Development of an Integrated Servo-Controller

W. H. Chen, T. J. Teo, W. Lin, G. L. Yang and E. Ho

Abstract – This report focuses on the development of an integrated servo-controller (ISC) for servomotors. Comprising of mainly servo-controller and servo-amplifier, this ISC is capable of controlling a wide range of servomotors to perform complicated tasks. Hence, integration of this ISC with a servomotor forms an intelligent modular actuator (IMA) that is essential to modern manufacturing industries. The development of such an ISC involves two major tasks. First, designing the hardware of a compact-sized and highly compatible ISC. Second, developing the software functions to facilitate its functionalities and capabilities. The developed ISC hence forms an integrated-servo-control module, which determines the capability, functionality, flexibility and responsiveness of these IMAs.

Keywords: Integrated servo-controller, Intelligent modular actuator, Modular technology

1 BACKGROUND

In the ever-changing and highly competitive global markets, most products are largely customized with short delivery period and life cycle. Due to such market demands, enhancing the responsiveness and flexibility of the manufacturing systems becomes the main focus for modern manufacturing industries [1-2]. As a result, the concept of modular reconfigurable automation systems (MRAS) was introduced to address the new challenges in modern manufacturing system [3].

The MRAS are mainly comprised of changeable modules, such as actuator, sensor, conveyor, etc. Such modules can be rapidly assembled and configured into a variety of manufacturing systems [4]. An intelligent modular actuator (IMA) is the key module that determines the level of responsiveness and flexibility of these MRAS. Such an IMA is formed through an integration of both an integrated servo-controller (ISC) and a servomotor.

An ISC is the key component of an IMA that determines its capabilities, such as, performing low-level motion control, communication with the host computer, etc. This results in the advancement of an actuator towards an intelligent and distributed module [5] or an IMA. Such ISCs are developed through integration of micro-controllers and other electronics devices, such as, servo-amplifiers, feedback circuits, etc.

A variety of IMAs have been developed in recent years, including, SmartMotor™ by Animatics [6], PowerCube by Amtec [7], etc. The capabilities of each IMA are achieved through a built-in ISC. The compatibility of such ISCs was limited as each ISC was designed and configured specifically for an individual IMA. This restriction reduces the flexibility of it being employed for the motion control on various servomotors. The control frequency of these ISCs is also limited by the communication speed established between the host computer and the ISCs.

This report mainly focuses on the development of a general-purpose and cost-effective ISC that can be integrated with a variety of servomotors. Results have shown that the developed ISC generates good transient responses and delivers low tracking errors during large trajectory motion. In addition, this ISC allows stand-alone operations, perform interpolation operations and provides a high control frequency. Such an ISC, not only enhances the capabilities of the IMAs, it also directly contributes to the level of responsiveness and flexibility of the MRAS. This allows the MRAS to facilitate the modern manufacturing industries in meeting the market demands efficiently.

2 OBJECTIVE

The main objective is to develop a general-purpose and cost-effective ISC for the IMAs. The two major issues addressed in this development are, the hardware design and software programming for the ISC.

3 METHODOLOGY

3.1 Hardware design

The hardware components of the ISC consist of a servo controller, Pulse-Width Modulated (PWM) power drivers, current detect and feedback circuits, I/Os and watchdog circuits. The communication between the host computer and the servo controller is through an asynchronous serial port. A network port is integrated for communication between multiple ISCs. Fig. 1 illustrates the hardware architecture of ISC.

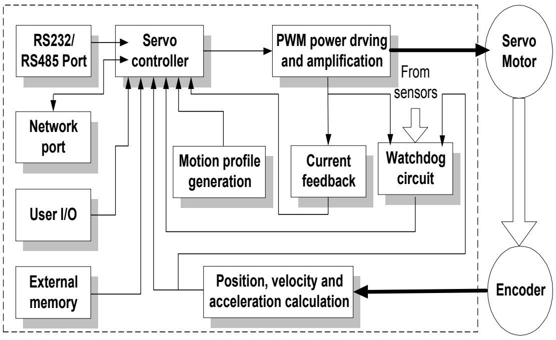

Fig. 1. Hardware architecture of the ISC.

3.1.1 Servo controller

The DC servo controller is basically a chipset that consist of a high-speed digital signal processor based micro-controller produced by Performance Motion Devices, Inc [8]. This servo controller is employed to reduce the substantial software tasks generally inherent by the host's processor. It contains special on-board hardware that makes it well suited for the task of motion control. Fig. 2 illustrates the block diagram of the servo controller.

This servo controller contains a motion profile generator that calculates velocity, acceleration and position values for trajectory planning. It also contains a PID-type servo filter that stabilizes the servomotor output signal. Such a servo filter can produce one of the two types of output:

- A PWM signal output, or
- A Digital-Analog-Converter compatible value routed via the data bus to the appropriate Digital/Analog (D/A) converter.

The servo controller receives the servomotor position in the form of encoder feedback. This feedback is either in incremental encoder input signals or via the bus as parallel word of the input devices. Such an input device can be an absolute encoder, an Analog/Digital converter, a resolver, a laser interferometer, etc. Regardless of the encoder-input mode, the information for the servomotor position is then used to maintain a 32-bit actual axis position counter.

The servo controller calculates the position, velocity and acceleration of the servomotor through reading the output signals of the encoder. These interpreted output signals will then be taken as the feedback of the servomotor motion and the inputs of the watchdog circuits. The servo controller is also connected with a current sensor to complete the current detection and feedback loop.

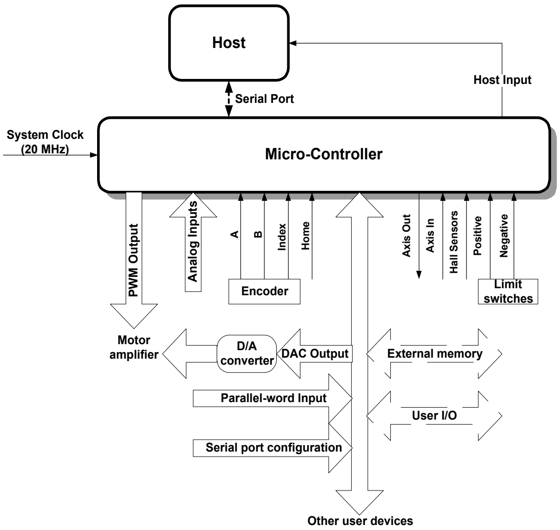

Fig. 2. Block diagram of servo controller.

3.1.1.1 Motion profile generator

The motion profile generator determines the instantaneous position, velocity and acceleration of the servomotor at an instant of given time. These values are known as commanded values. During a motion profile, some or all of these parameters will change continuously. Once the motion is completed, these parameters remain at the same values until a new motion command is given. The motion profiles are classified into the following:

- Trapezoidal point-to-point profile
- S-curve point-to-point profile
- Velocity-contouring profile

3.1.1.2 Digital PID-type servo filter

A servo loop is used to match as closely as possible between the commanded position that comes from the trajectory generator, and the actual servomotor position from the encoder. To accomplish this, the profile generator commanded values is combined with the actual encoder position to create a position error. This error is then passed through a digital PID-type servo filter. Hence, the scaled result of this servo filter calculation is the motor command. This motor command is either a PWM signal to the motor amplifier or a 16-bit input to a D/A converter. Fig. 3 illustrates the structure of the PID-type servo filter.

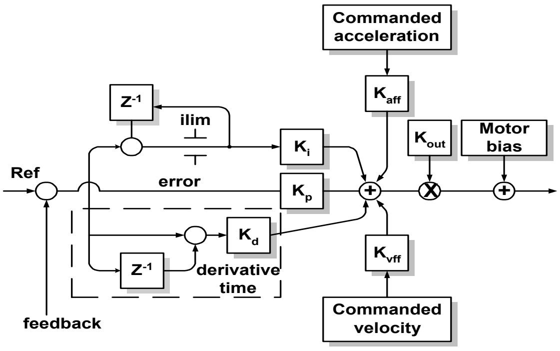

Fig. 3. Structure of the digital PID-type servo filter.

3.1.2 PWM driving and power amplification

Through the PWM driving and power amplification circuits, two functions can be achieved:

- To amplify the current of the control signals to drive the amplifier
- To supply the power to the servomotor through the control of the PWM signal.

3.1.3 Watchdog circuits

The watchdog circuits can be used for force control applications through current feedback. The circuits will detect and feedback the amount of current continuously to the servo controller. Increasing in the current indicates the increasing of the contact force, while stagnating in the current indicates the opposite.

These circuits can also provide circuit protections for the system integrated-components and operation security. The protection functions are listed in table 1.

Table 1. List of protection functions.

No.	Protection functions
1.	Over current protection
2.	Over velocity protection
3.	Over heat protection
4.	Over voltage protection
5.	Under voltage protection
6.	Position hard limitation protection
7.	I^2t protection
8.	Short circuit protection

3.1.4 User I/Os

External coordination and sensor messages such as force message can be input through user I/O interface. Users can also get the output messages of the servomotor through this interface. Hence, the ISC receives the capability of external interactions through these interfaces.

3.1.5 External memory

Up to 512KB RAM can be added to provide an external memory to enhance the capabilities of the ISC in three ways:

- Storing the optimised default control parameters of the servomotor
- Storing the traced data of the selected variables or parameters
- Storing a list of dynamics parameters for interpolation operations

Optimised default control parameters of the servomotor can be stored into the external memory after verifying through testing and evaluation. For example, mechanical limitations or optimised PID values of a particular servomotor can be stored to provide rapid usage through the ISC. Alteration of the data is also possible to provide flexibility when changing of servomotor is required. Hence, this enables the ISC, to utilize the maximum capability yet maintaining the lifespan, of the integrated servomotor.

External memory also provides storage spaces for the servo controller to capture and store data of up to four parameters continuously during data tracing. The host can then download the captured data by accessing into the external memory. It facilitates users to perform data trace that is useful for optimising the servomotor performance, verifying trajectory behaviour, capturing external sensors data, or monitoring a precise time-based record of the system's behaviour.

The most important feature of the external memory is to facilitate the ISC to perform interpolation operations. From the host, a list of dynamics parameters for interpolation, such as, position, velocity, acceleration, etc, will be calculated and downloaded into this external memory. Through this memory buffer, the servo controller will abstract the stored data to perform linear or circular interpolation. Hence, a standalone IMA can also be realized through the used of this external memory.

3.2 Software programming

The software programming has been divided into two stages. The first stage is to create a portable and generic class of application functions to facilitate programmers in utilizing the ISC for their applications. The second stage is to create a Graphic User Interface based Man Machine Interface (GUI-MMI) for controlling any integrated servomotors through the use of the ISC.

3.2.1 Class of application functions

This generic class is portable across C and Visual C++ platform. The class consists of all necessary functions that facilitate programmers to create any user interfaces that perform motion control via the ISC, on one or multiple servomotors. Each function of the class performs a specific task through an integration of substantial low-level software functions. Hence, this generic class becomes an inevitable link between the user interfaces and the ISC.

3.2.2 GUI-MMI

The GUI-MMI is divided into three main structures: Start-Up, Motion-Control and Edit-Setting. Start-Up will be an automated route to facilitate users to establish communication with the connected servomotors via the ISC. Once identifying each servomotor-type, it automatically downloads the optimised default control parameters and displays the status of individual servomotor. Figs. 4, 5 and 6 illustrate the flow charts of individual structure.

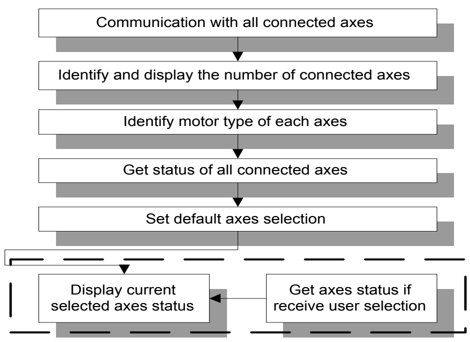

Fig. 4. Flow chart of start-up.

Motion-Control functions as an interactive feature for users to perform motion control on the connected servomotors. It loads the control parameters of individual servomotor into the servo controller to perform the desired tasks.

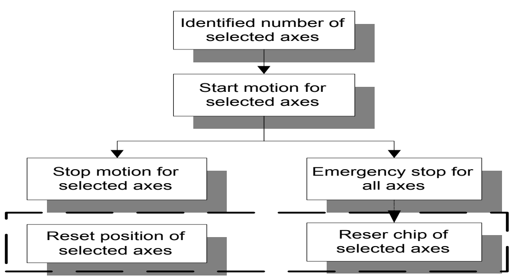

Fig. 5. Flow chart of motion-control.

Edit-Setting is an additional interactive feature to provide user the flexibility of modifying the parameters for individual connected servomotor.

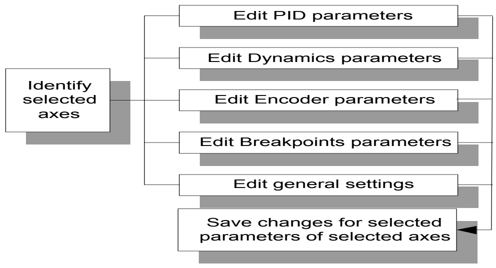

Fig. 6. Flow chart of edit-setting.

4 RESULTS & DISCUSSION

An ISC has been developed through the design and development of both its hardware and software. Fig. 7 shows the picture of a 96mm x 75 mm ISC prototype. Table 2 lists its specifications.

Fig. 7. ISC prototype.

Table 2. List of specifications.

Features	Specifications
Communication modes	Asynchronous serial (RS232/485)
PWM working frequency	20kHz (crystal frequency: 20MHz)
Servo loop timing range	100µsec to 3355 msec
Multi-axis synchronization	<10µsec
Bandwidth	Maximum servo loop frequency 10kHz
Range of velocity regulation	1:100,000
Motion profile modes	S-curve point to point; trapezoidal point to point; velocity-contouring
Filter modes	Scalable PID + Velocity feedback + Acceleration feedback + Bias
Filter parameter resolution	16bits
Maximum encoder rate	5 million counts/sec (5MHz)
Communication rate	410Kbps (RS485)
Voltage	48VDC

A GUI-MMI was developed using Window Visual C++ platform. Through the use of the class functions, the Window-based interface provides interactive features, via this ISC, to control multiple servomotors. Fig. 8 shows the main layout of the GUI-MMI.

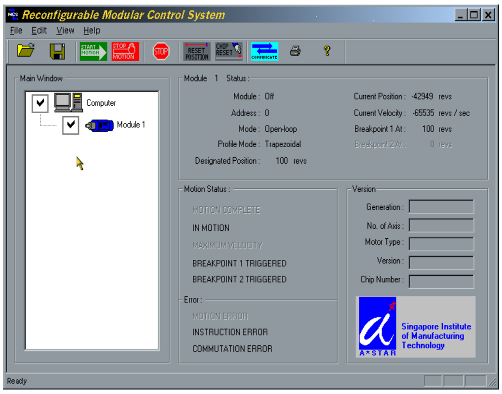

Fig. 8. Main layout of GUI-MMI.

The GUI-MMI also allows users to alter any control parameters of the selected servomotor through this ISC. All default control parameters will be displayed during the process. Fig. 9 shows the parameters alteration layout.

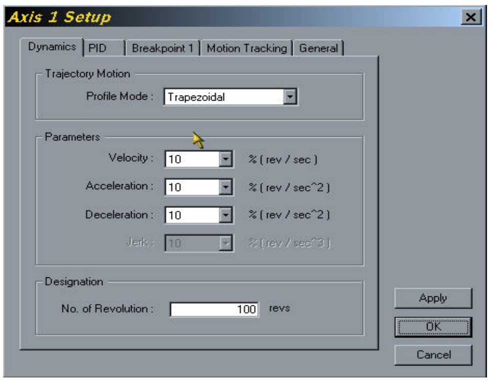

Fig. 9. Layout of control parameters.

Together with the GUI-MMI, this ISC allow users to control any servomotors through velocity or position control method. The performance of this ISC, in controlling a servomotor through velocity control method, can be evaluated through the transient responses generated by the servomotor. Hence, using a brushed servomotor with maximum velocity of 80 rev/sec, two transient responses of the servomotor were plotted for such an evaluation.

The first transient response was plotted through commanding the servomotor to rotate to its maximum velocity without applying any torque to its rotating shaft. Fig. 10 shows the plot of the first transient response.

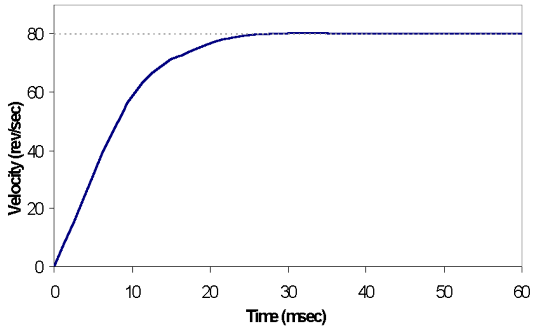

Fig. 10. Transient response of a brushed servomotor without applying torque to its rotating shaft.

The second response was plotted through the same commanded velocity with torque applied to the rotating shaft. Fig. 11 shows the plot of the second transient response.

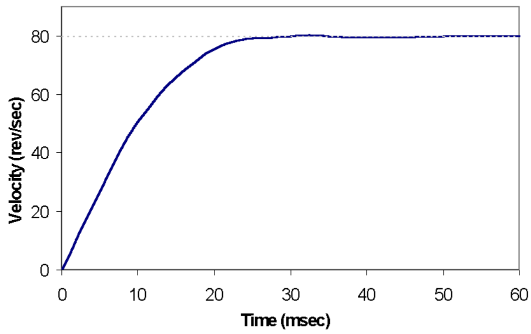

Fig. 11. Transient response of a brushed servomotor with torque applied to its rotating shaft.

The first transient response shows that the servomotor rotated to its maximum velocity with:

- Settling time less than 40 msec
- Overshoot less than 1%, and
- No steady-state error

Even with torque applied to the rotating shaft, the second transient response of the servomotor shows:

- Settling time less than 50 msec
- No overshoot, and
- Steady-state error less than 1%

Hence, this evaluation has shown that through velocity control method, this ISC can generate good transient responses from the servomotor.

This ISC also has high positioning accuracy that allows a servomotor to generate large trajectory with low tracking error. Such tracking errors are use to determine the performance of the ISCs that use position control method to control a servomotor. Two tests have been conducted for justification. Each test uses a tracking window of ± 1 pulse (0.18°), which is the minimum encoder reading, to track the tracking errors.

Test 1 was conducted through the use of an ISC developed by Amtec and a brushed servomotor. By feeding this "Amtec" ISC with a list of position parameters, a trajectory was generated. Fig. 12 shows a section of the trajectory generated in test 1.

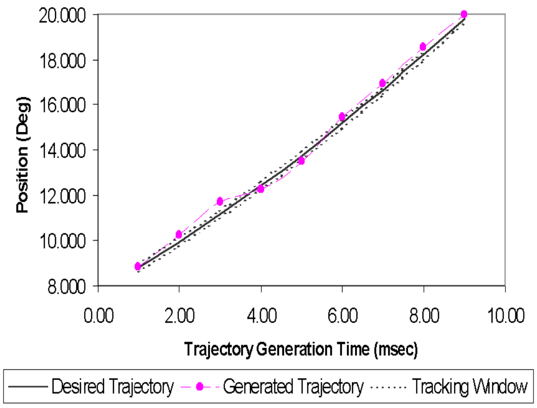

Fig. 12. Test 1 – A section of the trajectory generated by the "Amtec" ISC.

Test 2 was conducted using the developed ISC with the same servomotor. Fed with the same list of data, another trajectory was generated through this ISC. Fig. 13 shows a section of the trajectory generated in test 2.

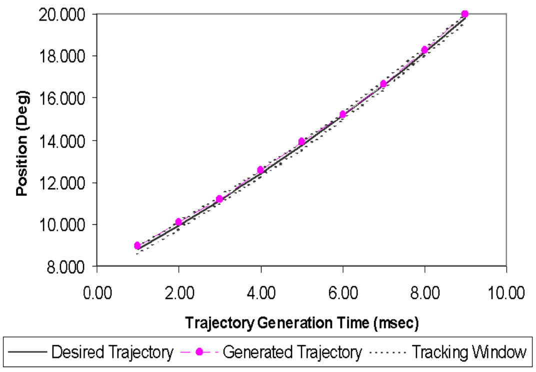

Fig. 13. Test 2 – A section of the trajectory generated by the developed ISC.

The generated trajectory in test 1 did not fall within the tracking window, while in test 2; the trajectory was generated within the tracking window. Hence, the test results have shown that through position control method, the developed ISC can generate a trajectory with tracking error of ± 1 pulse.

5 CONCLUSION

A general-purpose and cost-effective ISC has been developed. This compact-sized ISC can be integrated with any DC servomotors, allowing users to conduct motion control through velocity, position or even force control method. This ISC generates good transient responses from the servomotors with any velocity inputs. It also has high positioning accuracy that allows the servomotors to generate large trajectory with ± 1 pulse of tracking error. This ISC has a control frequency of up to 10 KHz that allows precise interpolation operations. Other functions of this ISC includes; tracing of selected parameters, storing of optimised default control parameters, allowing stand-alone operation and utilization of the servomotors maximum capabilities without reducing its lifespan. Its embedded communication architecture also facilitates multiple ISCs communication, which forms a decentralized control architecture adopted by most MRAS. Together with a user-friendly GUI-MMI, this ISC enhances the capabilities of the IMAs. As a result, such IMAs will significantly improve the level of responsiveness and flexibility of the MRAS.

6 INDUSTRIAL SIGNIFICANCE

The IMAs have been introduced to modern industries in recent years due to the increasing demand in reconfigurable automation systems. In the case of opto-electronic devices assembly, fixed assembly automation systems are unable to cope with the rapid changes in products and varieties of processes. This shows the need for reconfigurable assembly system that supports a wide range of assembly processes and products [9]. An IMA is a type of changeable module that forms such MRAS. The key concept of achieving high responsiveness and flexibility generally lies on the re-usability, "plug-and-play" capabilities and flexibility of these IMAs [10]. Therefore, an IMA with a well-designed ISC, allows the MRAS to assist the modern manufacturing industries in meeting the market demands efficiently.

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