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Research Article

Research and develop the motion controller in the mechanical servo system

Minh Tuan Nguyen, Ha Quang Thinh Ngo*

ABSTRACT

In the realm of mechanical engineering, the precision and rapid response of high-performance manufacturing machines play an indispensable role in meeting the demands of modern industries. To address the limitations of conventional servo systems, recent advancements have led to the emergence of innovative solutions aimed at overcoming these drawbacks. Some of them still exist the remaining issues, for example high cost, slow communication or large size. Consequently, this research proposes a meticulously designed motion controller that not only manipulates precise position control but also ensures the stability of the servo system, making it well-suited for the requirements of Industry 4.0. The first major contribution of this work lies in the comprehensive investigation of both hardware design and software programming aspects of the proposed motion controller. Achieving seamless data exchange between peripheral devices and the C-based program is a crucial element, and the research delves into the intricacies of this inter-regional communication. This meticulous attention to detail in establishing effective data exchange mechanisms ensures a robust and efficient system that can handle the complexities of modern industrial processes. To validate the effectiveness and feasibility of the proposed method, a one-axis system utilizing the Yaskawa Sigma IV servo system is implemented and tested in real-world applications. This system consists of our controller, one servo driver, one servo motor and cables. The motion generator, employing a seven-segment polynomial, is selected for its versatility and widespread applicability in servo control. This choice allows for an intuitive examination of the system's performance and responsiveness. The results obtained from these experiments affirm the prowess of the proposed design and control methodology, highlighting its efficacy, feasibility, and adaptability to diverse industrial applications.

Key words: Robotics, servo system, AC motor, positioning control

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INTRODUCTION

In the early days of the development of mechanical means, position and velocity control were accomplished by complex, expensive, and time-consuming solutions such as a series of cams [1,2], gears [3,4], and shuttlecocks, and the like. Other devices such as hydraulic and pneumatic cylinders [5,6], electric solenoids [7], pistons, and grips are often added to these systems. Some examples of these solutions include rudimentary textile machinery, coil manufacturing, and winding equipment.

The automotive and machine tool industries [8] are among those that view motion control as a means of delivering complex profiles and integrating versatile operations. Heavy materials can be moved and handled repetitively, adding value and increasing system productivity. While this dramatically benefits continuously repetitive and unchanged operations, it is not the optimal solution for short-stroke parts for any degree of variety or customization. This is, of course, because early automation systems are very specialized and require resetting the tool and setting up when different products or processes are required.

With the advent of computers and microprocessor technology [9], other design ideas became possible. In automation electronics-based systems, various parameters can be selected by simply changing the software in the system. This makes work less setup and more efficient. For example, to change the speed of a specific part's operation, a mechanical system might require exchanging an existing piece of equipment for a larger or smaller one. In the modern field of motion control, this can be done by entering a few lines of code or selecting a different velocity profile from the system's memory.

The motion control system is defined as the application of programmable hardware and software (in combination with sensors, actuators, and other feedback devices) to control one or more motions, such as linear motion [10] or rotary motion [11]. Extending this definition into today's concepts of devices used to control motion, motion controllers often take the

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form of microprocessor-based systems[12]. The system will include the following essential components: controller, amplifier, actuator, and feedback device.

The controller would consist of a device for entering a set of instructions or code into its memory, which is then translated into a sequence of electrical pulses or analog signals and outputs to an amplifier to control some controller. The amplifier receives the signals from the controller and increases or amplifies them to the appropriate levels for the actuator. The actuator provides realistic physical movement and will be closely matched to the design characteristics of the amplifier. Amplifiers or actuators can be one of several different design categories. Typically, these components will be electronic amplifiers and electric motors. Other standard motion actuators are pneumatic or hydraulic actuators. The final element of the system is the feedback device. Nowadays, there are many feedback devices commonly used in motion control systems to provide information about linear or rotational motion.

In general, a motion control system will base and adjust its functions based on the input of any combination of different devices. Multiple motion control systems can be integrated into a more extensive system. Various computer-based devices, such as programmable controllers[13], PC[14], stand-alone industrial computers[15], or remote operating host computers for linkage and coordination of motion control function with other functions. In addition, the operator interface is capable of receiving control logic input, changing an existing program, or providing real-time modification, such as turning the system on or off or changing the schedule.

Networked control systems (NCSs) have been one of the leading research areas focusing on academia and industry for decades and have become a multidisciplinary field[16]. In general, there are three types of networks applied to the controller, including centralized configuration, decentralized configuration, and distributed configuration[17].

With the strong development of Internet, embedded systems, wireless communication and new control strategies, distributed control network has been increasing its importance in various fields. industrial as well as civil. The authors[18] pointed out that the challenges to be solved in the distributed configuration include: network latency, data loss in transit (dropouts), out-of-order data feeds, and process errors. discretization – digitizing data, different network topologies affecting synchronization times, etc. Eliminating or reducing the problems caused by these challenges is the goal of the suites industrial network control.

In this paper, a novel approach in controlling multi-axes for mechanical system is introduced. The advantages of our method are to release the compact unit, multi-functional device, highly reliability and robust control. The hardware design is presented initially to launch the protentional schematic. Then, the flows of data exchange and communication protocol are illustrated in software design. Later, from the proposed structure, it is verified in many practical scenarios to approve the effectiveness, feasibility and possible applications in the real-world industry. The rest of this work is organized as following. Section **METHOD** generally describes the overall method. The hardware design in practical platform is depicted in Section **HARDWARE DESIGN AND SPECIFICATIONS**. The components of firmware and data communication are mentioned in Section **SOFTWARE DESIGN AND COMMUNICATION**. The results of our research are indicated in Section **RESULTS AND DISCUSSIONS** so that it could be seen easily the benefits and superior performance in proposed system. Finally, several conclusions in Section **CONCLUSION** are carried out to concentrate on the powerful specifications.

METHOD

The overall system could be classified into two sections that the first one contains controller and main computer while servo actuator and peripheral devices locate in the second part as Figure 1. In the first section, it plays as an important role in distributing user's command to actuating mechanism as well as delivering the servo status to operators. The second one senses the information and gathers the input data, execute the motion command as desired reference. It might include several measuring sensors, slave controller, power source and so on.

In most cases, one personal computer could be installed more than one slave controller simultaneously. The interface protocol should be usb HID or peripheral component interconnect (PCI) to ensure the rapid communication. The software package in Windows must be allowed to access most libraries. Moreover, the extendable ability of motion controller in multi-axes control is advantageous function which maintain the high performance in industrial application. It should be noticed that the servo system must fully support the network protocol.

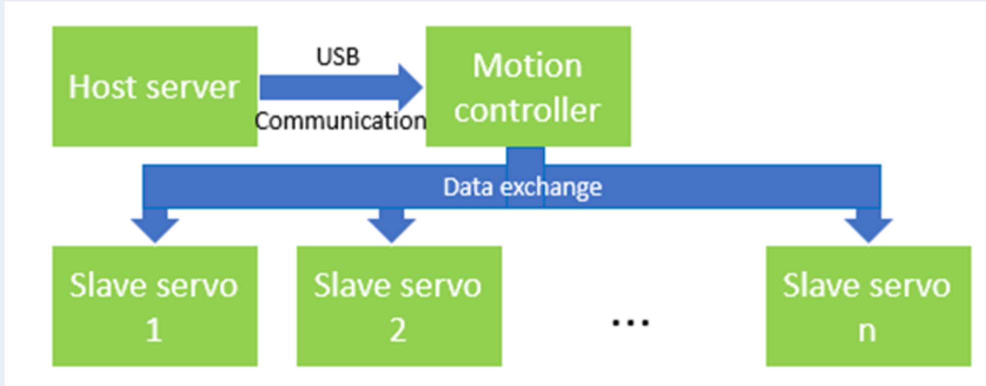

Figure 1: Framework of whole system

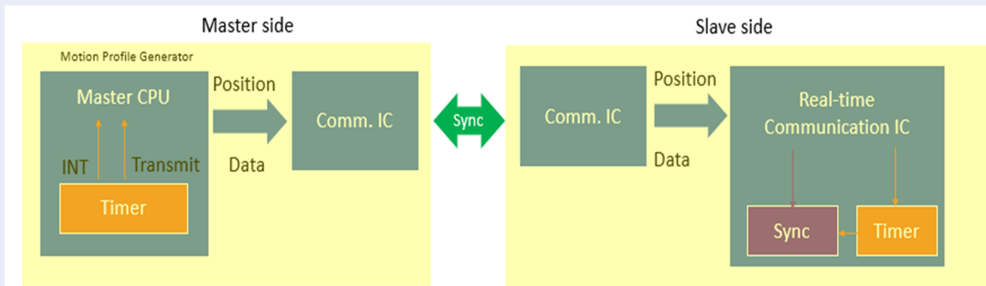

Figure 2: Block diagram of schematic design for proposed system

HARDWARE DESIGN AND SPECIFICATIONS

In hardware level, a description of the proposed system is visually shown as Figure 2. The core of motion controller is 32-bit micro-controller PIC32MX360F512L which is available with a variety of memory sizes and processing speeds, along with advanced analog and digital peripherals. It can be used to add functional capabilities to customized design. They also offer a variety of connectivity options including CAN, CAN FD, Hi-Speed/Full-Speed USB and Ethernet. The communication IC MINAS A6 provides the servo cycle up to 0.0833 ms, 32-byte mode with rapid transmit/receive, ring topology and two operating modes such cyclic transmission and non-cyclic transmission. Besides, it could compute the changes in command position during command updating period and generates the movement command. The design of MCX501 is based on the industrial standard, compact size, easy to obtain many signals from external sides, for instance programmable logic controller, desktop, micro-processor or embedded computer. This controller is typically utilized for several solutions in M2M, motion applications, smart transportation and so on. Additionally, several peripheral ICs could be implemented as interface signals to convert the proper standard.

In this design, most of micro-processor is low energy consumption, surface mounted package and small dimension. The power supply for this board is 5V DC which could be delivered by popular adapters.

SOFTWARE DESIGN AND COMMUNICATION

Conventional Ethernet protocol could not satisfy the real-time characteristics of motion control system owing to timing, synchronization, or data transmission. To surpass these limitations, a novel design of modular real-time express which fulfills the industrial communication standard, is recommended. Figure 3 indicates the comparative structure of data frame. Once, the operator manipulates on host personal computer in central control room. The popular USB connection assists easy plug-in, fast data transportation between host and network module. There

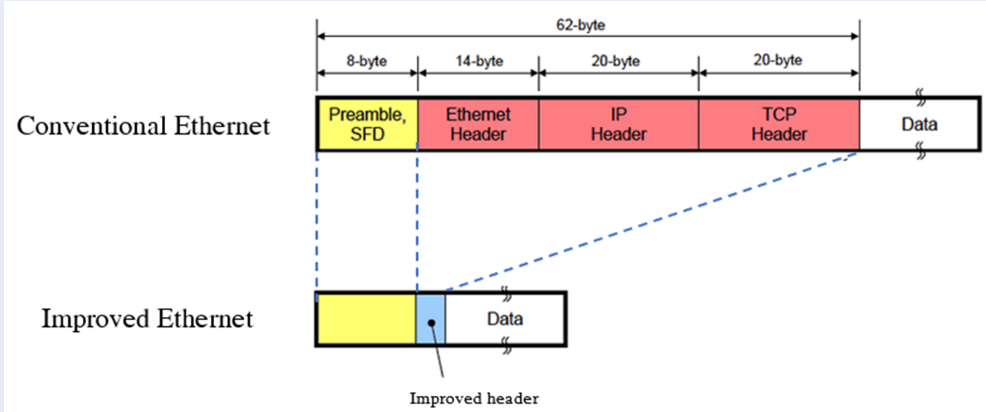

Figure 3: Comparative structure of data frame

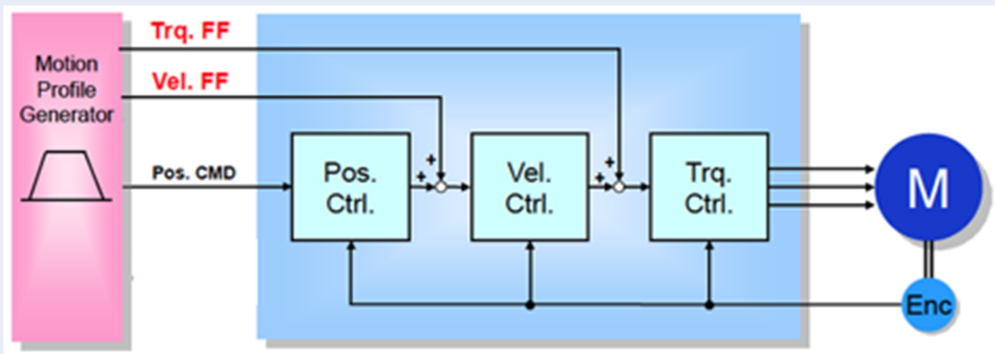

Figure 4: Control loop between slave controller and servo actuator

are two selections in circuit schematic, debug for development and release for commerce. The host controller links with servo pack by two LAN wires (receive and transmit) which could extend up to 100 meters. The servo pack-based system is our target of motion controller. To visualize the feed-back signals, a built-in software installed in host computer interconnects with servo via USB type-B.

For the control loop in servo system as Figure 4, data from controller feeds to actuator as reference signal and feed-forward signal. There are three main loops in servo pack: position, velocity and torque. While position command is supplied for positioning loop, values of velocity and torque are provided as feed-forward control for velocity loop and torque loop. The feed-back signal that is derived from encoder, is then responded to these loops.

RESULTS AND DISCUSSIONS

To verify the correctness and effectiveness of our approach, the overall platform is launched in practical scenario as Figure 5. This system is linked with several types of sensing equipment through USB2Serial protocol that needs two pins (Rx, Tx) to proceed. Data is received commonly, nevertheless, it is only kept in local station during each sampling period. The wireless communication is the intermediate connection between centralized station and local station. Later, data is set in cloud for easily accessing if required.

The experimental verification for single axis has been described in Figure 6. In such S-curve motion profile, the motion command is transmitted from master station to target servo pack. As well, destination and maximum speed are added in the frame of data. Then, these frames are delivered to each station based on the ring topology. In a cycle, master station gathers responses from all slave nodes. When receiving the feed-back frame, the system state of servo drives comprising the messages of servo ready, alarm, warning status or in position signal, supports master station to observe online.

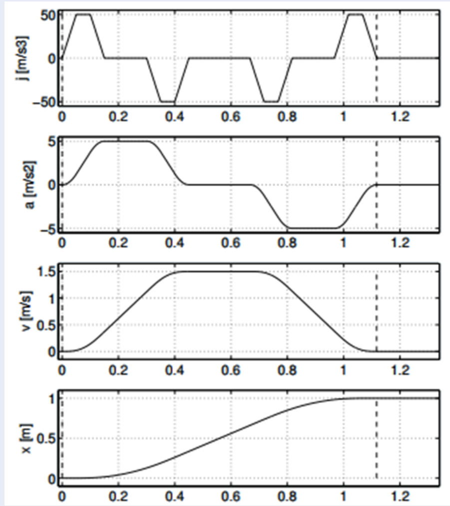

Figure 6: Experimental results using the proposed system of single-axis control with polynomial profile.

Figure 5: Experimental setup using the proposed system for single-axis test

For the polynomial profile from Figure 6a to Figure 6d, it requires additional parameters for setting. In the default mode, acceleration and deceleration have been registered in parameter identification (ID) 8.01 and 8.04. Some supplementary parameters such as filters, could produce better performance. Along with the user-defined parameters, different profiles could be reached.

Commonly, the symmetric shape of motion profile must guarantee the same cycling time for phases to accelerate and decelerate whilst the asymmetric profile causes more time slices to slow down. Henceforth, the total period of S-curve profile is smaller than that of AS-curve profile even though the same constraints are input. In addition, the real value of position in AS-curve profile is obviously more superior since it gradually reaches to target. Vibration suppression and flexible profile generation are the most advantageous outcomes of the asymmetrical profile. On the other hand, max velocity and max acceleration of symmetric profile could be precisely obtained because there is no need to lessen so much. Besides, it must come to a climax in the initial period, then it produces the trajectory of deceleration phase. It is well-acknowledged that the valuable benefits of AS-curve profile are better than those of S-curve profile.

CONCLUSION

In this paper, an effective design of motion controller in machining system is introduced. The hardware platform consists of slave micro-processor, motion control IC and several peripheral devices. The communication of both software and firmware is illustrated so that data exchange is transmitted with high speed and reliable. Several laboratory tests are carried out in the real-world application. It is verified that the feasibility, effectiveness and robustness of this approach are approved.

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CONFLICT OF INTEREST

There is no conflict of interest.

AUTHORS' CONTRIBUTION

Minh Tuan Nguyen: hardware, software, validation, formal analysis, writing draft

Ha Quang Thinh Ngo: review and editing.

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Bài nghiên cứu

Nghiên cứu và phát triển bộ điều khiển chuyển động trong hệ thống servo cơ khí

Nguyễn Minh Tuấn, Ngô Hà Quang Thịnh*

TÓM TẮT
Trong lĩnh vực cơ khí, độ chính xác và phản ứng nhanh của máy móc sản xuất hiệu suất cao đóng một vai trò không thể thiếu trong việc đáp ứng nhu cầu của các ngành công nghiệp hiện đại. Để giải quyết những hạn chế của các hệ thống servo thông thường, những tiến bộ gần đây đã dẫn đến sự xuất hiện của các giải pháp sáng tạo nhằm khắc phục những nhược điểm này. Một số trong số đó vẫn tồn tại những vấn đề còn tồn tại như giá thành cao, đường truyền chậm hay dung lượng lớn. Do đó, nghiên cứu này đề xuất một bộ điều khiển chuyển động được thiết kế tỉ mỉ, không chỉ thao tác điều khiển vị trí chính xác mà còn đảm bảo sự ổn định của hệ thống servo, làm cho nó phù hợp tốt với các yêu cầu của Công nghiệp 4.0. Đóng góp lớn đầu tiên của công việc này nằm ở việc điều tra toàn diện về cả khía cạnh thiết kế phần cứng và lập trình phần mềm của bộ điều khiển chuyển động được đề xuất. Đạt được trao đổi dữ liệu liền mạch giữa các thiết bị ngoại vi và chương trình dựa trên C là một yếu tố quan trọng và nghiên cứu đi sâu vào sự phức tạp của giao tiếp liên khu vực này. Sự chú ý tỉ mỉ đến từng chi tiết này trong việc thiết lập các cơ chế trao đổi dữ liệu hiệu quả đảm bảo một hệ thống mạnh mẽ và hiệu quả có thể xử lý sự phức tạp của các quy trình công nghiệp hiện đại. Để xác thực tính hiệu quả và tính khả thi của phương pháp được đề xuất, hệ thống một trục sử dụng hệ thống servo Yaskawa Sigma IV được triển khai và thử nghiệm trong các ứng dụng trong thế giới thực. Hệ thống này bao gồm bộ điều khiển của chúng tôi, một trình điều khiển servo, một động cơ servo và dây cáp. Bộ tạo chuyển động, sử dụng đa thức bảy đoạn, được chọn vì tính linh hoạt và khả năng ứng dụng rộng rãi trong điều khiển servo. Sự lựa chọn này cho phép kiểm tra trực quan hiệu suất và khả năng đáp ứng của hệ thống. Các kết quả thu được từ các thí nghiệm này khẳng định sức mạnh của phương pháp điều khiển và thiết kế được đề xuất, làm nổi bật tính hiệu quả, tính khả thi và khả năng thích ứng của nó đối với các ứng dụng công nghiệp đa dạng.
Từ khoá: Robotics, hệ servo, động cơ AC, điều khiển vị trí

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