Detection and synchronisation of moving packaging units on a conveyor belt using a synchronised portal crane

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Abstract—**In industrial food industry packaging units are often carried by conveyor belts to obtain a continuously high throughput. Thus, any operation on moving objects require highly precise and fast synchronization techniques. This paper presents the design and validation of a synchronized portal crane, that autonomously detects and synchronizes with moving packaging units on a conveyor belt. The portal crane is able to carry tools of up to 50kg and synchronizes within 0.19 seconds and an accuracy of 0.1mm to objects with a transport speed of 0.2m per second. Furthermore the system is able to apply and measure vertical forces of up to 500N on packaging units. 3-Dimensional force measurements are used to validate the synchronization accuracy.**

Keywords—motor control, industrial production systems, master-slave system.

I. Introduction

In industrial food industry, packaging units are often transported on conveyor belts to achieve a continuously high throughput. Therefore, any operation on moving objects requires high-precision and fast synchronization techniques. In addition, frequent market changes require systems to be highly flexible and scalable. Today's systems available on the market are mechanical solutions which are robust but inflexible regarding changing packaging and characteristics.

Within the scope of this project work, the design and validation of a synchronized portal crane is presented, which independently detects and synchronizes moving packaging units on a conveyor belt. An optical detection method is designed to detect the moving packaging units on a conveyor belt. The system is controlled by a program on a programmable logic controller (PLC). The master-slave configuration with spline interpolation manages the twin motor system. The cascade structure of the control loops regulates the state variables current, speed and position individually. Direct following of the setpoint, as well as the correction of disturbances, such as load changes, are decisive for synchronization accuracy. All axes can be individually configured and parameterized by a sophisticated drive technology, which can be easily adapted to new packaging units by software configuration. A user interface allows the user to read out process data and the status of the system at any time.

The portal crane is able to carry tools of up to 50 kg and synchronize itself to objects with a transport speed of 0.2 m per second within the shortest possible time and with a high degree of accuracy. For this purpose, methods of conception, dimensioning and development in the field of servo drive technology are dealt with. An optical recognition method can identify moving packaging units with a high resolution. Furthermore, the system is able to apply and measure vertical forces of up to 500N on packaging units. A developed 3-dimensional force measuring device is used to validate the synchronization accuracy and to optimize the process. The evaluation is automated, which allows a high test throughput and a comfortable process optimization. The results show that both the modular belt and the alignment of the can on the conveyor system have a significant influence on the closure and synchronization quality. A newly developed can transport system allows the infeed direction of the can to be adjusted based on the measured data.

There are a number of works based on the master-slave configuration and its various applications. A comparison of multi-motor synchronization techniques are discussed in [1] and [2]. A design of an automated pepper sorting machine, which is also based on a portal crane system, is discussed in [3]. The authors describe the successful design and development of an automated pepper sorting machine based on a conveyor system and linear axis system. In [4] high-speedpick-and-place tasks with multi-robot coordination are described.

This paper proposes a method for synchronized objects on a conveyor system by means of a lifting system attached to a linear axis system. The method was successfully tested on a test setup consisting of a conveyor and linear axis system with master-slave configuration and a force-measuring device.

The outline of this paper is as follows. The design of the experimental test set-up is given in Section 2. Section 3 explains the synchronization of the two axis. The design and impmentation of the force measuring device is statet in Section 4. The measurement results are presented in Section 5 and in Section 6 the conclusions are statet.

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II. Experimental Test Set-Up

The test system consists of two parallel linear axes with a length of 1300mm, which have a positioning accuracy of 0.1mm, as shown in Figure 1. The drive is provided by a synchronous servo motor, which mechanically copes both axes via a drive shaft. This is fed by a pulse width modulated converter. The optical encoder records the axis movement with a resolution of 16 bit. The two linear axes each have two carriages and can be moved in x-direction. The carriages are firmly connected to the belt drive of the linear axes. The force measuring device is located in the middle between the four carriages and is attached to a compressed air cylinder which is able to perform a movement, s, of 25 mm.

The conveyor belt system under the linear axes is made of extruded aluminium beams and provides a useful conveying length of 2m and is able to carry loads in Z-direction up to 50kg with 0.1mm displacement. Cast plastic segments are connected to form the conveyor chain, which is driven along the carrier by a synchronous servo motor and reduction gear. A pulse width modulated converter feeds the synchronous servo motor. The conveyor position is precisely measured by an encoder attached to the drive with a resolution of 16 bit.

The system is designed so that the conveyor system moves at a maximum constant speed of 0.2ms-1 in X-direction, while the portal crane system detects independently moving packaging units and performs synchronization within a test length, T, 0.15s and, s, 80mm.

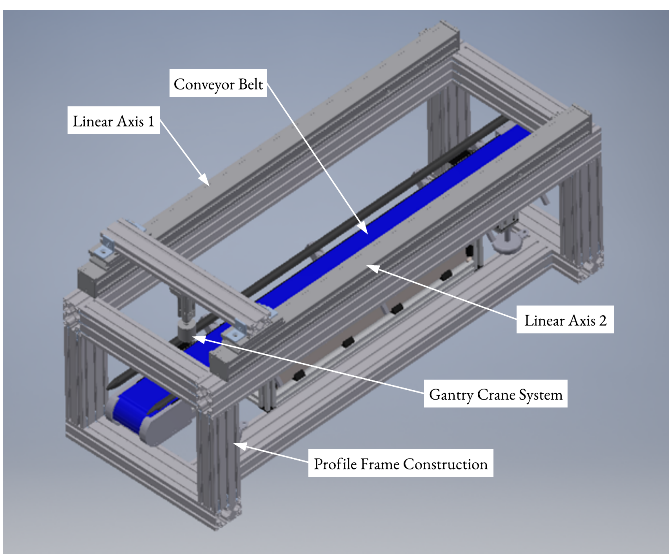

Fig. 1. Speed profile for the portal crane system

III. Synchronization

Before developing the synchronisation control loop, it is necessary to define the speed profiles of the two axes to enable the portal crane system to perform detection and synchronisation. Figure 2 shows the motion profile for the portal crane system during the synchronization process. Short acceleration times t_{av} and a high position accuracy are important to keep the cycle time t_{tot} of one second. The distance for forward s_v corresponds to the distance for backward s_r. The maximum forward speed v_V is set to 0.2m/s. The value of the maximum acceleration should not exceed 6.25m/s^2. The time for forward travel is 65% of the total time t_{tot}. Higher values lead to higher acceleration values, which makes the evaluation of suitable drives difficult. According to the illustration, it may be assumed that the speed and acceleration values during reverse travel during time t_r and distance s_r. Therefore the following calculations only show this part of the synchronization process.

The equation 1 shows the calculation of the maximum speed v_r during reversing process:

$$v_r = 2 * \frac{s_r}{t_r} = [m/s] \tag{1}$$

Where, s_r = reversing distance [mm] and t_{av} = acceleration time [s]. Based on this, the maximum acceleration a_r during the reversing process can be calculated according to the equation 2:

$$a_r = 4 * \frac{s_r}{t_r^2} = [m/s] \tag{2}$$

Where, s_r = reversing distance [mm] and t_{av} = acceleration time [s].

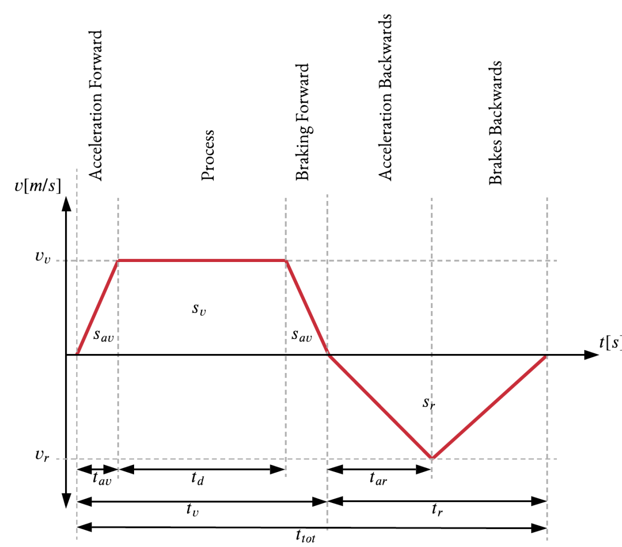

Fig. 2. Speed profile for the portal crane system

The parameter determination for each control loop of the cascade structure is individual and independent. If the control loops for the state variables current and velocity each have a PI controller, the control loop for the state variable position consists of only one P controller. The parameters are determined iteratively by both drives and optimized for a minimum contouring error. The figure 3 shows the parameterization of all three controllers. The current controller is able to reach the setpoint within 16ms and then remains absolutely stable. The specification of the speed difference shows a maximum value of 15 rpm, which speaks for an optimized control. In contrast to the parameterisation of the current controller, the settings for the controllers for the state variables speed and position are carried out by means of a standardised movement pattern and under load. Relevant for a correct synchronization is the tracking error which the drive exhibits during the critical phases of acceleration, change of direction and deceleration. This is very small at 0.036mm, which also speaks for optimal parameter settings.

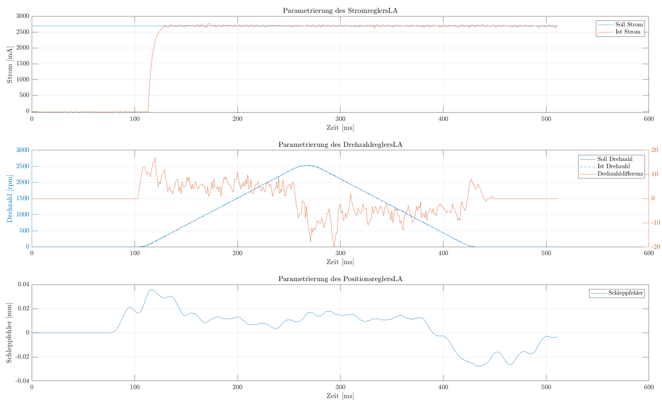

Fig. 3. Parameterization of all motion-controllers

Synchronization is performed by a master-slave configuration for the two-motor system and is shown in Figure 4. The master is the drive for the conveyor system, and the corresponding drive for the cantry crane system. The position of the master serves as a position reference for the slave. It follows that any speed or load disturbance acting on the master will be reflected back to the slave. On the other hand, the disturbances of the slave have no retroactive effect on the master.

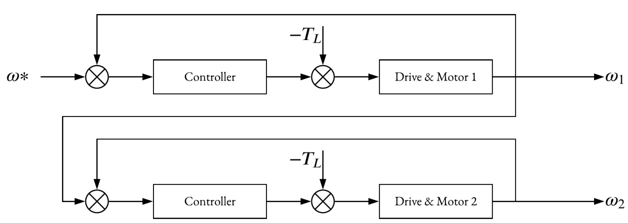

Fig. 4. Structure of the Master-slave for a two motor system scheme

Synchronization is performed by a master-slave configuration for the two-motor system and is shown in Figure 4. The master is the drive for the conveyor system, and the corresponding drive for the cantry crane system. The position of the master axis serves as a position reference for the slave axis. As a result, any speed or load disturbance acting on the master axis will reflect on the slave axis. On the other hand, the disturbances of the slave axis do not affect the master axis retroactively.

The reference value for the slave axis is set by a spline interpolation of individual position values of the master axis. The spline interpolation method allows the generation of a defined contour with smooth curves using a small number of spline points. This means that a spline is a curve without edges and with constantly changing radii of curvature. A spline consists of a series of 2nd degree polynomials. Using a higher degree of polynomials results in a longer calculation time and a correspondingly longer synchronization time. The individual curve segments each have the same inclination and curvature. This leads to smooth transitions and even critical sequences of spline points do not cause overshoot.

Figure 5 shows the coupling process using a path-time diagram and a velocity-time diagram. Before the coupling, the conveyor belt axis is already in constant forward motion. When a positive edge of the detection device, see red arrow, the actual position of the conveyor system is adjusted to the actual position of the portal-crane system. The detection device is only able to detect objects at their front edge and not their centre. For this reason, the radius s_R of the object is additionally subtracted when the conveyor belt position is transferred. During coupling, the master axis moves a predefined path s_M at a predefined speed. Accordingly, the slave axis moves a predefined distance s_S and has a predefined target speed with zero acceleration at the end.

The use of a polynomial-shaped speed curve allows the slave axis to move smoothly during the coupling process. After the coupling, the current phase can be queried. If method returns 7, the axis is in the coupling phase (i.e. is not yet synchronous with the master axis). If the method returns 8, the axis is synchronous with the master axis.

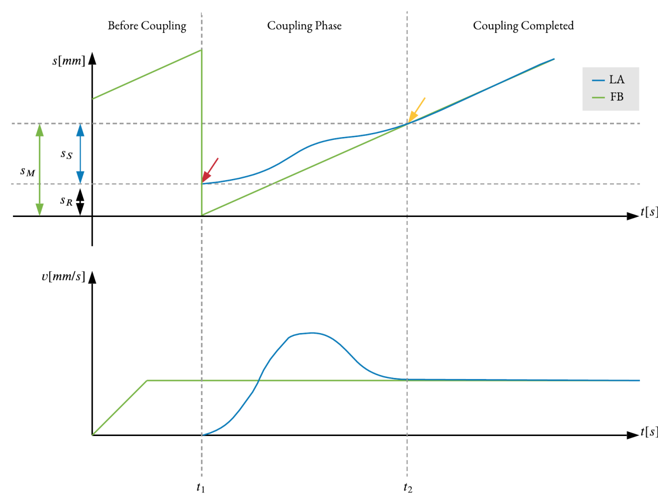

Fig. 5. Speed and position profile of the axes during the coupling phase

IV. Validation

A 3-dimensional force measuring device is used to validate the synchronization accuracy and to optimize the process. The structure of the force measuring device and the placement of the four force measuring sensors is shown in Figure 6. The force measuring device allows the exact placement of the sensors in a 90 degree distance. The distance radius to the centre corresponds to the size of the packaging units. The sensors are compression load cells consisting of strain gauges and output a certain voltage when the force changes. Relevant for this application is the high speed and reliability. A structure of 3D printed parts holds the sensors in the intended place and allows only movements in the desired area.

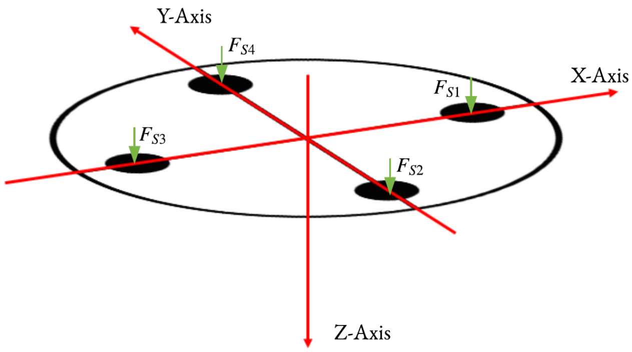

Fig. 6. Design of the force measuring device

The calibration is done by applying different fixed weights to the sensors. Figure 7 shows the recording of ten measuring points within the measuring range (0N-500N). The x-axis shows the measured stress values of each sensor, the y-axis represents the corresponding force values. It is assumed that when the force measuring device is loaded, all four sensors experience the identical force deflection. The use of a 2nd degree polynomial compensates for the non-linear characterization of the sensors. The accuracy of the regression is reflected in the coefficient of determination, which is 9.91 for the system in the minimum.

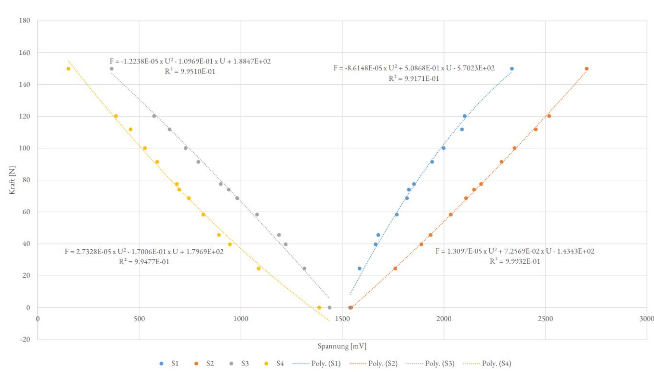

Fig. 7. Calibration characteristics of the four force measurement sensors

From the force measurement data of the four sensors the forces in the corresponding direction can be derived with the following formulas 3, 4 and 5.

$$F_x = F_{S1} - F_{S3} = [N] \tag{3}$$

$$F_y = F_{S2} - F_{S4} = [N] \tag{4}$$

$$F_z = F_{S1} + F_{S2} + F_{S3} + F_{S4} = [N] \tag{5}$$

Where F_x, F_y and F_z [N] are the forces in the corresponding direction, F_{S1}, F_{S2}, F_{S3} and F_{S4} [N] he force values of the sensors.

V. Measurements

The data sources for the measurements are on the one hand the direct drive data of the two mo-tors, on the other hand the data from the force measuring device are relevant for a quantification of the process.

Figure 8 shows a path-time diagram and a velocity-time diagram. In the upper of the two diagrams, the nominal and actual values of the two axes are recorded. The two vertical lines show the range of the synchronization phase. The coupling phase takes only $\approx 150ms$. During the synchronization phase there is a deviation of both actual values of ¿0.1mm. During the return process, there is a slight deviation between the nominal and actual values of the linear axis, which cannot be avoided due to the high dynamics. In the speed profile, there are also small deviations between the nominal and actual values, especially during the coupling phase and the return phase. During the synchronization phase, on the other hand, the speed profile remains very constant. The force in the Z-direction is also shown in the diagram. Due to the use of a throttle check valve in the direction of the impact, the force increases only gradually and remains at a constant value of $\approx 500N$. There are no disturbances when the force in Z-direction is completely built up. This shows the robustness of the motion-controller and its parameter settings.

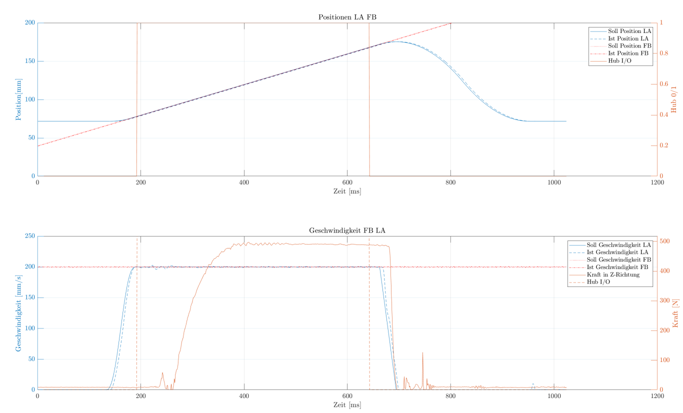

Fig. 8. Nominal and actual values for position and speed of both axes

The figure 9 shows a section of the measurement report from a single measurement. In addition to the raw data of the force sensors, the forces in X, Y, Z direction are given. With the help of these it is possible to detect the alignment of the packaging units under the force measuring device. In the ideal case, the forces for the X and Y direction are 0N, which means absolute equilibrium. The maximum deviation of the forces for the X and Y direction is only 30N, which is only 6% of the total force in the Z direction. Possible reasons for the deviations are the placement of the packaging units, the base of the conveyor belt system or also measuring errors caused by the force measuring device. During the synchronization phase, the force values remain very constant. The peaks before and after the synchronization phase are due to the mechanical design of the force measuring device.

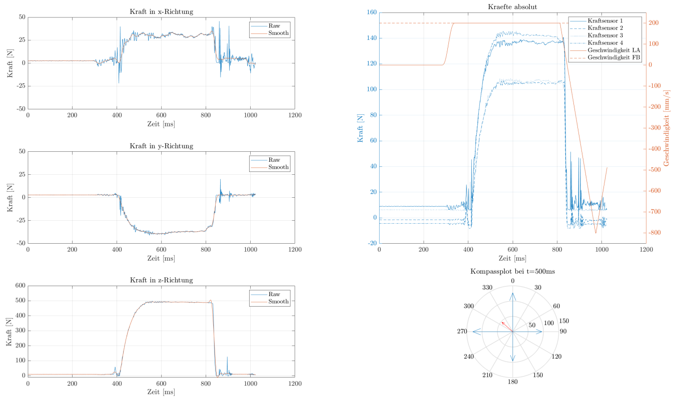

Fig. 9. Measurement evaluation from a sealing process

VI. Conclusion

The paper describes the successful design and development of a synchronised portal crane using multi-motor synchronisation techniques. The entire system consists of the selection of mechanical and electronic components, architectural design and the production of hardware prototypes. The developed system is able to carry tools of up to 50kg and synchronizes within 0.19 seconds and an accuracy of 0.1mm to objects with a transport speed of 0.2m per second. Furthermore the system is able to apply and measure vertical forces of up to 500N on packaging units. 3-Dimensional force measurements are used to validate the synchronization accuracy. It can be successfully used in industry for the handling process of moving objects on a conveyor belt system. In the future the accuracy and performance of this concept can be further improved and transferred to automated industrial applications.

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