

Implications of a Control-Theoretic Approach to Human-Automation-Plant Interface Design

Greg A. Jamieson¹ and Kim J. Vicente²

Cognitive Engineering Laboratory

Department of Mechanical and Industrial Engineering

University of Toronto

5 King's College Rd.

Toronto, Ontario, Canada M5S 3G8

¹ gimlet@me.utoronto.ca

² benfica@ie.utoronto.ca, www.mie.utoronto.ca/labs/cel/kim.htm

Abstract

This article critically evaluates some of the design guidelines proposed by researchers investigating human-automation interaction. A control-theoretic framework is proposed to introduce a set of important conceptual distinctions that need to be respected in automation research and design. The framework is applied to a specific topic of recent research focus, modes in aviation automation. Although previous research in this area has advanced our understanding of key issues, the existing design guidelines lack the necessary specificity to contribute to major improvements in design practice. Our control-theoretic perspective helps clarify these issues, and demonstrates why existing design guidelines are unlikely to fully support automation designers in their efforts to reduce the frequency of mode-related errors. An alternative perspective, which we believe will yield more concrete design criteria and more appropriate tools, is suggested.

Introduction

The use of automation in complex sociotechnical systems has proved to be a double-edged sword. On the one hand, it promises unprecedented reliability, reduced workload, improved economy, and fewer errors. On the other hand, it whispers of less tangible, but no less real, costs to operators in terms of skill degradation, mental isolation, and supplemental monitoring tasks [1, 2]. Repeating patterns demonstrated in other technology-driven enterprises, designers have focused on the beneficial cutting edge of automation while ignoring or downplaying the costs to the human stakeholders who must necessarily remain as aspects of the system. How can we convince engineers that automation technology is

a tool and not a panacea [3] for human-machine interaction problems? The ironic solution we adopt in this article is to use automation designers' own language, control theory, to point out the role of human factors considerations in the design of automation.

The purpose of this article is to propose a domain-independent, control-theoretic framework for investigating human factors issues in automation. This framework is used to evaluate some of the design guidelines that have been put forth in the literature and to discuss how these guidelines might be augmented to more effectively contribute to the design process. We also show the value of this generic framework by using it to critically review a particular body of automation research, that dealing with mode proliferation, mode transitions, mode awareness, and mode error in aviation automation.

A Control-Theoretic Framework For Studying Automation

Definitions

In examining the literature on human-automation interaction, we have noted frequent terminological inconsistencies. In order to avoid imprecise language ourselves, we offer the following definitions which will be employed for the duration of this article:

- Process: The thing being influenced by the Final Control Components.
- Final Control Components: Controllable equipment that is used to influence a Process.
- Plant: Final Control Components + Process.
- Controller: The means by which action is exerted on the Final Control Components.

- Instrumentation: The means by which data about the Plant and Controllers are gathered.
- Displays: The devices through which Operators obtain information about the System.
- Controls: The devices through which Operators take Action on the System.
- Interface: Displays + Controls.
- System: Plant + Controllers + Instrumentation +

valve position) which then influences the Process itself, causing the Controlled Variable (e.g., flow rate) to change as well. The Instrumentation (e.g., a flow meter) gathers information about the Controlled Variable and feeds it back to the comparator.

The upper portion of Figure 1 serves as a placeholder for the Interface and the Human Operator, two System elements that play a role in feedback control loops that

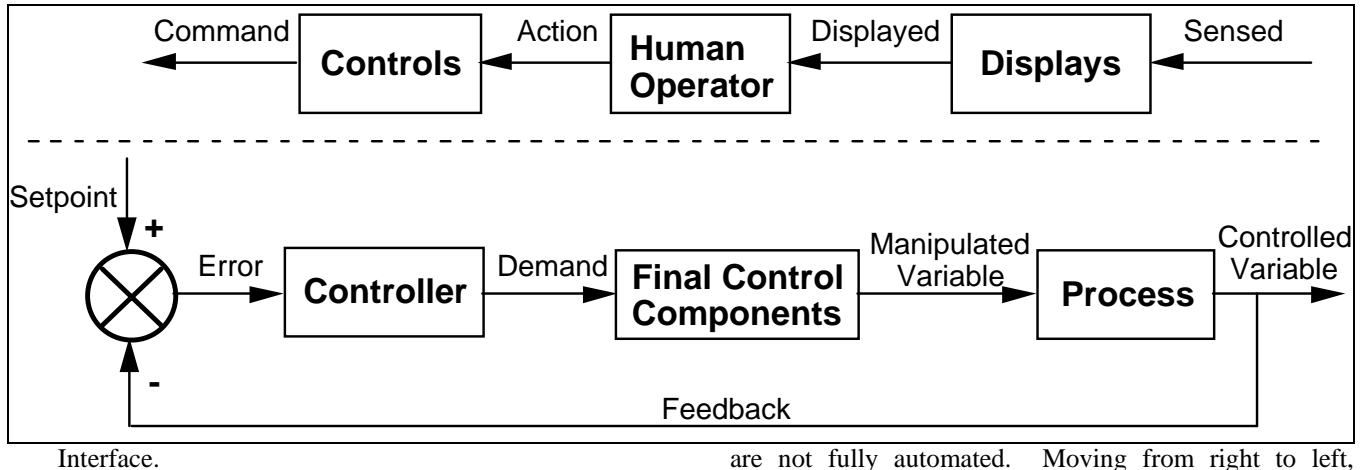


Figure 1. A negative feedback control loop.

Throughout this article we have capitalized these terms. The relationships between the terms should become more clear as we place them in the context of a negative feedback control loop.

Negative Feedback Loop

Figure 1 presents a very simple but conceptually powerful model of automation based on a standard negative feedback control loop (adapted from [4]). In this figure, boxes represent System elements and arrows denote signals between elements. The lower portion of Figure 1 is a traditional regulatory feedback loop composed of three distinct elements (the upper portion will be described later). If all of the elements are working as planned, then the behavior of the feedback loop can be described in a relatively straightforward fashion. Tracing through the diagram from left to right, the comparator subtracts the Feedback signal from the Setpoint (i.e., the goal) to create an Error signal. This Error signal is sent to an automatic Controller which generates (via programmed logic) a Demand signal that is sent to the Final Control Components. The Final Control Components (e.g., a valve) map this Demand signal onto a change in the state of the Manipulated Variable (e.g.,

are not fully automated. Moving from right to left, Sensed data signals are fed into the Displays element and

Displayed to the Human Operator. The Operator takes Action by manipulating the Controls in the Interface which generates a Command signal. The manner in which the elements in the upper portion of the figure are connected to the rest of the feedback control loop (i.e., what signals serve as inputs and outputs) cannot be described generically because there is no process that is agreed upon by automation designers for identifying which connections are required. Connecting the upper and lower portions of Figure 1 involves making a set of design decisions. One of the contributions of this paper is to propose how these decisions should be made.

Implications

While control engineers will find this feedback model highly oversimplified, it serves to make five important points. First, there are four different elements that must be distinguished conceptually: the automation which is the Controller, the Final Control Components that the automation acts on, the Process itself, and the Interface. Frequently, researchers do not discriminate clearly and consistently between these elements. A common approach is to use the catch-all label, "system". In some cases, "system" seems to mean automation, whereas in other cases it seems to include the Final

