Toward Application of an Active Fence for Object Detection, Manipulation and Alignment on Conveyer Belt

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Abstract

This paper presents a novel approach for orienting an object on conveyer belt utilizing an Active Fence. The Active fence was implemented with low cost sensory system used for tracking the contact/collision force generated from interaction between the Active Fence and the object. A generalized mechanical model of the collision/contact event is developed and basic relations between impact signature and object properties are established. Also, the conditions in which manipulated object displays slip-stick (relaxation) motion during the process of the manipulation are investigated.

1. Introduction

In automated packing or assembly often it is necessary to bring randomly oriented objects to a specific position/orientation due to the needs in assembly process. There are two general class of applications for object orientation: sensor-less and sensor-based. Both classes are based on manipulation strategy constituted from sequence of deterministic manipulation procedures. The objective of each of these procedures is to lower the randomness in the orientation of the object, eventually living the object in desired configuration. The sensor-less object orientation was explored by Erdeman [1] where they gave a general motion strategies for sensor-less manipulation. Sensor-less manipulation leads to implementing an manipulation strategy constituted by far more object states than appropriate sensor-based manipulation. The former strategy is constrained by passive nature of manipulating agent so that it has to assume the worst orientation case for each incoming randomly oriented object .

Object alignment on conveyor belt by passive fences [2] is one of possible applications based on sensor-less object orientation. An object lying on the belt is forced through series of interactions with different oriented fences. For example, when the vertex (edge) of the object collides with a fence it will start rotating until it achieve an aligned (stable) configuration with the fence. Due to conveyor movement object will continue to slide along the fence until it leaves the fence [3].

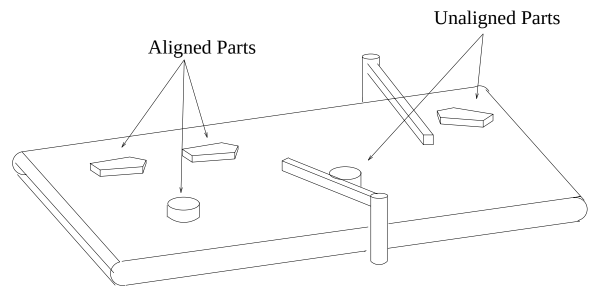

Figure 1: Conveyer Belt with Active Fences

Sensor-based manipulators interact with the environment through a set of sensory systems. The additional data acquired through sensory system is used to determine the current condition of the manipulated object. Compared to sensor-less manipulators, sensor-based manipulators are able to select the optimal manipulation strategy for object orientation, which result in higher throughput of the system.

In this paper it is proposed that determination of the contact point between Active Fence and identification of object could be accomplished through observing the changes in oscillatory frequency in Fence-Object system[4].

One possible system for object orientation is the implementation of two Active Fences is shown in figure 1. The implementation of the Active Fences with sensory system gives the system an ability to make distinction among different classes of objects. Furthermore, having this information system can select the appropriate set of manipulating rules according to the incoming type of object and its desired orientation. Ability to process several different classes of objects yield much higher throughput than systems based on passive fences. Also, flexibility in selecting several different sets of manipulating rules combined with simplicity of their implementation can make the proposed system to be an important component of the Flexible Manufacturing System (FMS).

An investigation of contact/collision event is presented in the next section. Due to nonlinear nature of the environment the event is divided in three sequential phases. For each phase a simple model of contact is proposed. The motion of the manipulated object is investigated and are given general boundaries of factors governing the object movement on conveyer belt. In section 3, experimental results are presented which confirms the proposed hypothesis of this paper. Section 4 presents conclusion and directions of future work.

2. Modeling

Object movement on the conveyer belt is heavily governed by the friction forces generated between object and belt. Furthermore, it is assumed that the contact between the Fence and manipulated object usually is periodic during the collision event.

Determination of the contact point between the object and Fence can be accomplished through observing the oscillatory movement of the fence-object system during the collision/contact event. It is also assumed that during the collision/contact event, the Active Fence will react as a flexible cantaliver beam. In a short time of the contact/collision event, the object and the Active Fence system will act as a fence (beam) with substantial changes in its mass. Due to change in total mass $m = m_F + m_o$ where m_F is equivalent mass of the Fence and m_o is mass of the object, the natural frequency of the fence $\omega_o = \sqrt{k/m}$ will change, where k is the equivalent spring coefficient of flexible cantaliver beam.

The flexibility of the flexible cantaliver beam can be defined as a spring coefficient $k(l)$ as a function dependent on position of the contact point between Fence and object. In general, the deflection of the beam due to external force f_{impact} is given:

$$\Delta x = -\frac{l^3}{3\,E\,I}\,f_{impact} \tag{1}$$

Where f_{impact} is the external force acting at the contact point on a distance l from supported side of the beam, E is Young's modulus and I is the corresponding moment of the inertia. According to this equation, the equivalent spring coefficient $k(l)$ can be expressed as:

$$k(l) = \frac{3\,E\,I}{l^3} \tag{2}$$

as a function of the contact distance l. The equivalent

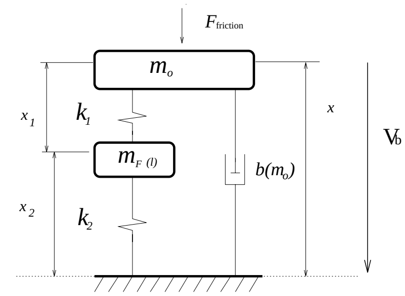

Figure 2: Second Phase Model

mass load for small deflections is:

$$m_F(l) = \frac{m_{fence}\,L^2}{4\,l} \tag{3}$$

where the m_{fence} is mass of the Active Fence, L is its length and l is the distance of the impact point from the supported end of the fence. The damper coefficient b is dependent of the friction between object and the conveyer and its definition is given latter in the paper.

Here we are proposing a model of the contact/collision event constituted of three consecutive phases: 1) collision phase, 2) damped oscillation phase, and 3) balanced phase.

The collision phase determines the actual collision of the incoming object into the Active Fence. The sensory system will produce an collision signature output with peak value that can be expressed as:

$$V_{peak} = f(m_o, l) \tag{4}$$

where the value of V_{peak} is given in volts, m_o is the mass of the incoming object and l is actual location of the contact point. However, the proposed transformation is not one to one transformation, and parameters can be defined by using the additional information extracted in next phasess.

Second phase is the damped oscillatory movement. In this phase we can assume that contact between Active Fence and incoming object is continuous. Figure 2 represent a model of the second phase. The mass load m_o is actual mass of the incoming object, the m_F is equivalent mass load of the Active Fence mass m_{fence}, the k_1 is the spring coefficient representing the stiffness of the incoming object, k_2 is equivalent spring coefficient $k(l)$ of the Active Fence. Damper b is representing the damping force f_d generated from the friction between the conveyer and object.

The total displacement from equilibrium point is $\Delta x = \Delta x_1 + \Delta x_2$. Constrained in quasi-static movement we can assume that system of two loads m_o and m_F will exhibit synchronous movement with negligible phase shift. Therefore relation

$$k_1\,\Delta x_1 = k_2\,\Delta x_2 \tag{5}$$

will hold. Further we can assume that Object-Fence system is exhibiting periodic or nearly periodic oscillatory movement. The damping ratio of that movement is defined by friction between object and conveyer while exhibiting a slip-stick motion. In this motion part will generate friction force only in slip period of oscillation i.e. following the Figure 2, for $\Delta\dot{x} < 0$ while in stick period it will be sticked onto the conveyer (for $\Delta\dot{x} > 0$). The half period when the friction force f_d is active is represented by the damper b acting on object with mass m_o with force f_d:

$$\begin{aligned} f_d &= -\mu_d\, g\, m_o\, \frac{(1 + sign(\Delta\dot{x}))}{2} \\ where & \\ f_d &= \mu_d\, g\, m_o \quad for\ \Delta\dot{x} > 0 \\ f_d &= 0 \qquad\qquad for\ \Delta\dot{x} < 0 \end{aligned}$$

Because system oscillatory movement is periodic we can further simplify previous equation with a force active full period of oscillation $f_d{}' = \frac{f_d}{2}$ acting in opposite direction of the object movement:

$$f_d' = -\frac{\mu_d\, g\, m_o}{2}\, sign(\Delta\dot{x}) \tag{6}$$

The dynamics equations for the model can be written as:

$$\begin{aligned} m_o\,\Delta\ddot{x} &= -k_1\,\Delta x_1 - f_d' \\ m_F\,\Delta\ddot{x}_2 &= k_1\,\Delta x_1 - k_2\,\Delta x_2 \end{aligned} \tag{7}$$

Form (5),(6) and (7) the dynamics equation of the oscillatory system expressed through term Δx_2 is:

$$\begin{aligned} (m_F\frac{k_1}{k_1+k_2} + m_o)\Delta\ddot{x}_2 + \\ +\frac{\mu_d\, g\, m_o}{2}\, sign(\Delta\dot{x}_2) + \\ +\frac{k_1\,k_2}{k_1+k_2}\,\Delta x_2 = 0 \end{aligned} \tag{8}$$

where the oscillatory frequency is:

$$\omega_o = \sqrt{\frac{\frac{k_1\,k_2}{k_1+k_2}}{m_F\frac{k_1}{k_1+k_2} + m_o}} \tag{9}$$

while the middle term $\frac{\frac{\mu_d\, g\, m_o}{2}}{m_F\frac{k_1}{k_1+k_2}+m_o}$ is defining the damping in the Object-Fence system.

Generally, three different configurations of interrelation between the spring coefficients k_1 and k_2 can exist. In the case of $k_1 \gg k_2$ which will hold for stiff object, the equation (9) transforms in:

$$(m_F+m_o)\Delta\ddot{x}_2+\frac{\mu_d\, g\, m_o}{2}\, sign(\Delta\dot{x}_2)+k_2\,\Delta x_2 = 0 \tag{10}$$

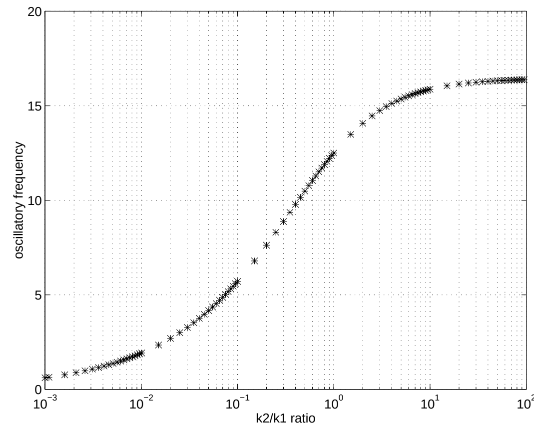

Figure 3: Frequency - Coefficient Curve

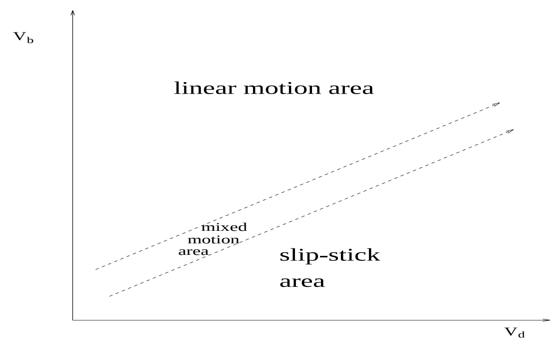

Figure 4: Dynamics of the Moving Object

yielding the spring-damper system on figure (2). When the $k_1 \ll k_2$ i.e. case of very rigid Fence, the equation (9) transforms into:

$$(m_o)\Delta\ddot{x}_2 + \frac{\mu_d\, g\, m_o}{2}\, sign(\Delta\dot{x}_2) + k_1\,\Delta x_2 = 0 \tag{11}$$

since the ratio of $m_F\frac{k_1}{k_1+k_2}$ tends to zero and $\frac{k_1\,k_2}{k_1+k_2}$ tends to k_1. In the case where the values of the both spring coefficient are close, the ω_o oscillatory frequency is defined in the equation (9). However, the transition from one to other spring coefficient configuration is not linear and it is presented on the Figure (3). Both asymptotes are defined by two extremum relationships while transition curve is defined by (9). Figure (3) represents transition frequency curve for particular configuration of : $\frac{k_1}{k_2} = 100$ to $\frac{k_1}{k_2} = .001$ with $m_o = 270g$.

The last stage of contact model is the balanced phase. Object movement in this phase is defined by various factors and object can exhibit linear or slip-stick (relaxed) motion on the conveyor belt. Defining the motion in the plane of the object and conveyer velocities V_c and V_d we can express object motion behavior(figure 4). The first variable is actual velocity of the conveyer belt and second variable V_d [7] is a variable proportional to maximum velocity attained by manipulated object when it slips along the slipping direction.

$$V_d = g\sqrt{\frac{m_o}{k_{eq}}} \tag{12}$$

where m_o is object mass and k_{eq} is equivalent spring coefficient $k_{eq} = \frac{k_1\,k_2}{k_1+k_2}$. Considering the object-fence system in the third phase as a undamped oscillatory system we can model its motion as a harmonics oscillatory system with position $x(t)$, velocity $\dot{x}(t)$ and natural frequency $\omega_o = \sqrt{\frac{k_{eq}}{m_{eq}}}$:

$$\begin{aligned} x(t) &= X_o\,\cos(\omega_o\,t) \\ \dot{x}(t) &= X_o\,\omega_o\,\sin(\omega_o\,t) \\ \dot{X}_{o\;max} &= X_o\,\omega_o \end{aligned} \tag{13}$$

The maximum displacement of the spring when object is entering slip state (between the object and conveyer) is given as:

$$\begin{aligned} X_o &= \frac{f_{slip}}{k_{eq}} \\ f_{slip} &= \mu_s\,m_o\,g \end{aligned} \tag{14}$$

where the μ_s is a static friction coefficient of the object. Figure (4) shows a general velocity space diagram of an Object-Fence system in third phase. For belt velocities smaller than particular V_d system will always exhibit linear motion. The boundary between two spaces is a narrow belt of mixed motion.

In case where Active Fence attains an angle which is not perpendicular to the direction of the conveyer motion, the conveyer velocity relative to slip direction will be:

$$V_{c(\alpha)} = V_c\,\sin((\alpha) \tag{15}$$

Furthermore, considering a case where active manipulation of the object by Fence is implemented, the relative conveyer velocity to the object is defined:

$$V_{c\,rel} = V_c\,\sin((\alpha) + V_{fence} \tag{16}$$

Where V_{fence} is the contact point linear velocity $l\,\dot{\alpha}$ and $\dot{\alpha}$ is actual angular velocity of the Active Fence.

3. Experimental Setup

The experimental setup is shown on figure 5. An Active Fence was implemented as a aluminum beam of length 20 cm. The actual Active Fence was built with a notch close to the supporting side in order to simulate the flexible joint. The sensory system able to track force generated due to impact event between object and Fence was implemented through force transducers based on two strain gages. Each of the strain gages was

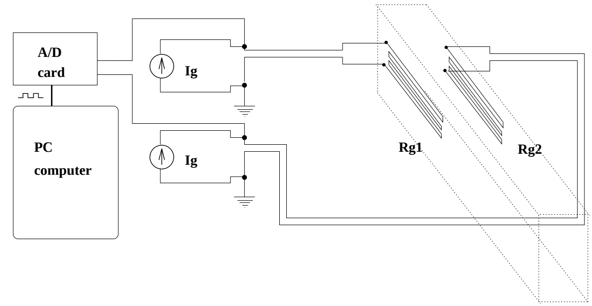

Figure 5: Experimental Setup

glued on opposite side of the Fence close to the pivoting point. Each strain gage was driven by constant current supply circuit. Such configuration by sensitivity and linearity equals to full Wheatstone bridge. Differential voltage measured at the ends of strain gages was passed to acquisition card through standard PC. Measuring the differential voltage nulled the temperature drifts of the gage resistance. Sampling rate was chosen significantly high 8.12kHz even the final system should use rate less than 1000Hz. Power source for the sensory system was battery. The achieved white noise in the system was less then 5nV. The calibration of the sensory system is software based in order to minimize degradation of the sensitivity and decrease the white noise in the system due to additional elements present in hardware based calibrator.

The first object of the experiment was devoted to recognition of the incoming objects using the measured data from the strain gages. The Active fence was mounted with a 90° angle to the moving direction of the conveyer belt. Moving speed of the belt during the experiments was kept constant at $V_c = 11cm/s$.

4. Experimental Analysis

Figure 6 (a and b) shows an typical collision/contact signature of the event obtained through the force transducer during sample time length of 1.15 sec. The nonlinear relations among the belt, object and fence are resulting in complex collision/contact signature. The processed object is an aluminum cylinder with weight of 280g (fig. 2.a). Figure 2.b shows contact/collision between the Fence and flexible object. Flexibility was simulated with covering the impact side of the cylinder with masking tape. In both signatures friction coefficients were the same.

The first phase is shown in Figure (7). Figure 8.a part shows collision of the stiff object while Figure 8.b shows collision of the flexible object. Generally, following the model the peak values are very close to each other and

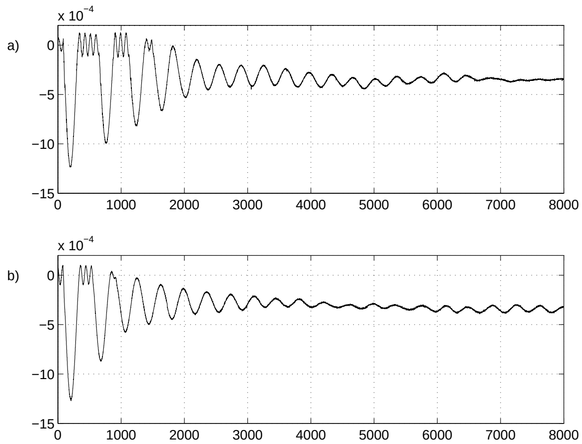

Figure 6: Collision/Contact Signature of Objects with Different Stiffness

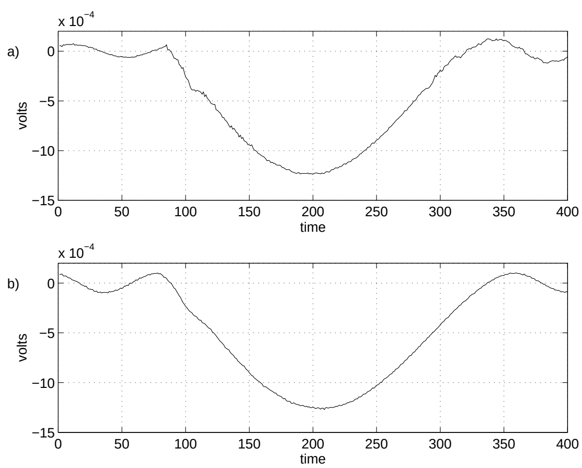

Figure 7: Collision Phase

both curves shows difference in length of the collision time. The flexible object produced longer impact time and lower ω_o frequency of oscillations according the model.

In second phase both objects exhibit damped oscillatory movement with same damping ratio but different oscillatory frequency ω_o. According to the equation (9) stiff object oscillatory frequency $\omega_{o(stiff)}$ is higher than $\omega_{o(flex)}$.

The third phase (Figure (7)) shows that both objects are entering slip-stick area of the motion plane. However, the stiff object is having higher spring coefficient so that it is closer to the linear motion area. Figure (8) shows tree different mass configurations of the third phase and its relationship to the oscillatory frequency.

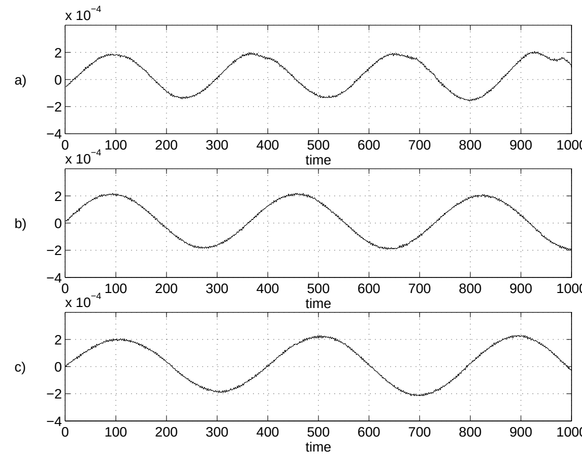

Figure 8: Balanced Phase

5. Conclusion and Future Work

This paper introduces a novel application of orienting the randomly oriented objects utilizing the Active Fence. We proposed the general model of the colision/contact event signature incorporating the basic object properties. Also, the moving behavior of the manipulated object is defined.

The executed experiments provided data that follows the dynamics of the proposed model. In further work we are going to address the issues of the choosing the optimal manipulation strategy and develop the general algorithm for object recognition from collision/contact signature.

6. Literature

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