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Using iterative learning control with basis functions to compensate medium deformation in a wide-format inkjet printer

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ABSTRACT

The increase of paper size and production speed in wide-format inkjet printing systems is limited by significant in-plane deformation of the paper during printing. To increase both the production speed and paper size, the compensation of paper deformation is essential. A potential approach to compensate the paper deformation is actively changing the longitudinal paper position during a lateral pass of the printheads. This paper aims at developing an Iterative Learning Control (ILC) algorithm suited for this compensation strategy. The paper position is measured directly, but in non-real-time using image data obtained with a scanner located at the printheads. The proposed controller is experimentally validated and compared with standard norm-optimal ILC in a reproducible experiment, where a set of benchmark trajectories is used that represents severe paper deformation. The results show that in contrast to standard ILC, the ILC with basis functions achieves good tracking performance for the reference set and is hence a proper candidate algorithm for the compensation strategy.

1. Introduction

The increase of production speed and paper size for wide-format inkjet printing systems is limited by significant deformation of the paper during printing [35]. This deformation affects the alignment of print-passes and also distorts the printed image. In present commercial systems, this is one of the reasons for introducing more than 50% overlap between passes. The overlap mitigates the effects on the print quality, but as a result, significantly reduces the production speed. To increase both the paper size and production speed, the compensation of these deformations is required.

A potential approach to compensate the paper deformation is actively changing the longitudinal paper position during a lateral pass of the carriage [4]. The shape of the deformation gradually changes in time [35], and therefore the reference trajectory for the paper motion must also change each pass. In [4], only measurements of the motor position were used for control. Despite the significant performance enhancement at the motor side, an evaluation at the paper revealed insufficient performance.

Although the approach in [4] is conceptually promising, the disturbances introduced by the medium position drive [16] cannot be suppressed by applying control using the measured motor position. Therefore, in the present paper, the use of a newly developed scanner in the control loop is proposed. This scanner is located in the carriage (that holds the printheads), and is used to directly measure the longitudinal paper position. The measurements results from an image processing algorithm that analyzes each scan offline.

Iterative Learning Control (ILC) updates the command signal offline in a batch-to-batch fashion and is hence well-suited to be used in combination with the offline measurements. Although ILC is known to achieve very good tracking performance, the learned command signal is optimal for a specific task only [5], extrapolation to other tasks can lead to significant performance degradation [34,18].

In [22], a segmented approach to ILC is presented and applied to a wafer stage. This approach is further extended in [17], where the complete task is divided into subtasks that are learned individually. The use of such a signal library is restricting in the sense that the tasks are required to consist of standardized building blocks that must be learned a priori. The use of a time-varying robustness filter [7,30] introduces extrapolation capabilities for specific filter structures [30], but only for a restricted class of reference variations. In [13] an initial input selection for ILC is proposed. This method can be used to re-initialize the ILC after a reference change, see the related results in [18]. The re-initialization mapping is only static, hence modeling errors directly affect the extrapolation capabilities.

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0957-4158/

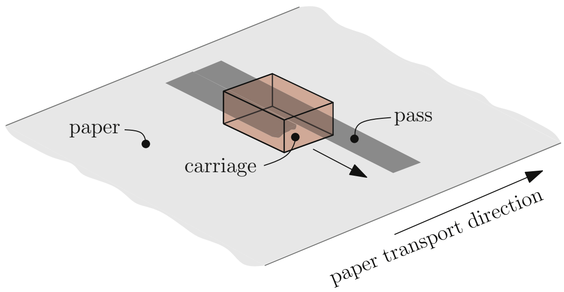

Fig. 1. Mono-directional printing, the paper is printed on during each from left-to-right pass of the carriage. The paper is transported with a fixed step size after a pass is completed.

In [9] an ILC algorithm for LPV systems is proposed. The approach deals with the varying dynamics and introduces extrapolation capabilities for different initial positions of the system.

In [33,34,23], basis functions in ILC are introduced. In [23], the tracking errors are projected onto a basis in order to only learn the repetitive part of the tracking error. In [34], the ILC command signal is parameterized using basis functions, in order to achieve extrapolation capabilities. The difference between these two approaches is projecting either the measured output onto a basis, or, construct the ILC command signal from a basis; both approaches can be encompassed in the framework presented in [33].

In this paper, basis functions are used that enhance the extrapolation properties in ILC. Potentially, this method achieves improved performance and extrapolation capabilities simultaneously. The earlier approach in [4] cannot be applied directly since the controller structure is not suitable for the additional non-real-time measurements, moreover, the extrapolation capabilities are not investigated. The results in [5] employ a more complex set of basis functions than considered here, to further increase performance and extrapolation capabilities. These results however, only include experimental results on a simple laboratory-scale motion system, and are more suited for a different class of systems than considered in this paper. The main contribution of the present paper is the design and experimental implementation of an iterative learning controller [8,10,24], in which the varying references and offline position measurements are explicitly addressed.

An experimental comparison of the proposed ILC with standard norm-optimal ILC in a reproducible validation experiment is presented. A set of benchmark references is employed that represents severe paper deformation. The key result is that the ILC with basis functions achieves good tracking performance that is insensitive to the changes in reference, in contrast to standard ILC.

This paper is organized as follows. First, the problem that is addressed in this paper is defined in detail in Section 2. The experimental setup and paper position measurements are elaborated on in Section 3, followed by the presentation of the learning controller framework in Section 4. Finally, the controller design and experimental results are elaborated on in Section 5.

2. Problem formulation

In this section, the addressed problem is defined. First, in Section 2.1, the printing process is introduced. Then, in Section 2.2, the paper deformations that arise during the printing process are explained. Finally, the problem statement is formulated in Section 2.3.

2.1. Scanning printing process

Fig. 1 shows an overview of the so-called scanning printing process. The medium, e.g. paper, is printed on by the printheads that are located in the carriage. The carriage moves from left-to-right and vice versa, and each time such a pass completes the paper is translated with a fixed step size. In the present paper the mono-directional printing process is used. This means that the printheads only print when the carriage is moving from left-to-right, indicated with the arrow, see Fig. 1. The results in this paper are also applicable to bi-directional printing, the main differences are tighter requirements on the computational cost of the algorithm and larger changes in the reference trajectories.

2.2. Paper deformations

The printing process typically introduces temperature and moisture changes in the paper [35]. In the printing process used, temperature increase is caused by the use of a heated print-surface, and the use of molten ink. The ink is molten inside the printheads and crystallizes on the paper after printing. This drastically increases the paper temperature, that in turn leads to the evaporation of moisture that was already present in the paper before printing. These changes in temperature and moisture content in turn lead to deformation of the paper.

The measured paper deformation for 145 passes of the carriage is shown in Fig. 2 (the measurement procedure is elaborated on detail in Section 3.2). Each line represents the deformation position with respect to a straight line for a certain time instance, indicated by the colorbar. It shows that the paper suffers from planar deformation that gradually evolves into a parabolic-like shape as time progresses. The deformation evolves unidirectional and the magnitude is in the order of 600 μm.

The scale of this deformation is large enough to severely deteriorate the print quality [29], especially when production speed is maximized and no overlap between the passes is used. Fig. 3 shows how the paper deformation negatively affects the alignment of passes. It shows that at the edges of a pass there may be overlap, in contrast to the center of the pass, that aligns properly with the previous pass. Proper alignment leads to improved print quality, and is hence pursued.

2.3. Problem formulation

The main idea is to compensate the misalignment by actively changing the longitudinal paper position z, see Fig. 3, during a pass of the carriage (which is lateral to the paper transport direction). The deformation measurement in Fig. 2 shows that the shape of

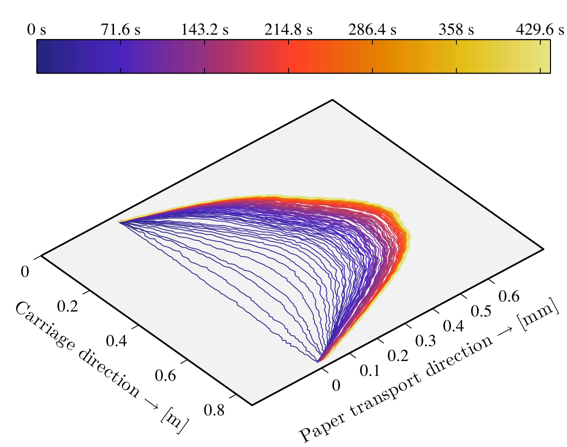

Fig. 2. Measured paper deformation. Each line represents the paper deformation with respect to a straight line for a certain time instance, the time is indicated by the colorbar. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)