposed to measurements on serial axis concepts the systematic deviations show additional systematic effects: At axis reversal similar effects are noticed as are typical for axis having semi-closed position feed-back. In addition to these at the axes reversals similar affects are visible at positions on the ±45° diagonals. These effects are caused by drive reversal, where stiction occurs on the driven pulley and/or motor bearing in combination with backlash of the belt.

Based on these first measurements on the prototype, a number of improvements could be achieved using feedforward torque computation. By this effects of friction and inertia could strongly be reduced as can be seen in Figure 3. Especially the effects on the ±45 locations could be reduced significantly.

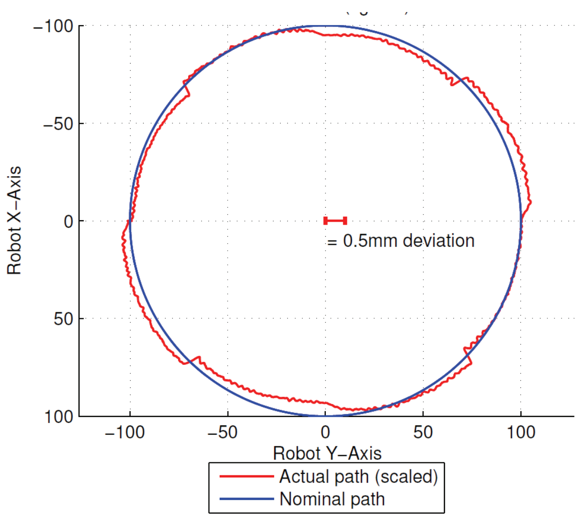

FIGURE 2. Result of a circle test in CCW on the H-Bot prototype without application of compensations, radius 100mm

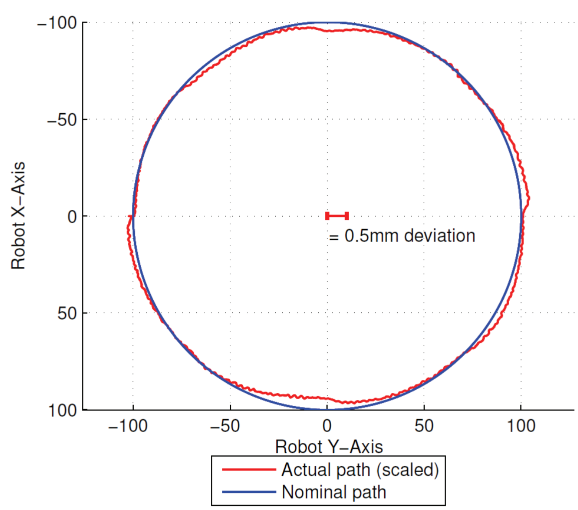

FIGURE 3. Result of a circle test in CCW on the H-Bot prototype with controller compensations, radius 100mm

For pick and place applications that the robot is designed for, position accuracy is only important at the end of a motion. In Figure 4 and 5 the results of a positioning measurement according to ISO 230-2 are shown. As can be seen, a quite good repeatability is obtained, when regarding unidirectional approach of measuring positions. The reversals are quite large and slightly position dependent. The position deviations show a systematic slope, which could be reduced, when applying linear pitch error compensation.

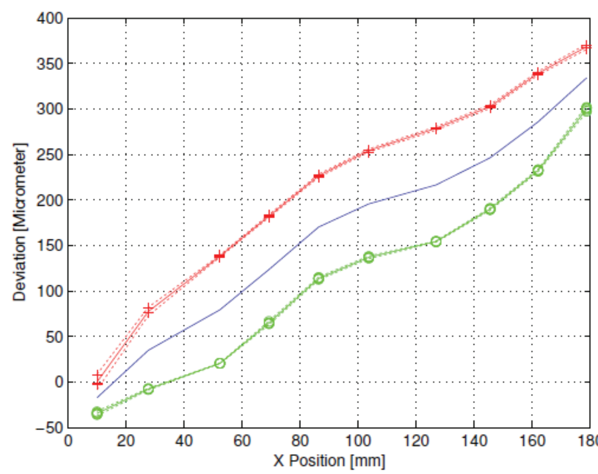

FIGURE 4. Positioning results in X-direction on the H-Bot prototype according to ISO 230-2.

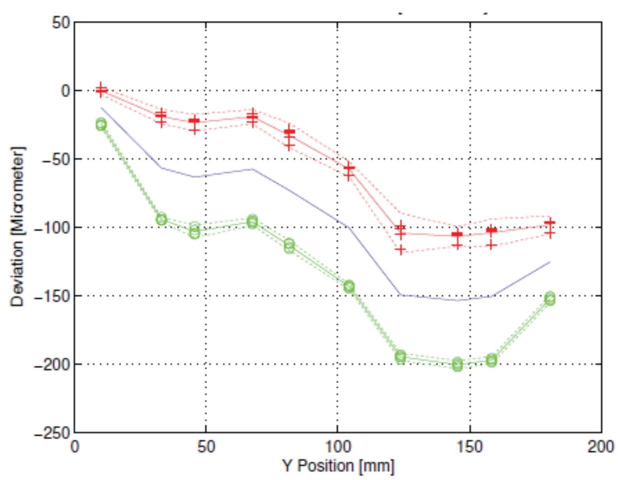

FIGURE 5. Positioning results in Y-direction on the H-Bot prototype according to ISO 230-2.

In Figure 6 2D-measurement results for a series of pendulum motions in Y-direction over 100 mm 0.4 m/sec programmed feed rate, dwell times at 0 / 100 mm: 2 seconds.

Also in this case a high repeatability between the different runs is given. As for the positioning measurements a large, in this case lateral hysteresis can be seen. Friction in combination with limited stiffness of the belt can be seen as reason for this behavior.

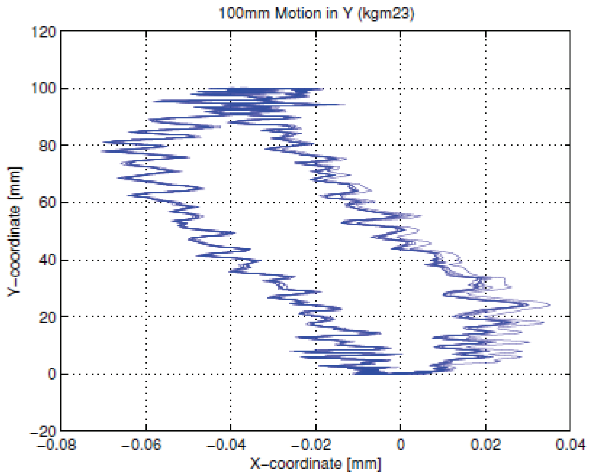

FIGURE 6. 2D-Path measurements (cross-grid) for a series of pendulum movements over 100mm in Y-direction at 0.4m/sec feed rate.

MODELING

In order to gain knowledge about the systems behavior before a prototype has been built and measurements can be made, appropriate modeling can be a very useful way to eliminate uncertainties concerning technical decisions [2].
In a first step, the kinematic parameters can be used to elaborate the relationship between the movements of the drives, the other components of the mechanism and the TCP also known as Jacobian matrix of the system. Taking into account the inertia values of the components and the friction parameters, the major requirements for the drives needed for dimensioning are obtained.
In a second step, the system shall be described for analyses regarding static loads and behavior in the frequency-domain. Here, additionally to the previous step, stiffness and damping values are required for the state-space representation of the system. At this stage, the linear control of the drives can be added.
In a third step, the system is finally completed with the non-linearities such as coulomb friction, backlash, and quantization of measurement systems e.g.
Regarding the H-Bot configuration shown in FIGURE 1, there are ten bodies which primarily define the systems behavior. For the investigation of the planar X-Y-behavior only 22 degrees of freedom have been selected:
- C-DOFs of all bodies,
- X- and Y-DOFs of bodies 5 to 10.

In this way, the yaw movements of the X-cross beam carrying the y-slider are included in the model.
The pulleys are connected by linear stiffnesses representing the belt. Linear stiffnesses in Y- and X-direction connect the X-cross beam with the inertial system and the Y-slider with the X-cross beam respectively.
Based on the inertia, stiffness and damping values and the configuration of the components a state space representation has been elaborated.
As inputs the torque of the two drives, nonlinear friction and external loads acting at the TCP are available.
As outputs of the state-space system the TCP-movements and the signals for the semi-closed or alternatively closed-loop position feed back are used for the simulation.

Alternative Model

In Figure 7 an alternative way to model an H-Bot like structure as robot model [4] is presented:
Here, the yaw movements of the X- and Y-slider and the single pulleys have been omitted.
In this case the focus was laid on the application of state space control using acceleration values obtained at the TCP [2].
Special attention was given on the backlash of the belts which are responsible for the effects at the ±45° locations noticeable in Figure 2.

Regarding the effort required for the optimisation of the compensator parameters to obtain the promising results shown in Figures 3 to 5, the availability of those models shall represent a significant support. Also the further improvement/ development of the system comprising modifications of configuration parameters such as dimensional proportion parameters (lengths / widths of sliders e.g.) or use of alternative feed-back system parameters are significantly simplified by the availability of these models.

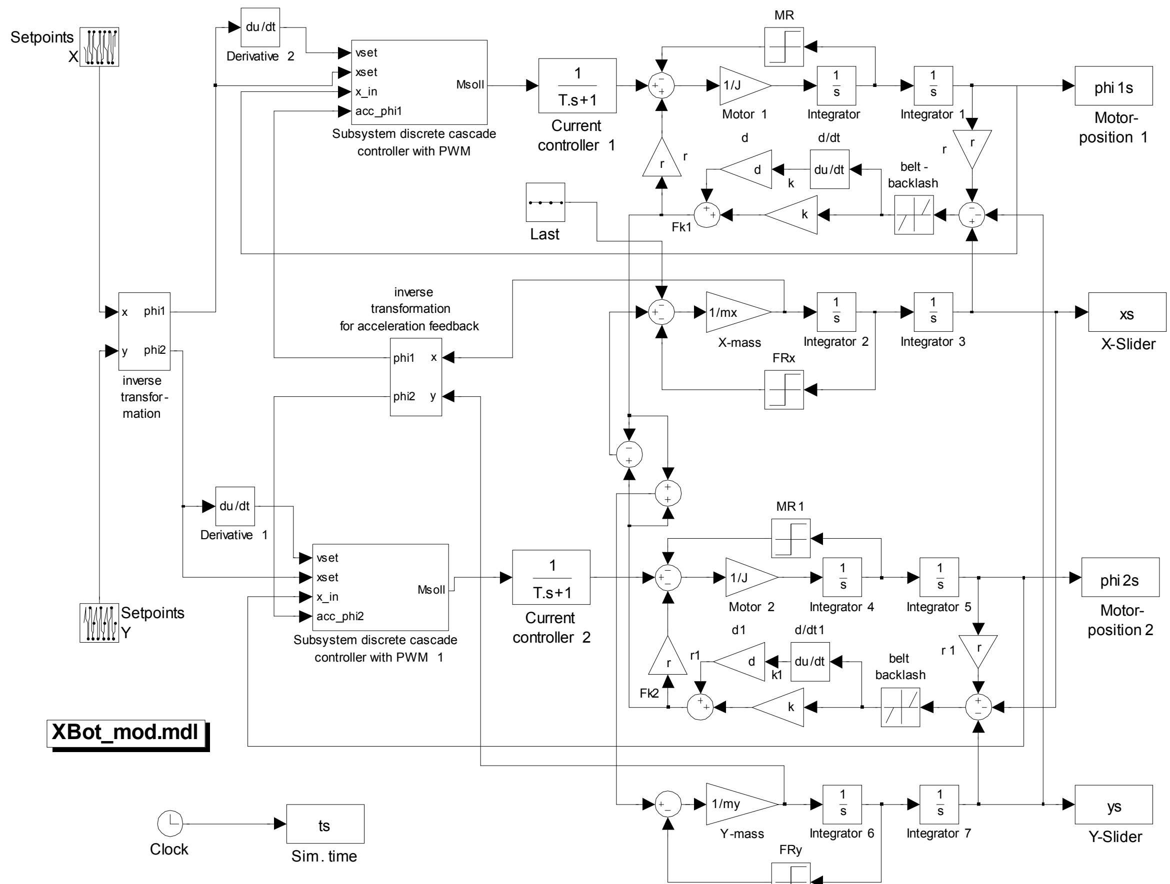

FIGURE 7. Mechatronic Simulink model of a X-Bot kinematic (similar to H-Bot) containing drives and sliders

CONCLUSION

The principal systematic effects of a new kinematic concept have been investigated using measurements and simulations.

The H-Bot prototype shows very good repeatability and systematic effects due to friction and elasticity.

On the simulation side different modeling approaches have been discussed. The models derived here will significantly support the further development of H-Bot like configurations.

ACKNOWLEDGEMENT

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