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Design Requirements and Reference Trajectory Generation for a Copier Paperpath.

Carlo Cloet, Masayoshi Tomizuka and Roberto Horowitz

Department of Mechanical Engineering, UC Berkeley
Berkeley, CA 94708, USA

ccloet@me.berkeley.edu

Abstract— **This paper presents a new approach to introducing closed loop control in a copier paperpath in order to achieve robust, high-speed media handling. The basic idea exploits periodicity in the relative position of correctly fed sheets and their corresponding images. It is shown that the periodic behavior allows to design polynomial position reference trajectories for sheets as a function of their initial position error. Only longitudinal position errors are considered. By measuring sheet positions and using closed loop control to track the reference trajectories, position errors can be successfully removed. In addition to the reference trajectories, the paper also offers a design strategy that minimizes the required paperpath length while satisfying given bounds on sheet velocities and accelerations. Two examples, each with different initial error bounds, illustrate the design algorithm.**

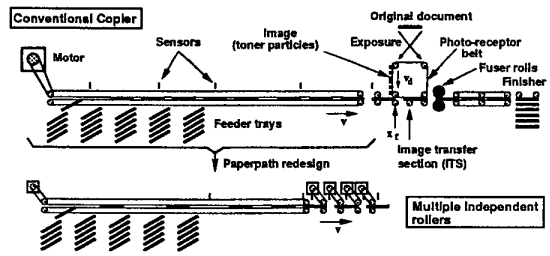

Fig. 1. Schematic overview of a standard and redesigned cut sheet copier machine. Note that the paperpath does not need to be flat.

I. Introduction

A central issue in the design of tomorrow's high throughput copier machines is reliable sheet handling. Today's copiers operate mainly in an open loop fashion, i.e. sheet transport assumes nominal sheet behavior with little room for deviations. This approach limits the achievable throughput for any given design. Error correction is usually achieved by modification of the open loop position reference trajectory, based on a measurement of the position error. There is no further control after this correction [1].

This paper presents a possible way to achieve robust media handling by introducing closed loop sheet position control and *in addition, specifies the corresponding paperpath design requirements.* It is organized as follows. First, some assumptions are made regarding the paperpath layout in order to achieve a high throughput. These assumptions are described in section II, together with a formulation of the problem to be solved. Independently driven rollers are used to provide independent sheet position control.

The solution approach, described in section III, is based on the observation of periodicity in both the sheet feeding and sheet arrival times. Polynomials are used to generate position reference trajectories. Since the sheets are independently controllable, feedback control can be used to track the reference trajectories [2]. In addition to the reference trajectories, an iterative algorithm allows the designer to determine the minimum required paperpath length such that the worst case trajectories still satisfy design constraints on sheet velocities and accelerations.

Next, section IV illustrates the results for two different worst case initial position errors. Section V ends the paper with some conclusions.

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II. System Description and Problem Formulation

The system under control is a cut sheet copier paperpath. Its purpose is to transport sheets from a feeder unit to an image transfer section (ITS). This is schematically represented in figure 1. The paperpath considered in this paper contains one long section and multiple independent rollers right before the ITS, as opposed to a traditional paperpath, which usually consists of only one single roller before the ITS for open loop error correction [3].

Some specific assumptions are made concerning the different components in the cut sheet copier. These are described next.

A. Achieving High Throughput of Sheets

The feeder trays contain various types of sheets or other media. The first section, a set of rollers, connected by timing belts and driven by a single motor, transports sheets when they leave the trays. It is assumed that this first section is *driven at a constant velocity.* This simplifies the feeding process.

In general, it is hard to obtain reliable and repeatable feed characteristics. Typical feed errors will depend on the media type, feeder type, environmental conditions, component wear and manufacturing tolerances. Apart from position errors introduced by the feeder units, additional errors may accumulate during sheet transport in the first section. This is mainly due to slip, roller wear and sheet bending between rollers.

Due to the feeder errors and additional disturbances during transport in the first section, it is impossible to feed sheets close together. In order to obtain a high troughput,

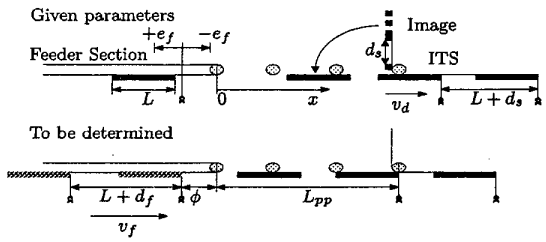

Fig. 2. Trajectory design nomenclature.

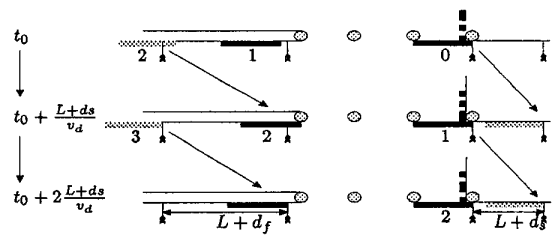

Fig. 3. The periodic nature of sheet entry and sheet arrival.

it is therefore necessary to run the first section at a high velocity. On the other hand, the photoreceptor belt, responsible for the image creation and transfer process, runs at a constant, but lower velocity, both due to xerographic reasons. In order to obtain a high throughput, sheets are placed close together inside the ITS. This corresponds to placing images close together on the photoreceptor belt.

The combined approach is to feed sheets at a large spacing, but fast, as opposed to close together and slow in the ITS. This approach maintains a constant mass flow of sheets throughout the machine and makes sure that the first section can accommodate large feed errors.

B. Paperpath Subsystem

The actual paperpath forms the link between the first section and the ITS. Its purpose is to match the sheet positions with their respective images on the photoreceptor belt. Note that a typical copier machine contains a registration station to correct for both longitudinal and lateral position errors and skew. This discussion will only consider longitudinal errors.

The paperpath is *assumed to only contain independently driven rollers.* Sheets driven by independent rollers can be controlled independently.

C. Problem Formulation

The paperpath must deliver sheets from a fast first section, running at constant velocity, to a slow ITS, also running at constant velocity. In doing so, it must correct any feed errors and accumulated position disturbances, handle disturbances during sheet transport and match the sheet positions with their respective images when they reach the ITS. This is the control goal.

This paper presents a possible strategy for controlling the independent roller(s) in the paperpath. The approach taken makes use of polynomial sheet position reference trajectories for closed loop tracking [2],[4].

III. Solution Approach

The solution approach is based on the observation that conservation of mass flow implies a certain periodicity in the sheet transport process. The nominal sheet positions repeat with a given period. Polynomials are consequently used to interpolate between the periodic way points.

A. Nomenclature and Design Variables

The nomenclature used in this paper is illustrated in figure 2. Sheet positions (leading edge) are denoted by x. The vertical arrows denote nominal sheet positions. In the ITS, nominal positions correspond to image positions. Note that all sheets inside the ITS must match up with their respective image. The grey sheets denote the nominal sheet positions inside the first section, further referred to as feeder section. The actual sheet positions may differ from the nominal positions by worst case errors $\pm e_f$.

It is assumed that some parameters are given, such as the sheet length L, the spacing between images d_s and the ITS velocity v_d. The throughput α is then

$$\alpha = \frac{v_d}{L + d_s} \tag{1}$$

The parameter ϕ is defined such that the nominal position of the first sheet inside the feeder section equals $-\phi$ when a downstream sheet enters the ITS. The parameters to be determined are ϕ, the paperpath length L_{pp} and the nominal spacing between fed sheets d_f. Those are the 3 *design parameters.* The velocity of the feeder section then follows automatically from the fact that the throughput is constant throughout the machine

$$\alpha = \frac{v_d}{L + d_s} = \frac{v_f}{L + d_f} = \beta \quad \text{or} \quad v_f = v_d \frac{L + d_f}{L + d_s} \tag{2}$$

B. Periodicity in the Sheet Transport Process

Figure 3 illustrates the periodic nature of sheet transport inside a copier. Assume at time t_0, a sheet enters the ITS with zero position error. For a given ITS throughput α, the time between images appearing at the entrance of the ITS equals

$$\frac{1}{\alpha} = \frac{L + d_s}{v_d} \tag{3}$$

This follows directly from equation (1). Therefore, at times $t_0 + i\,\frac{L+d_s}{v_d}$ with $i \in \{0, 1, 2, \ldots\}$, an image appears at the entrance of the ITS.

For a feeder throughput β, the time between sheets leaving the feeder section equals

$$\frac{1}{\beta} = \frac{L + d_f}{v_f} \tag{4}$$

Therefore, from the definition of ϕ, at times $t_0 + i\,\frac{L+d_f}{v_f}$ with $i \in \{0, 1, 2, \ldots\}$, the nominal position of the first sheet in the feeder section equals $-\phi$.

From equation (2), β must equal α. Therefore, $\frac{L+d_s}{v_d} = \frac{L+d_f}{v_f}$ or every time a new image appears at the entrance of the ITS, the nominal position of the first sheet in the feeder section equals $-\phi$. This is illustrated in figure 3. The vertical arrows denote nominal sheet positions. At

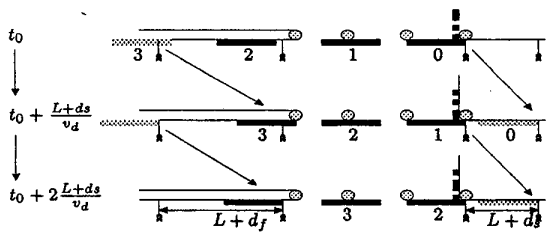

Fig. 4. The periodic nature of sheet entry and sheet arrival with 2 sheets in the paperpath.

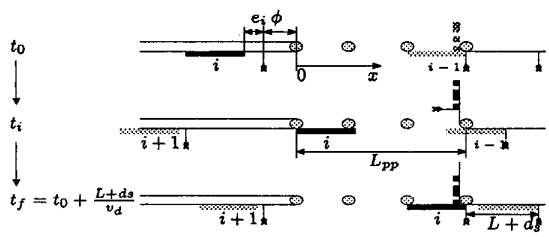

Fig. 5. Every trajectory consists of two distinct parts: from t_0 to t_i and from t_i to t_f.

time t_0, sheet 0 enters the ITS. The nominal position of sheet 1 equals $-\phi$. Sheet 1 is late however, as it lags behind its desired position.

At time $t_0 + \frac{L+d_s}{v_d}$, a new image appears at the entrance of the ITS. From t_0 to $t_0 + \frac{L+d_s}{v_d}$, sheet 1 must travel to the entrance of the ITS to match up with this new image. In the meantime, sheet 2 has become the first sheet in the feeder section and will have to match up with the next image in line. Sheet 2 in this case is early. Sheet 3 is on time. This sequence repeats itself every $\frac{L+d_s}{v_d}$ seconds.

The periodicity still holds when there is more than 1 sheet being controlled by the independent rollers. This is illustrated in figure 4. Sheet 2 no longer matches up with the next image in line, but waits another $\frac{L+d_s}{v_d}$ seconds for the second image in line. This is an important result as it provides more time for error correction and therefore will allow larger initial position errors.

C. Polynomial Trajectories

Based on the observation of periodicity, it becomes relatively easy to design polynomial reference trajectories for individual sheets. Every sheet passes through the same sequence illustrated in figure 5. At time t_0, sheet $i-1$ enters the ITS. The nominal position of sheet i equals $x_{i,nom}(t_0) = -\phi$. The initial position error of sheet i is denoted by $e_i \in [-e_f, e_f]$, with $e_i > 0$ denoting a delayed sheet. Therefore, the initial position of sheet i equals $x_i(t_0) = -\phi - e_i$.

Sheet i travels at velocity v_f until it leaves the feeder section at time t_i. Since $x_i(t_i) = L$ and $\dot{x}_i(t) = v_i(t) = v_f$ for $t \in [t_0, t_i]$, it follows that

$$t_i = t_0 + \frac{L - x_i(t_0)}{v_f} = t_0 + \frac{L + e_i + \phi}{v_f} \tag{5}$$

From t_i on, sheet i is freely controllable. It must reach the ITS at time $t_f = t_0 + \frac{L+d_s}{v_d}$, when the next image appears at the ITS entrance. The total time between leaving the feeder section and arriving at the ITS equals

$$\begin{aligned} t_f - t_i &= (t_f - t_0) - (t_i - t_0) && (6)\\ &= \frac{L + d_s}{v_d} - \frac{L + e_i + \phi}{v_f} && (7)\\ &= \frac{L + d_f}{v_f} - \frac{L + e_i + \phi}{v_f} && (8)\\ &= \frac{d_f - e_i - \phi}{v_f} && (9) \end{aligned}$$

This analysis provides all the necessary information to design a reference trajectory for sheet i. From t_0 to t_i, the reference trajectory is simply

$$x_i(t) = x_i(t_0) + v_f(t - t_0) = -\phi - e_i + v_f(t - t_0), \qquad t \in [t_0, t_i] \tag{10}$$

For $t \in [t_i, t_f]$, specify the reference trajectory as a 6th order polynomial

$$\begin{aligned} x_i(t) &= p_6(t-t_i)^6 + p_5(t-t_i)^5 + p_4(t-t_i)^4 + p_3(t-t_i)^3 \\ &\quad + p_2(t-t_i)^2 + p_1(t-t_i) + p_0 \end{aligned} \tag{11}$$

subject to the following 7 constraints

$$\begin{array}{llll} x_i(t_i) = L & x_i(t_f) = L_{pp} & v_i(t_i) = v_f & v_i(t_f) = v_d \\ a_i(t_i) = 0 & a_i(t_f) = 0 & \dot{a}_i(t_f) = 0 & \end{array}$$

where $\dot{x}_i = v_i$ and $\dot{v}_i = a_i$. Requiring that $\dot{a}_i(t_f) = 0$ ensures a jerk free arrival at the ITS and will simplify trajectory tracking.

The 7 constraints on $x_i(t)$ result in a unique solution for the 7 unknowns p_j, $j \in \{1, \ldots, 7\}$. From observation,

$$p_0 = L \qquad p_1 = v_f \qquad p_2 = 0 \tag{12}$$

The remaining parameters then follow from

$$\begin{bmatrix} \Delta T^6 & \Delta T^5 & \Delta T^4 & \Delta T^3 \\ 6\Delta T^5 & 5\Delta T^4 & 4\Delta T^3 & 3\Delta T^2 \\ 30\Delta T^4 & 20\Delta T^3 & 12\Delta T^2 & 6\Delta T \\ 120\Delta T^3 & 60\Delta T^2 & 24\Delta T & 6 \end{bmatrix} \begin{bmatrix} p_6 \\ p_5 \\ p_4 \\ p_3 \end{bmatrix} = \begin{bmatrix} L_{pp} - v_f\Delta T - L \\ v_d - v_f \\ 0 \\ 0 \end{bmatrix} \tag{13}$$

with $\Delta T(\phi, e_i) = t_f - t_i = \frac{d_f - e_i - \phi}{v_f}$.

The actual trajectory is a function of the initial position error e_i via ΔT. This result is expected, since the total time $t_f - t_0$ is fixed, but t_i varies with e_i. It takes longer for a delayed sheet to leave the feeder section and therefore, the time during which it can be controlled is shorter.

The derivation of the position trajectories for multiple downstream sheets in the paperpath only requires modest changes. The scenario with one extra downstream sheet was illustrated in figure 4. The trajectory design calculations are identical, but with ΔT replaced by $\Delta T + \frac{L+d_s}{v_d}$.

D. Collision Avoidance

The velocity trajectories are designed for individual sheets and depend on the initial position error of every sheet. It is important to verify that the trajectories for neighboring sheets maintain a minimum relative spacing between sheets. One possible approach to ensuring adequate intersheet spacing is to avoid overshoot of the position of a sheet past its target image position, projected onto the paperpath. This is explained next.

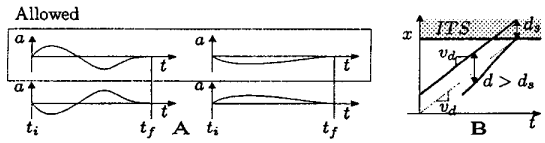

Fig. 6. All possible non-zero acceleration trajectories.

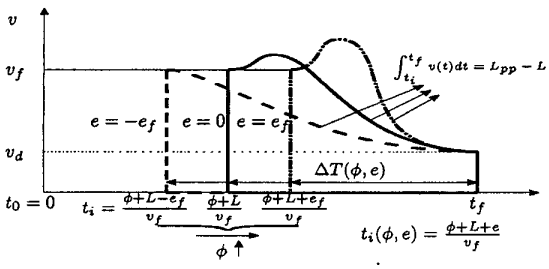

Fig. 7. Effect of modifying ϕ on velocity trajectories.

The position trajectories, derived in section III-C, are 6th order polynomials. The corresponding velocity, acceleration and jerk trajectories are 5th, 4th and 3rd order respectively. The roots of the jerk polynomial determine the acceleration peaks. Since the jerk equals zero at arrival time at the ITS, there are at most 2 acceleration peaks along the trajectory. The possible non-zero acceleration trajectories for $t \in [t_i, t_f]$ are shown in figure 6.A. For fast initial error reduction, it is assumed that $\dot{a}(t_i) \neq 0$.

The time available for error correction equals $\Delta T = t_f - t_i$. During time ΔT, sheets must decelerate from v_f to v_d and travel the distance $L_{pp} - L$, as shown in figure 5. ΔT is maximized for the worst case early fed sheet, $e_i = -e_f$.

$$\Delta T_{max} = \max_{e_i} \Delta T(\phi, e_i) = \frac{d_f + e_f - \phi}{v_f} \tag{14}$$

Sheets fed later (larger t_i) must necessarily run faster in order to cover the distance $L_{pp} - L$ in less time, since ΔT is now shorter. This is shown in figure 7. Therefore, the only possible velocity trajectory for these sheets has an acceleration phase followed by a deceleration phase, corresponding to the top left acceleration trajectory in figure 6.A.

In order to avoid overshoot past the projected image position, moving with velocity v_d, the sheet must decelerate before entering the ITS, as shown for the trajectory (bottom solid line) in figure 6.B. The dotted line corresponds to the projected image position, the top solid line is the trailing edge of the downstream sheet in the ITS. Therefore, the only acceleration trajectory types allowed must end with a deceleration phase, which corresponds to the top row in figure 6.A.

As mentioned above, trajectories for larger e_i will need to accelerate more initially in order to cover the distance $L_{pp} - L$ in less time. It can be shown that velocity and acceleration requirements are minimized by minimizing the acceleration of the worst case early fed sheet, which corresponds to choosing the top right trajectory in figure 6.A. This trajectory is of 4th order, such that the corresponding jerk polynomial has three roots. As there is only one extremum, where the jerk equals zero, and $\dot{a}(t_i) \neq 0$, both $\dot{a}(t_f)$ and $\ddot{a}(t_f)$ must necessarily be zero. This introduces the following additional constraint on the trajectories

$$\ddot{a}_i(t_f) = 0 \qquad \text{when } e_i(t_0) = -e_f \tag{15}$$

or from equation (11)

$$360 p_6 \Delta T_{max}^2 + 120 p_5 \Delta T_{max} + 24 p_4 = 0 \tag{16}$$

When combined with the results of section III-C, assuming L_{pp} is initially unknown, a new set of 7 equations is obtained with 7 unknowns p_j, $j \in \{1, \ldots, 7\}$. L_{pp} then follows from the first row in (13),

$$L_{pp} = p_6 \Delta T^6 + p_5 \Delta T^5 + p_4 \Delta T^4 + p_3 \Delta T^3 + v_f \Delta T + L \tag{17}$$

Equation (17) provides the value for L_{pp} such that the worst case early fed sheet needs no acceleration and all trajectories satisfy the no overshoot criterium. A complete design algorithm is described next.

E. Design Algorithm

The sheet position trajectories are a function of the design parameters L_{pp}, d_f and ϕ. This section describes an iterative algorithm that optimizes the following design problem, *assuming polynomial trajectories*:

For given d_s, v_d, L and e_f, find the optimal values for L_{pp}, d_f and ϕ, such that
1. The paperpath can handle any initial position error e with $e \in [-e_f, e_f]$.
2. The paperpath length L_{pp} is as small as possible. This minimizes the required number of independent rollers.
3. The feeder section velocity v_f is as small as possible. This simplifies feeding sheets at the nominal feed position and therefore reduces initial position errors.
4. The worst case sheet velocities and accelerations are within given bounds.
5. Sheet position trajectories do not overshoot past the target position, i.e. the image projected onto the paperpath.

The design steps are now as follows:
1. Choose $d_f = 2e_f + d_{min}$ in order to maintain a minimum spacing of d_{min} between sheets in the feeder section. The worst case spacing d_{min} occurs when sheet i has initial position error e_f and sheet $i+1$ initial position error $-e_f$. Since $v_f = v_d \frac{L+d_f}{L+d_s}$, this minimum required value of d_f results in the smallest value of v_f.
2. Assume no extra sheets in the paperpath, i.e. first sheet in feeder section must match up with next image.
3. Choose $\phi = -L + e_f$. From figure 7, this choice sets $t_i = t_0$ and therefore maximizes $\Delta T(\phi, e)$, $\forall e \in [-e_f, e_f]$ while ensuring that the trailing edge of the sheet for $e = -e_f$ still touches the feeder section, as required by the boundary conditions for the polynomial trajectories. Increasing ϕ shifts t_i to the right, see figure 7.
4. Determine L_{pp} using equation (17). Solve for the trajectories for $e = e_f$ and $e = -e_f$.
5. For the obtained L_{pp}, verify whether worst case sheet velocities and accelerations are within desired bounds. If not, add one extra downstream sheet in the paperpath, and start over again. If bounds are satisfied, continue.

Variable	Value	Variable	Value
v_d	0.5 [m/s]	d_s	0.04 [m]
L	0.2159 [m]	60α	117[sheets/min]
d_{min}	0.02 [m]	v_{max}, a_{max}	1 [m/s], 10 [m/s^2]

TABLE I
DESIGN PARAMETERS AND SPECIFICATIONS

6. Increase ϕ by a small amount and solve again for L_{pp}. $L_{pp}(\phi)$ decreases for increasing ϕ. This is intuitively clear from figure 7. If the new worst case sheet velocities and accelerations for $e = e_f$ and $e = -e_f$ are within the desired bounds, repeat this step. Else, stop.

Note that it is possible to relax the no overshoot criterion. By allowing $v(t) < v_d$, the minimal spacing between sheets during transport to the ITS will decrease. The design algorithm must then be modified such that for any given L_{pp}, one adjusts ϕ until a desired minimum inter-sheet spacing is satisfied. By iteratively decreasing L_{pp}, one again finds the shortest paperpath.

IV. RESULTS

This section illustrates the design algorithm for two different bounds e_f on feed errors.

A. Design parameters and specifications

Table I gives the design parameters and specifications. The bounds on sheet velocity $v(t)$ and acceleration $a(t)$ are

$$v_d \leq v(t) \leq v_{max} \qquad -a_{max} \leq a(t) \leq a_{max} \tag{18}$$

for all trajectories. The lower bound on the sheet velocity follows from the no overshoot criterion as discussed in section III-E. The sheet length corresponds to a standard letter sized sheet.

B. Worst case feeder error of ±0.03 meter

Assume $e_f = 0.03$ m. Fed sheets can therefore deviate from their nominal positions by at most $\pm e_f = \pm 0.03$ m. The design algorithm specifies

$$d_f = 2e_f + d_{min} = 2 \times 0.03 + 0.02 = 0.08\,\text{m} \tag{19}$$

in order to guarantee a minimum spacing $d_{min} = 0.02$ m between fed sheets. For the given throughput and d_f value, the minimum required value for the feeder section velocity equals

$$v_f = v_d \frac{L + d_f}{L + d_s} = 0.58 \frac{m}{s} \tag{20}$$

The only remaining parameters to be determined are L_{pp} and ϕ. A few iterations of the design algorithm result in the following values

$$L_{pp} = 0.41\,\text{m} \qquad \phi = -0.1\,\text{m} \tag{21}$$

No extra downstream sheet is needed. The trajectories are shown in figures 8 and 9. Figure 8 illustrates the sheet positions versus time for 2 sheets. The middle solid line for each sheet represents the nominal leading edge trajectory,

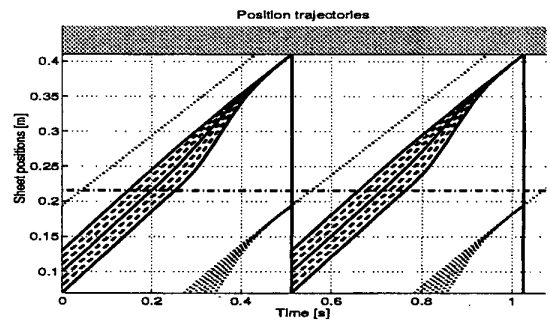

Fig. 8. Sheet position trajectories for $e_f = 0.03$.

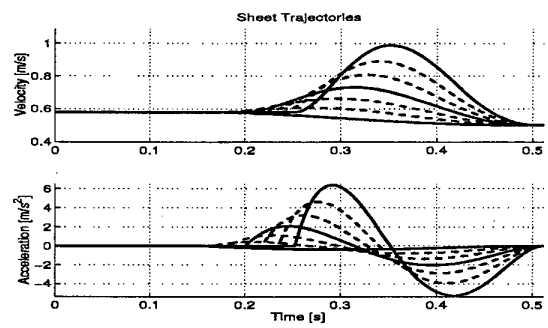

Fig. 9. Sheet velocity and acceleration trajectories for $e_f = 0.03$.

the neighboring solid lines denote the worst case early and late sheet. Other initial position errors are shown with a dashed line. The dotted lines represent the corresponding trailing edge trajectories. The horizontal dash-dotted line denotes position $x = L$.

Note that all trajectories evolve with a slope v_f until $x = L$, i.e. when the sheet leaves the feeder section. As shown in figure 2, the exit of the feeder section is located at position $x = 0$. At time $t = t_0 = 0$, a sheet enters the ITS. Its trailing edge continues with velocity v_d. Also at time $t = 0$, the nominal sheet starts at $x = -\phi$, which follows from the definition of ϕ. The worst case early and late sheet start at position $x = -\phi + e_f$ and $x = -\phi - e_f$ respectively.

The solid vertical lines denote $t = \frac{L+d_s}{v_d}$ and $t = 2\frac{L+d_s}{v_d}$, i.e. the points in time at which a new image appears at the entrance of the ITS. The grey region, with width d_s, denotes the entrance of the ITS. All trajectories deliver sheets in time to the ITS. Notice also how the no overshoot criterion ensures $d > d_s$ once the downstream sheet has entered the ITS.

The velocity and acceleration trajectories are shown in figure 9. In this case, the bound $v_{max} = 1$ determines the minimum required paperpath length. The middle solid line represents the nominal trajectory. Note that all trajectories start with $v = v_f$ and $a = 0$ when the sheet is in the feeder section. All boundary conditions are satisfied. The no overshoot criterion requires $v(t) > v_d$, which is indeed satisfied.

Figure 10 shows the resulting paperpath. For $L_{pp} =$

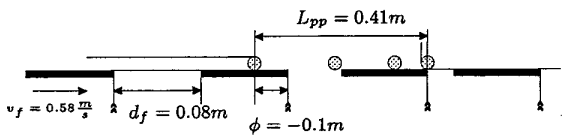

Fig. 10. Paperpath layout for $e_f = 0.03$.

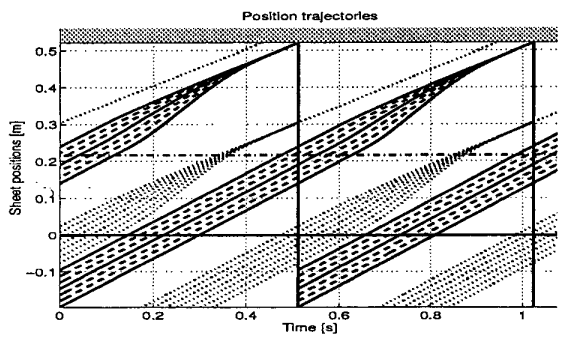

Fig. 11. Sheet position trajectories for $e_f = 0.05$.

0.41 m and $L = 0.2159$ m, one roller suffices in theory to guarantee a sheet is always in contact with at least 1 roller. However, at least two rollers are required in practice. This follows from the fact that it is desirable to have a roller close to the entrance of the ITS. The closer a roller is located to the leading edge of a sheet, the more precise the position control. Figure 10 illustrates a possible layout.

C. Worst case feeder error of ±0.05 meter

Assume $e_f = 0.05$ m, all other given parameters remain the same. The design algorithm specifies

$$d_f = 2e_f + d_{min} = 2 \times 0.05 + 0.02 = 0.12\,\text{m} \tag{22}$$

$$v_f = v_d \frac{L + d_f}{L + d_s} = 0.66\frac{m}{s} \tag{23}$$

$$L_{pp} = 0.52\,\text{m} \qquad \phi = 0.145\,\text{m} \tag{24}$$

This time, one extra downstream sheet is needed in order to satisfy the trajectory constraints.

The trajectories are shown in figures 11 and 12. Figure 11 illustrates the sheet positions versus time for 3

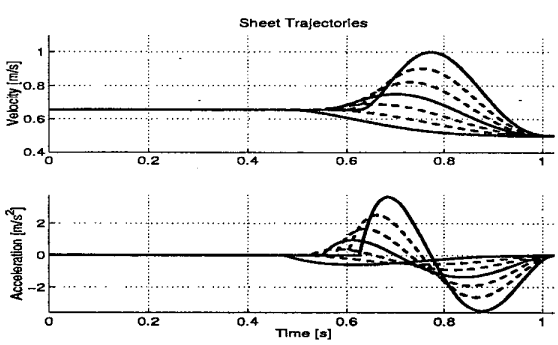

Fig. 12. Sheet velocity and acceleration trajectories for $e_f = 0.05$.

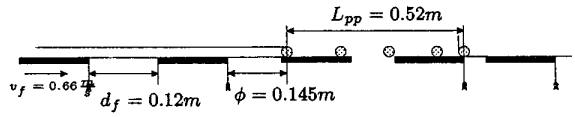

Fig. 13. Paperpath layout for $e_f = 0.05$.

sheets. Note the sheets have twice the amount of time to travel to the ITS as compared with figure 8. This follows from the fact that one extra downstream sheet was assumed in the trajectory calculation.

As expected, a larger initial error requires a longer paperpath. Figure 13 illustrates a possible layout. At least 3 rollers are required this time. Note that the optimal phase ϕ has a different sign compared to that of the solution for $e_f = 0.03$ m.

V. Conclusions

This paper presents a possible approach to design and closed loop control of a copier paperpath. Sheets are first transported in open loop in a feeder section, followed by closed loop sheet position control with independent rollers right before image transfer. A polynomial trajectory design approach shows that just 2 independent rollers can already correct a fairly wide range of initial position errors.

Only longitudinal position errors are assumed. No details are given on how to measure the sheet positions. The use of an additional skew and lateral error correction device [5] and an observer or analog position sensor is implicitly assumed. The theory can also be extended to handle sheets with different lengths. Note that a longer paperpath allows position control sooner and can therefore handle larger initial errors. A long paperpath requires many rollers unfortunately. It may be possible to maintain the long paperpath while reducing the number of actuators by grouping some rollers into sections. This approach no longer allows independent sheet control however and requires a different approach [2],[6],[7].

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