System model of reconfigurable embedded motion control system based on IEC61499

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Abstract

Based on the function block (FB), and distributed system model of IEC61499 standard, the application and system model of embedded and reconfigurable motion control system are modelled. According the motion control system architecture built by embedded microprocessor and reconfigurable logic devices, the function block of IEC61499 can modified to describe the function unit which being used as the basic element to construct the application. Based on the modified function units, in combining with the distribute resources of reconfigurable logic devices, the distributed application model of the motion control system can be configured. To testify the application model, the interpolation process based on the digital differential analyser (DDA) of computer numerical control (CNC) system is carried out, and the results show that the application model is well performed to describe the embedded reconfigurable motion control system.

Keywords: IEC61499, function block, embedded reconfigurable system, motion control, function unit

1 Introduction

Embedded reconfigurable computer systems (ERCS) are generally described as platforms consisting of programmable elements (such as microprocessors) and reconfigurable logics (Such as the FPGA: Field Programmable Gate Array). To an application, the ERCS can provide full flexibility, adaptability and better performance, comparing to architectures based only on embedded microprocessor or on application specific integrated circuit (ASIC).

Researchers have made great efforts to the methodologies of how to map an application into the ERCS. The relating research subjects of the mapping methodologies include task scheduling, software/hardware partition, reconfiguring methods, operation system configuration, memory management et al. [1-3]. Generally, before the mapping subjects having been implemented, the functional units (defined as the instances of tasks being implemented on the ERCS in this paper) interconnection diagram is always necessary. Although varies functional units interconnection diagrams (or system model) have been carried out, there have no one standard model for all kinds of application construction, the main reason is that the system models are always based on different ERCS platforms or to different applications. In addition, transplanting, or updating, an existing system model to new platform with different hardware framework always means more costs.

In robot or computerized numerical control (CNC) system, the motion control is always afforded by the controller system, which is in charge of the interpolation, path planning, tracking, obstacle avoidance, communication and other control tasks. To the controller of robot or NCS that have all the control tasks implemented in software, it would almost be a “mission impossible” to carry all the tasks out under real-time constraints, especially with computation-intensive tasks such as interpolation, path tracking with video information, path planning et al. The expensive ASIC can fulfil the speed criteria; however it is a complicated and expensive procedure if a slight changes occurs [4]. To the flexibility, real-time requirements of robot or NCS, a controller system based on the architecture of ERCS obviously would be a feasible solution, as the ERCS can provide both software and ASIC with reconfiguration.

To configure a motion control system based on ERCS, a distributed functional unit’s interconnection diagram (system model) should be confirmed. In consideration of the computation-intensive characteristic of the algorithms in motion control system of robot or CNC, and the extensible, distributable requirements of system, a coarse-grained functional unit model is presented in this paper. To set up a uniform functional unit model for both software and reconfigurable implementations in the system, the function block of IEC61499 standard is introduced.

The IEC61499 standard defines a set of implementation-independent basic concepts for modular, reusable, distributed industrial process measurement and control system (IPMCS). The function Block (FB) is the basic unit, which can perform a specific algorithm or a kind of operation. The packaged function block (FB) can

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be interconnected or called through the interfaces, in respond to different applications.

In order to building a motion control system for robot or CNC based the architecture of ERCS, the main job of this paper will focus on the functional units interconnection diagram (system model) based on function block (FB) of IEC61499. The rest of this paper is organized in 5 sections. Section 2 describes the function block (FB) and distributed system model of IEC61499. Section 3 presents the analysis of application model of motion control system for robot or CNC based on ERCS. In Section 4, the distributed model of the motion control system based on ERCS is described and confirmed. Experiments and results are described in Section 5. Section 6 draws the conclusions.

2 The distributed model of IEC61499 based on function block

The IEC61499 is a standard, proposed by International Electro-Technical Commission, for the development of distributed industrial process measurement and control system (IPMCS). The standard also describe the methodology that utilizes the Function block (FB) as the main building block and defines the way that FBs can be used to define robust, re-usable software components that constitute complex IPMCSs. Complete control applications can be built from networks of FBs that are formed by interconnecting their inputs and outputs [5].

2.1 FUNCTION BLOCK

The FB can also be described as a class that encapsulates a functionality, which could be one kind of algorithm or operation. One FB instance is described as the event-driven object of a defined FB class. During the construction of distributed application, the FB selection would depend on different FB libraries (such as the control algorithms, alarming manager, communication), and the selected FB eventually would be turned out as the FB implemented instance.

In IEC61499, basic FBs are the basic building blocks. The basic function block consists of a body with interface for data inputs and data outputs and of a header with interface for event inputs and outputs (Figure 1). The Execution Control Chart (ECC) takes charge of the execution of algorithms depending on input data, input events, inner variables and produces output events and output data. Composite function blocks may contain multiple FBs-basic FBs or/and composite FBs.

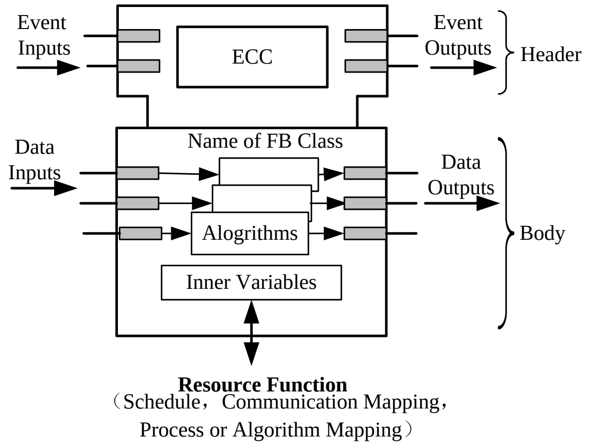

FIGURE 1 The basic function block

2.2 APPLICATION MODEL AND DISTRIBUTED SYSTEM

By interconnecting the basic FBs and composite FBs, a so-called sub-application can be built. The complete application model can be configured through interconnections of the sub-application and different FBs. The interconnections generally are afforded by event streams and data streams.

The distributed system (Figure 2) of IEC61499 is primarily described as the set of interconnected devices or of devices that can communicate through one kind, or more kinds, of communication network.

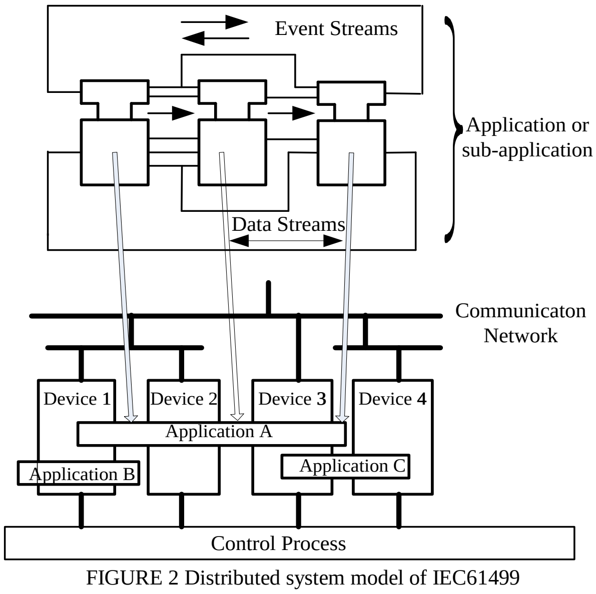

FIGURE 2 Distributed system model of IEC61499

The performances of the distributed system are always described by the complete application model and sub-application models. The application or sub-application would be distributed, as the FBs instances can be distributed, or mapped, to the resources (hardware or software resources being provided for the FBs instances) of one or more devices.

3 Analysis of application model of embedded reconfigurable motion control system

In the motion control system of robot or CNC, involved tasks include path planning, interpolation, tracking, obstacle avoidance, PIC control, communication and other control or signal processing tasks. Corresponding to variations of control objects and working environments, each kind of tasks may be realized by different algorithms. For example, algorithms relating to path planning task include simulate annealing algorithm, artificial potential field method, fuzzy logic algorithm, neural network, particle swarm algorithm and et al.; algorithms involved in interpolation task include pulse increment method (point-to-point comparison method, digital integration method), data sampling, the B spline curve interpolation method etc. In the application design, generally, the algorithms of the tasks are always implemented as executable functional units (or blocks) which can be called by the main procedure of the system. Obviously, the executable functional units (or blocks) are always coarse-grained. This kind of application design method is just object-oriented and justly meets the reusable and interchangeable requirements of system design. Just like the distributed system model in IEC61499, the motion control system can be described by an application model with functional units (of algorithms) interconnected by control and data streams.

To a motion control system based on ERCS, the control tasks or operations are implemented in microprocessors and reconfigurable logics. The available resources (such as the arithmetic unit in CPU, the registers and the memories) in microprocessor, to its software tasks in time domain, can be regarded as infinite, while in the space domain is finite. To algorithms implemented only in software, the only method to realize the parallel structure of one algorithm is to add microprocessors. The reconfigurable logics, otherwise, not only provide the infinite resources in time domain by reconfiguration, but also provide the platform on which the algorithms can be implemented in parallel structure. Especially, many kinds of commercialized reconfigurable logics can provide distributed resources (many FPGAs can provide multi-core of arithmetic units, different scales of memories and programmable bus etc.), which would benefit the applications configuration.

4 The distributed model of controller system based on ERCS

4.1 APPLICATION MODEL BASED ON FUNCTIONAL UNITS AND MANAGER UNITS

As mentioned in Section 3, the controller system of robot or CNC can be described by an application model with functional units (of algorithms) interconnections depending control and data streams. Referring to the basic FB, one functional unit (i.e. one implementation of an algorithm) in controller system can be shown in Figure 3. The interface of the functional unit is a set of data inputs interface, data outputs interface, control streams interface and status streams interface. By the interface (or interfaces), one functional unit can be interconnected to other functional units, or can be called by other procedures or functions. Two or more functional unit can be interconnected into a sub-application or application.

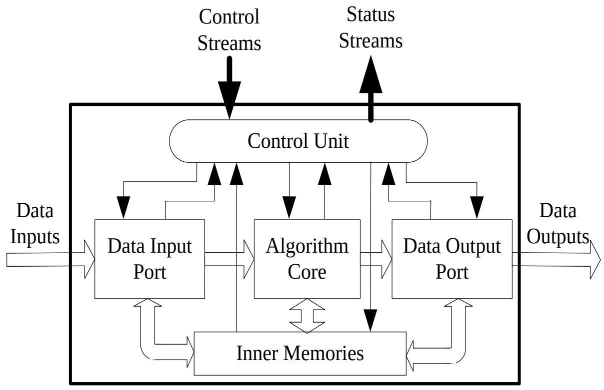

FIGURE 3 The functional unit

During the work of system, the functional unit will be activated by the change of control streams (control events), and begin to receive the input data through the data input port. The algorithm core also be activated and start to perform the data processing: receiving input data and outputting the data being produced during operation. The status streams, through the status port, reflect the operation states (e.g. the idle, busy or suspend) of functional unit and can be read by other functional units or the manager unit (the module bridging the functional units and the task scheduling).

In IEC61499, all the behaviours of the FB are controlled by the Execution Control Chart (ECC). According IEC61499, the behaviours being reflected from ECC include Execution Control status, Execution Control transform and Execution Control action. Thus the behaviours of the ECC can be described by the Finite State Machine (FSM). In this article, the role of the control unit in functional unit of the controller system based on ERCS is as almost same as the role of ECC in FB of IEC61499. The FSMs about the control unit in functional unit are always varied in correspond to the variation of the algorithm. The jobs of the control unit in functional unit include the control to algorithm behaviours, the communications between functional units and responding to the manager unit.

Unlike the functional unit, the role of the manager unit is to bridge different functional units, and to provide management information to upper manager units. The control mechanism of the manager unit can also be described by the FSM. The communication between functional unit and manager unit is performed through the events ports (control stream port and status stream port). By the event communication, the manager can control and monitor the behaviour of the functional units. Two or more manager units can also be combined into a new manager unit by combining the FSMs of the manager units into a new FSM [6]. In addition to the controls to the functional units, the manager units are also interconnected to the task management and scheduling units, which always belong to layer of operation system (OS). The application model based on the functional units and manager units can be described in Figure 4.

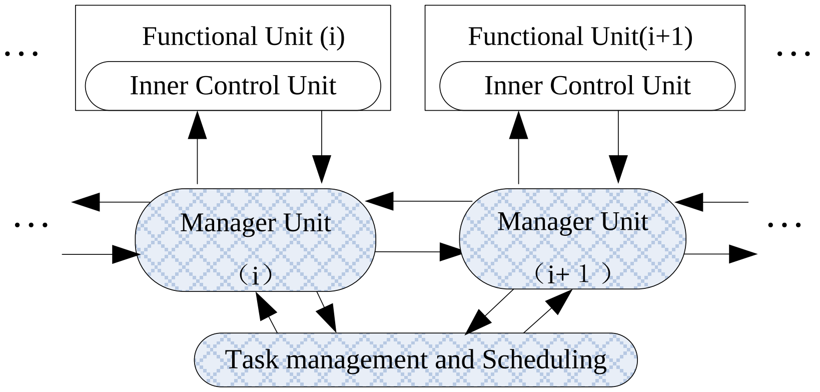

FIGURE 4 Application model based on functional units and manager units

4.2 DISTRIBUTED MODEL OF EMBEDDED RECONFIGURABLE MOTION CONTROL SYSTEM

Based on the devices and application model as shown in Figure 4, the distributed system model of the motion control system can be configured, as shown in Figure 5.

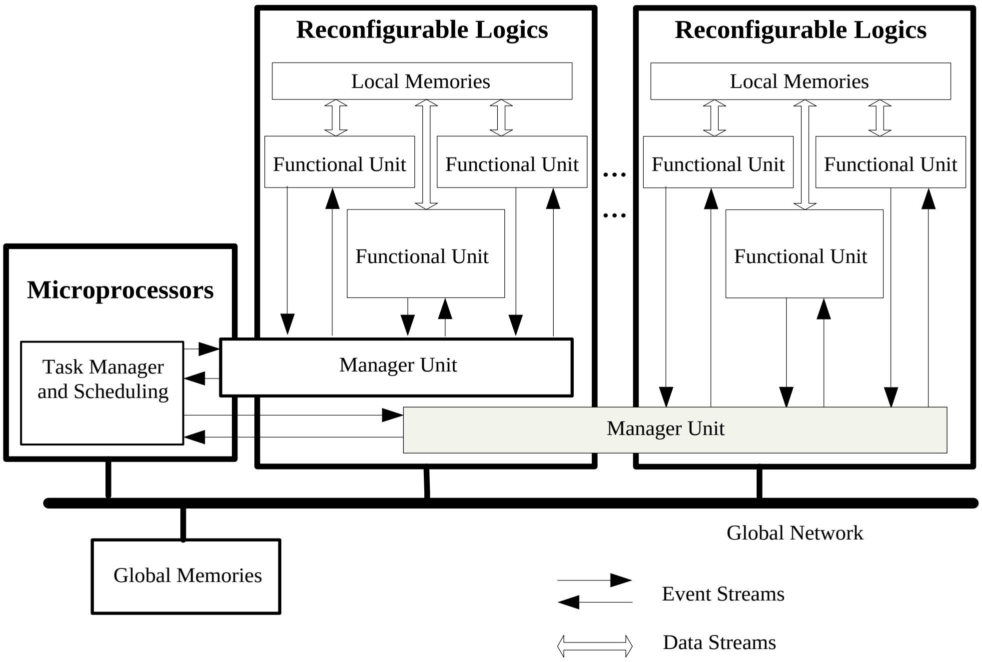

FIGURE 5 The distributed system model of motion control system

Since the devices of the motion control system based on ERCS are microprocessors and reconfigurable logics, the resources (e.g. the arithmetic units, the memories and networks) for the operation of functional units and manager units would be distributed, with temporally and spatially, in the microprocessors and reconfigurable logics (see Figure 5).

5 Experiments

According the proposed design ideas and system model based on IEC61499, an application (Figure 6) about interpolation process of motion control system (for CNC), under the architecture of ERCS, is designed and implemented.

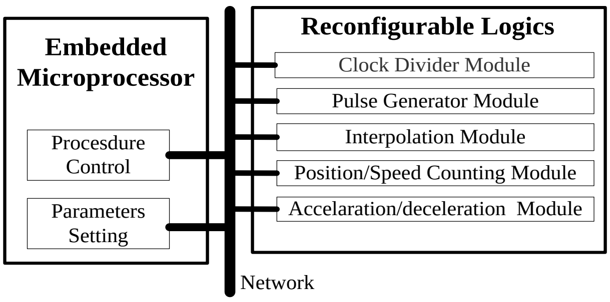

FIGURE 6 Diagram of interpolation

The interpolation process can be considered to be composed of the following modules: clock divider module, the pulse generator module, the interpolation module, position/speed pulse counting module, acceleration and deceleration control module. Each module of the interpolation is designed as a functional unit. The interpolation application is composed of functional units.

Figure 6 shows the procedure control and parameters setting are performed in software, while the modules of interpolation are implemented in reconfigurable logics. The procedure control is manager unit that responds to the task manager of operation system and takes charge of the interpolation scheduling. Parameters setting provide parameters needed for the interpolation before the state changing from idle to activation. The realization of the interpolation in reconfigurable logic is shown in Figure 7, where the clock divider module (**clock_div**) is designed in FSM. The position/speed pulse counting module (**capture**) is designed in FSM by combining the filter FSM and the direction discrimination FSM to the two signals of the incremental optical encoder. The implementation of interpolation module (**interpolate**) is a FSM, which is combined by two FSMs: one is the FSM of the interpolation algorithm (the Digital Differential Analyser is adopted), another is the FSM of acceleration and deceleration control module.

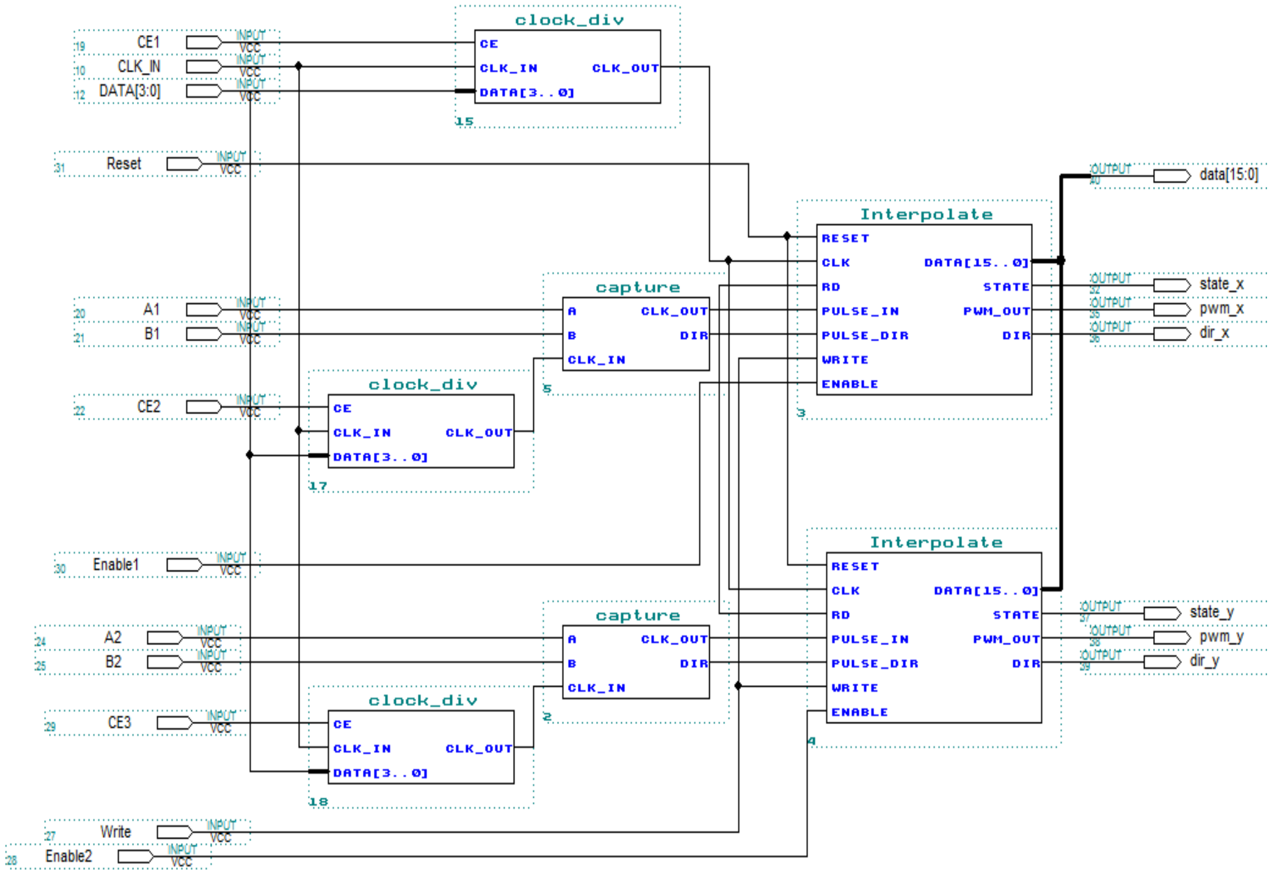

FIGURE 7 The realization of the interpolation in reconfigurable logic

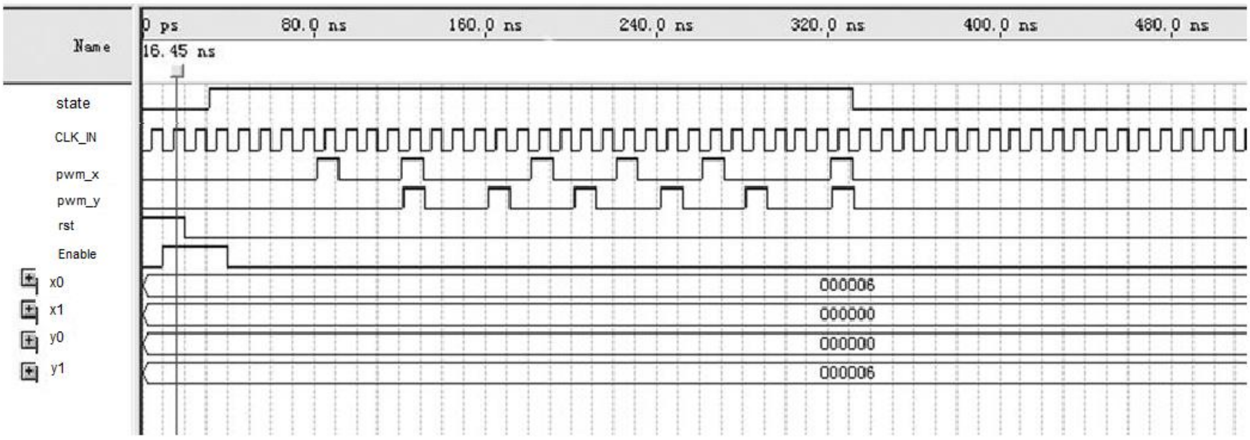

FIGURE 8 The simulation result of interpolation

The interpolation process is synthesized and simulated in Quartus II, and main results are shown in Figure 8. The results show that the outputs of the control pulse are in compliance with the Digital Differential Analyser (DDA).

6 Conclusions

In this paper, the concepts of the function block (FB) and the distribute architecture of IPMCS in IEC61499 are introduced to the configuration of motion control application based on embedded reconfigurable computing system (ERCS). The experiments results show that the introduction and application are feasible. Nowadays, the researches on applications of function block (FB) and the distributed system model of IEC61499 have been from the initial definition of the semantic model to the configuration of applicable model. Some researchers believe that the Unified Modelling Language (UML) would be very suitable to describe the behaviours of the FB and the distributed system architecture of IEC61499 for application construction [7]. At same time, the UML has been used to describe the embedded reconfigurable computing system [8, 9]. Out next research object will concentrate on the application of UML to the embedded reconfigurable motion control system.

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