INDUSTRIAL APPLICATIONS OF 2D CONTROL SYSTEMS

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Summary

A number of industrial processes (such as paper making, plastic film extrusion and steel sheet production) exist in which the product is a continuous sheet of material. The control of such processes is a 2D problem, since the sheet properties must be controlled across the width (the CD or cross direction) and breadth (the MD or machine direction). Traditionally, the CD and MD problem are treated separately.

However, increasing demands on production speed and quality demands that 2D modelling, control and analysis be used. This article describes the background and approaches to this problem.

1. Introduction

Products such as paper, plastic film and strip metal are manufactured in the form of continuous sheets. Taken together with the many associated industrial processes which process and convert continuous sheets, they can be considered as a generic class of industrial systems. Moreover, they are a class, which has a growing economic importance as manufactured products increasingly rely upon processed sheet material. From the control engineer's viewpoint the challenge is to develop the control theory that will make the new generation of sheet based production processes capable of very fast production rates, and yet have consistent and accurately specified properties.

Computer diskettes and CD blanks are two examples of the new generation of consumer products that depend upon the initial production of a sheet with accurately controlled properties, this is coupled with a subsequent coating process with films which must have precise and consistent magnetic and optical properties respectively. The mass production and processing of sheet-based products is a recent phenomenon, (diskettes and optical disks did not exist 30 years ago). However the basics of sheet manufacture are as old as paper making itself, while metal sheet forming and polymer film extrusion and the associated coating and converting processes are 20th century developments.

The starting point for the control of sheet forming systems is an understanding of the dynamics involved. The underlying dynamics of sheet forming and coating processes are governed by sets of PDEs. In certain cases, and depending upon the application, these PDEs can be simplified and replaced by ordinary differential equations or some other tractable approximation. However if the PDE's are directly discretized for digital processes then 2D difference equations are the result. This article describes how the 2D classification gives a systematic basis for the analysis and control of industrial web forming processes using 2D control and analysis theory of the types described in the other articles in the 2D topic area.

Currently, almost all existing sheet manufacturing systems are controlled using a special form of multivariable model in which the two dimensions interact in a specific way that can be characterized by a so-called interaction matrix. The interaction matrix approach assumes that the underlying physical dynamics are separable. Previously this has been an acceptable proposition, but as production processes become more complex and standards become higher, then the 2D representation gives a more natural interpretation of the underlying physical and dynamical behavior. The use of an explicit 2D dynamical systems representation leads to useful improvements in signal processing and control which includes the interaction between the two dimensions in a way which complements developments in n-dimensional systems theory.

The article is laid out as follows. Section 2 describes the form of 2D representations and in particular the limitations and relevance of 2D concepts in industrial sheet forming processes. A particular issue that must be addressed is the determination of 2D model forms that can be used for industrial process identification, prediction and control. A desirable feature of identification algorithms is that they should allow direct synthesis of 2D controllers from the identified model. Section 4 presents the estimation methods, which enable 2D-ARMAX models to be determined.

Section 5 discusses 2D control for industrial processes. The control and structural theory of 2D systems are covered in the other articles in this topic area, however there is a need to link these theories firmly to the industrial application. In this context, section 5 deals with the formulation of 2D controllers based on the models developed in sections 3 and 4, with appropriate linkages to the structures and characteristics of 2D systems theory.

Section 6 deals with alternatives to 2D control methods. Specifically, most current sheet manufacturing systems use the Interaction Matrix approach to control. In this approach, it is assumed that the response characteristics of the actuators can be separated. By assuming that the dynamic responses of all the actuators are the same, the response of the full array of actuators becomes the product of a scalar dynamic term and the "steady-state" spatial responses of each of the actuators. This description of the system is infinitely dimensional, but simplifications can be introduced which allow the interactions between actuators to be characterizecharacterized by a matrix of constants. Section 6, outlines this approach and describes the links to more sophisticated implementations sheet forming such as the 2D approach and the closely related basis function methods.

Section 7 describes the 2D-sensing problem in sheet manufacturing. This is a vital issue in industrial sheet forming processes since in order to assure quality and consistency of products the full (e.g., 2D) properties of the moving continuous sheet should be measured. However until recently scanning gauges have been used to sense the properties of the sheet product. These gauges are suspended above the production line and move back and forth across the moving web of material, tracing a zigzag line of measurements. Such gauges can only measure a very small percentage of the sheet and thus give inadequate information for product quality assurance and for control. Sensor researchers and manufacturers have developed sensors, which increase the percentage of the sheet surface that is measured. Signal processing research has complemented the sensor research with analyses of the theoretical properties of data sampled from a 2D surface using a scanning gauge using Generalised Sampling Theory.

Section 8 closes the article with some remarks about 2D actuation and pointers to future developments.

2. Sheet manufacturing processes

Figure 1 shows a typical sheet forming process. The delivery mechanism supplies material through a narrow slit to form a continuous sheet or web of material. The narrow slit is controlled by an array of actuators, which control the formation of the sheet. Specifically, a movement in one of the actuators in the array influences the product over an area in the region of the actuator's spatial location and the sheets temporal location. The spatial direction across the process is called the cross direction (CD) and the direction of material movement is the machine direction (MD). The properties of the product are normally measured by a scanning device, which measures the web properties by a zigzag path. Scanning sensors of this form are the current industry standard with the dominant manufacturers being ABB, Measurex/Honeywell and NDC/Infrared Engineering.

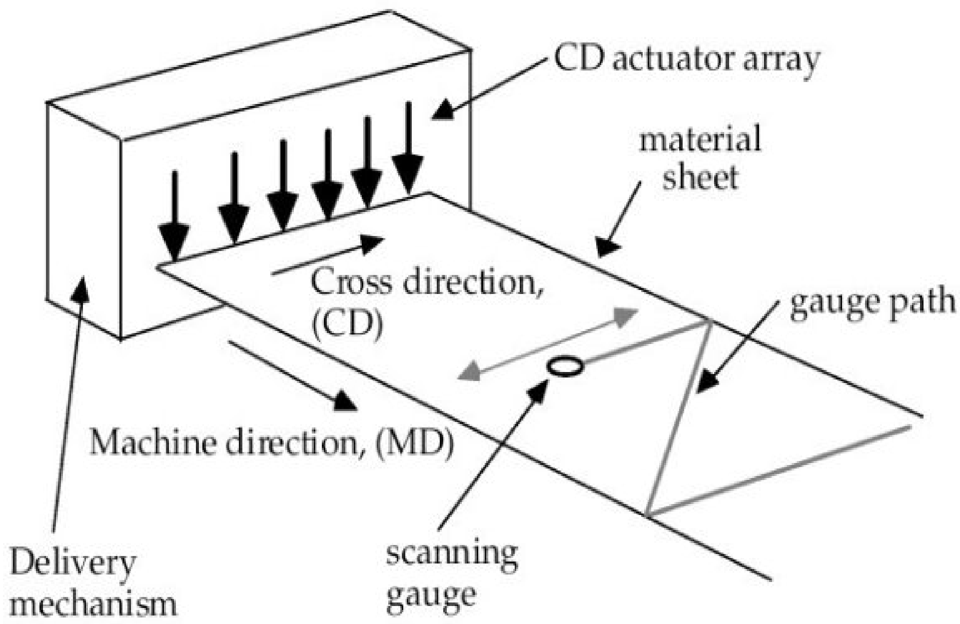

Figure 1. Schematic of a Sheet Forming Process

Figure 1 is a highly stylized picture of an actual process, since the sheet may be manufactured and treated in a number of additional ways. As specific illustrations of the complexity of sheet manufacturing process the following sections describe some typical processes.

2.1. Polymer Blown Film Production

A polymer film production line is shown in Figure 2 in schematic form. The basis of the production process is to form a tube of film using an extruder of molten polymer which is attached to an annular die (at the bottom of the figure) this forms a circular polymer tube which is then heated by a circular heater and inflated with compressed air to form a bubble. The film is also drawn off at the top of the bubble at a faster rate than the extrusion rate.

The inflation, combined with drawing in both MD and CD, reduces the film thickness by a factor of between 40:1 and 100:1. In the diagram the main extruder melts a polymer granule feed stock and extrudes it through an annular die to form a plastic tube. An array of heater elements are arranged in a circle around the tube.

The array applies heat in a controlled manner around the polymer tube and this changes the elastic properties of the tube and thus allows the tube thickness to vary differentially under the action of the bubble inflation and drawing sections. The temperature of the tube may be raised further by additional heaters, depending upon the specific process and product.

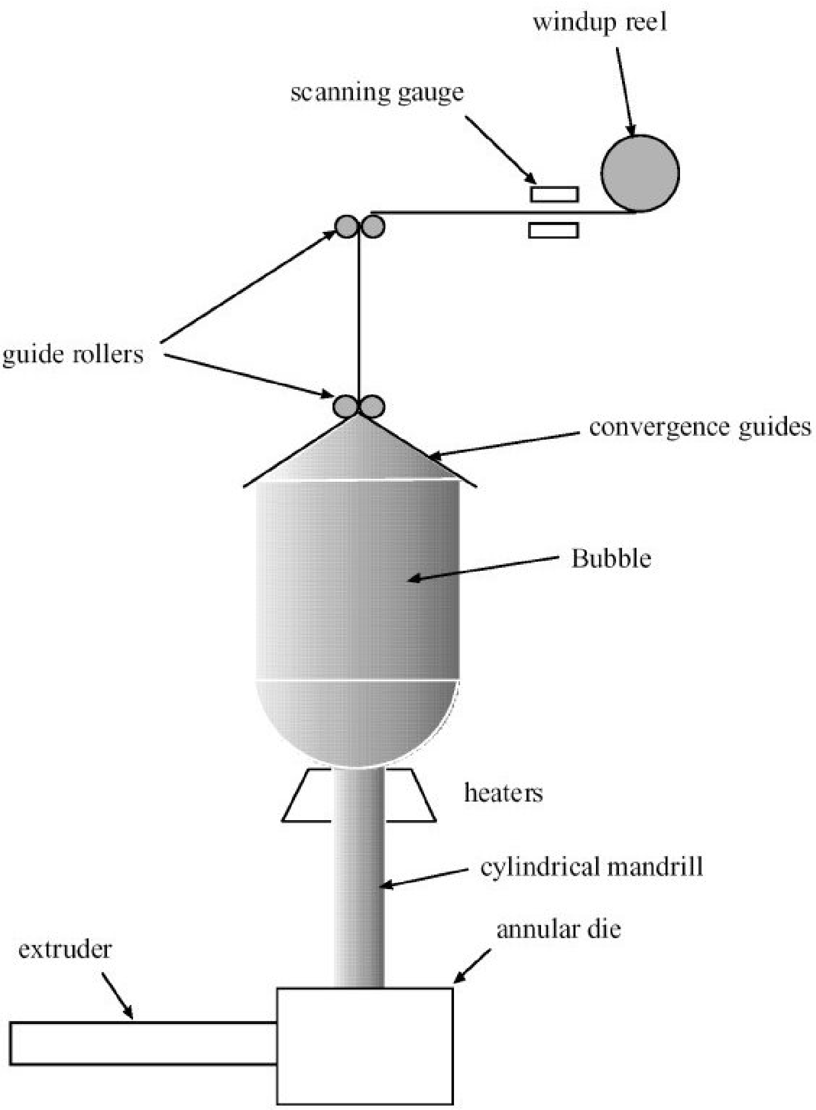

Figure 2. Blown Film Polymer Film Extrusion Process

The bubble may then pass through a set of air rings, which act like air bearings by holding the bubble in place, and also provides a curtain of air, which cools the bubble and prevents further deformation of the polymer bubble from taking place.

After the air bearings, the bubble passes a set of convergence guides, which causes the cylindrical bubble to be flattened. The flattened tubular film is drawn off for further processing before being wound onto a product roll.

In addition to the stages described above, there are other processes that may be included in the overall system. These range from co-extruders, actuators to distribute small systematic CD thickness irregularities and coating/printing processes.

This is a simplification of the blown film process and given only to describe the complexity involved. For detail descriptions see the bibliography.

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Biographical Sketch

Peter Wellstead was born in 1944 in England. He was for many years Professor of Control Engineering at the Control Systems Centre, University of Manchester Institute of Science, and currently holds a senior position with the Hamilton Institute (www.hamilton.may.ie). He spent the first part of his career in the electronic instrumentation industry, and gained his first professional qualifications as a part-time student at Hatfield College of Technology (now Hertfordshire University). He then studied signal processing and control at Warwick University, obtaining Masters and Doctorate degrees in 1968 and 1970, respectively. After two years working on real time image processing and computer control at the European Centre for Nuclear Research (CERN) in Geneva, he joined the Control Systems Centre at UMIST. While at UMIST, he has performed and led research into a range of signal processing and control areas. He works actively with industry and has held a Royal Society Industry Fellowship in the area of 2D sensing, and led a 15-year collaboration with Lucas Industries (now TRW Automotive) in the area of automotive control systems. He is best known scientifically for his contributions to self-tuning control, system identification, system modeling and 2D systems. He has written two books and published over 140 scientific papers. As an educator, he is known for the laboratory methods and the extensive range of control teaching equipment that he developed for the Control Systems Centre postgraduate school. This equipment is used world wide, and has become a benchmark for control teaching and laboratory practice, (www.control-systems-principles.co.uk).