Resource-Efficient Pipelined Control with Data-Intensive Sensing

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ABSTRACT

Data-intensive controllers are control systems that use a data-intensive device (e.g., a camera) as one of its sensors. The signal processing needed to extract relevant information from the data creates challenges from the control point of view, regarding for example stability and quality of control, and from an implementation point of view, in terms of for example throughput and latency. This extended abstract discusses several applications that include such a data-intensive sensor. It also reviews existing solutions for one of the most challenging problems, which is the latency added to the sensing loop by the signal processing algorithm. Finally, it outlines our proposed research direction to address the problem of designing a resource-efficient controller for systems that involve data-intensive sensing.

KEYWORDS: Embedded control, data-intensive sensing, pipelined sensing.

1 Introduction

As the computational power of embedded devices increases, data-intensive sensing is now a feasible strategy for the control domain in applications such as Advanced Driver Assistance Systems (ADAS), medical applications, robotics and visual servo positioning systems. In ADAS, data-intensive sensing can provide information for object detection, object classification and object tracking, which can be useful to either assist the driver or to automatically control the vehicle. Ref. [JKK$^+$15] describes the implementation of an autonomous car. This system has three kinds of sensors: ranging objects sensors (radar and laser scanner), a path planning sensor (GPS) and an object recognition sensor (camera). The information provided by the sensors is used by a control system to manipulate the steering wheel, brakes and acceleration in order to move the car along a desired trajectory. In the medical domain, control systems that use a camera sensor help with procedures that require precise object movements. As an example, [GS08] shows a vision-based control system for an endoscope, where a camera is used as a sensor to track a target point while a control system positions the

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endoscope towards that point. A representative application from the robotics domain is presented in [Fen10] where a vision-based ground-target tracking controller is developed for an automated helicopter. Finally, visual servo positioning systems are commonly used in industrial robotics. One of the most representative papers in this field is [CH06] that explains the basic approaches for such systems. Although the mentioned applications have received a great deal of attention from the scientific community, some research trends in the fields of control, embedded systems and signal processing open up new opportunities. These trends can be summarized as follows:

1. Signal processing algorithms and implementation techniques that yield efficient implementations in terms of processing and storage resources are being developed [KPS+12], [AGML14] [LTZ+15];

2. Control strategies capable of coping with a high latency in the sensing are being investigated [INW+13], [WNFH14].

This extended abstract is aligned with the first mentioned research trend. More specifically, with the design of efficient implementations to deal with the latency in the loop of a data-intensive controller. As a first strategy, we explore pipelined sensing where multiple instances of a sensing algorithm running in parallel in a pipelined fashion on a multi-core processing platform.

2 Related work

The literature describes multiple approaches to design control systems that deal with long sensing latencies. From the implementation point of view, multiple configurations have been studied: firstly, the serial configuration that does the acquisition and processing in a sequential mode; secondly, a parallel configuration that starts the acquisition of new data before the processing of the previous data is finished, in such a way that new data is available as soon as processing is finished; finally, a pipeline configuration in which every time the sensor finishes data acquisition, a processing unit is ready to perform the signal processing algorithm. Ref. [KV98] compares the three mentioned implementation configurations. The pipelined configuration is shown to have the best performance for applications that requires object tracking. This comparison is summarized in Figure 1. The sequential and parallel configurations both use the same hardware, a sensor for acquisition and a core for processing, but they differ in their control flow.

From the control domain, the most common approach to deal with a high latency is to use strategies to increase the sample time of the system. For example, [FH01] presents a multi-rate controller able to actuate faster than to sense. Other approaches use distributed computation in order to reduce the latency of the signal processing strategy. For example [WLC+13], [WLC+11] discuss a visual servo control application, in which the images are sent over a cloud processing platform where the computing is performed faster than in a local platform, increasing the sample frequency of the controller.

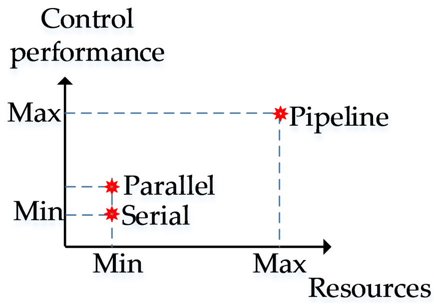

Figure 1: Comparison between resources usage and control performance done in [KV98]

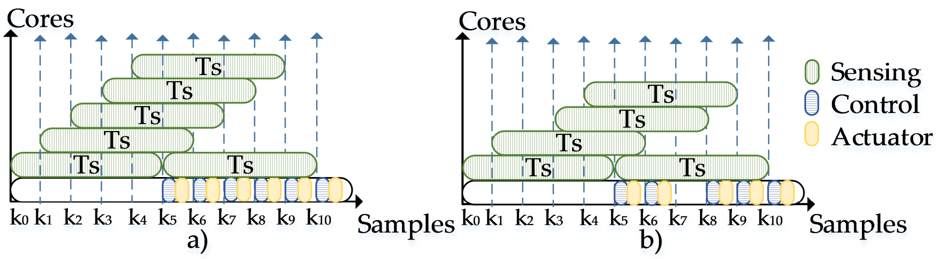

Figure 2: Pipelined sensing structure: a) optimum case; b) reduced case.

3 Pipeline sensing

Our work for data-intensive controllers builds upon the pipelining approach implemented on a multi-core processing unit, as shown in Figure 2a. This solution increases the sample frequency of the system by using multiple instances of the sensing algorithm on different processing cores, while performing the controller and actuation tasks on a fixed core. Ref. [KV98] reports that the optimal performance for a control system is achieved when the number of pipes is equal to the latency divided by the sample time of the system. This results in an implementation with the highest resource cost in terms of processing cores. In our work, we plan to explore resource-efficient approaches for data-intensive controllers. To this end, we are developing strategies for decreasing the number of pipes in the sensing stage, reducing the resource requirements (see Figure 2b), while keeping the quality of control as close as possible to the optimum. We furthermore are considering adaptive strategies where the number of pipes may be adapted online based on resource availability, data availability, and current quality of control.

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