PWM Noise Reduction in OFDM-Based Power Supply Overlaid Communication System for Industrial Machine Control

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Abstract. This paper presents a design and prototyping of power supply overlaid communication system for industrial machine. In industrial machine, the control signals require for real-time and reliable. However, there is no power supply overlaid communication system for industrial machine to meet such requirements with current technology. We have developed a power supply overlaid communication system to meet the demands of these two. We also report to develop a channel emulation system using power line model for industrial machine, since the evaluation of the proposed system.

Keywords: PWM Noise, Power supply overlaid communication, Industrial machine control.

1 Introduction

Represented by the industrial machine, industrial robot is constructed by many actuators. Used only for communication lines that are routed to the actuator from the controller this controls the whole machine of the actuator. In addition, the actuator power supply lines and the controller power supply lines are wired separately from this. For this reason, many cables are used for the control signal and power supply, in the industrial robot. The cables gradually deteriorate from twisting and bending from the robot position, expansion and contraction. As a result, the cable is disconnected, and it will waste the cost of the replacement cables. Thus industrial machine is necessary to wire saving. In addition, if could wire saving, it is able to contribute to saving resources of copper material.

Previously we explain the communication cables and power supply cables is distributed to industrial machine. The method of wire saving is communication on the power supply cables. It enables to control industrial machine over one power supply cable. However, the power supply cable has a number of branches, so the superposed signal is reflected [1]. This makes the power supply overlaid

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communication channel multipath. Then receiver receives signal which added multipath signals. If these signals delay long, receiving characteristic deteriorates by Inter-Symbol Interference (ISI) [2] [3]. In the power supply overlaid communication, Orthogonal Frequency Division Multiplexing(OFDM) modulation method enables high throughput communication against multipath channel[4]. OFDM modulation is also used by wireless LAN (WLAN) system including IEEE802.11a system [5]. OFDM divides high throughput data into low throughput data. Then transmit in parallel by using lots of sub-carriers. This enables to reduce multipath distortion and to complement channel condition flexibility. Sub-carriers are orthogonal each other, so it enables to communicate in high frequency usage efficiency. Moreover the inserted redundant signals called guard interval (GI) between the symbols avoid multipath delay interference efficiently and the received sub-carriers are just influenced by attenuation. Although the attenuated sub-carrier is susceptible to the noise effect, it enables to correct code error by combine with error correction. On the other hand, within the multipath channel, a bit loading algorithm to maximize the bit rate has been proposed in the simulation [6]. For this reason, we need to develop a power supply overlaid communication system for industrial machine control [7][8].

However, the noise is assumed Gaussian white noise in these systems, the impulse noise generated from the actuator of the machines is also present in practice. In such environment, the bit error rate much degrades because the affection of impulse noise spreads all carriers in OFDM. As a proposal to a power supply overlaid communication system in impulse noise environment, by using a limiter amplifier, it is shown that it can improve the BER deterioration due to impulse noise [9], Method of re-modulated in the OFDM time domain signal samples, it has been degraded by impulse noise [10]. There is nothing that can ensure communication reliability and real-time either.

This paper is a proposal for improvement of communication reliability. This paper is organized as follows. In the section 2, shows the impulse noise occurs in industrial machinery. The section 3 describes the proposed method. The section 4 shows the construction of the proposed power supply overlaid communication system for industrial machine control. The section 5 shows the result of the proposed system performance. Finally in section 6, we describe some of the challenges and future works.

2 System Specification

Fig.1 shows the basic robot control system. The basic robot control system controls the attitude of the robot. First, the robot controller sends position information request from the servo amplifier to the encoder. Then, position information requested encoder responds position information. Next, the robot controller controls attitude of the robot using by this position information.

Fig.2 shows a schematic diagram of the basic robot control system which is applied by the proposed power supply overlaid communication system for industrial machine control.The new system saves the use of encoder cables.

Table 1. Rate- Dependent Parameter

Data Rate $[Mbits/s]$	Modulation	Coding Rate	Coded bits per sub-carrier	Data bits OFDM symbol
81	64QAM	3/4	6	216

Fig.3 shows details of the wire-saving on encoder cable. The left side shows the structure of conventional encoder cables. Three pairs of wires are necessary for one encoder communication: one pair of DC power supply wires, one pair of battery power supply wires and one pair of serial communication wires. So the whole encoder cable that used to connect all six encoders consists of six lines of such bundled wires (Total 18 pairs). The right side shows the structure of encoder cables used by the proposed new system. By communalizing the communication line and power supply line between controller and encoder, the power supply lines which are connected to the encoder are reduced from threes pairs to two pairs. Additionally, because all six encoders are connected by Bus connection method, the whole encoder cable consists of only two pairs of wires.

On the industrial robot, the control period shifts from msec to μsec, so control signals are required to be sent at high data rate to control multi-axial robot. For this reason, considering the safety of robot control, the data rate is set to 81Mbps. On this system, 48 data sub-carriers for data transmission and 4 pilot sub-carriers for detecting frequency offset are used, OFDM symbols are modulated by 64 point Fourier fast transmission (FFT). Then, the robot power supply line channel is showed Fig4. The robot power supply line channel uses band width of 30 MHz, each sub-carrier frequency space gets into 0.469 MHz. Depending on this space, FFT period gets into 2.13 μsec as the reciprocal of this space.

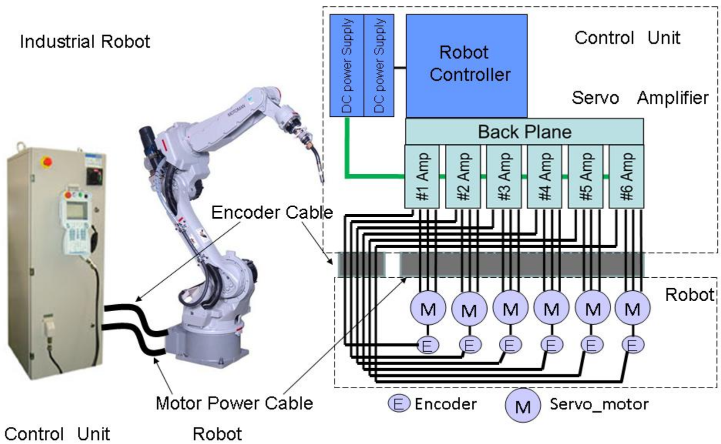


Fig. 1. The basic robot control system

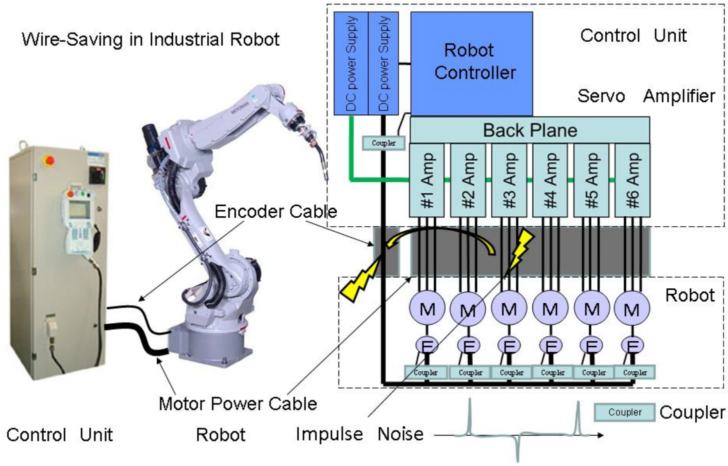


Fig. 2. Applying by the proposed power supply overlaid communication system for industrial machine control

As shown in Figure 2, the impulse noise is generated from the servo amplifier, however BER is significantly reduced. Fig.5 shows a general circuit configuration of the actuator used for industrial robots. This circuit is called a voltage output inverter. By comparing the voltage command value (triangle wave) and carrier frequency, this circuit generates PWM signal and carries out switching operation according to the PWM signals[11]. With the switching operation, voltage which is proportional to the voltage command is applied to the motor. Fig.6 shows the PWM signal which is generated by comparing the voltage command value (triangle wave) and carrier frequency. This signal is the gate signal of switching devices(a^+,a^-,b^+,b^-,c^+,c^-) showed in Fig.5. These switching devices turn on and off according to the PWM signal and drive the induction motor. Fig.7 shows

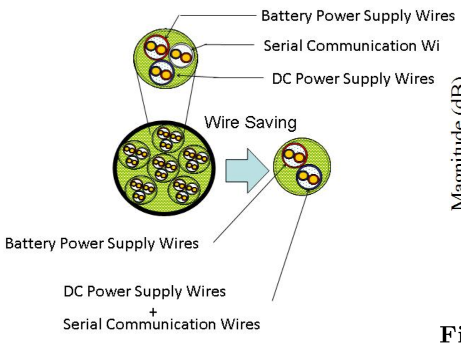


Fig. 3. Detail of the wiring-saving

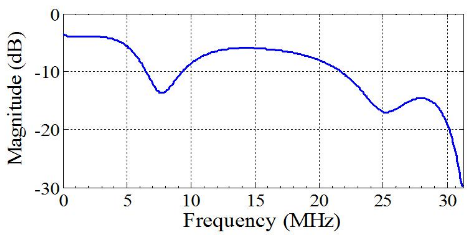


Fig. 4. Channel Characteristic of Amplitude

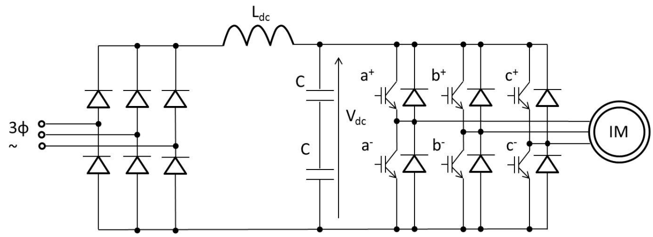


Fig. 5. Main power converter structure of widely utilized diode-rectifier front-end-type PWM-VSI drive

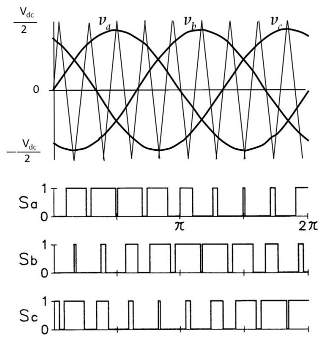


Fig. 6. Relation of Voltage command and PWM

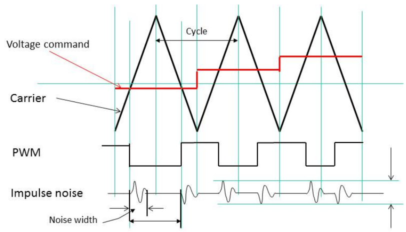


Fig. 7. Voltage Command, Carrier and PWM Signals

the impulse noise which is induced by encoder communication cable laid with the motor power supply cable. Impulse noise generates by the rising and falling edges of the PWM signal.

3 System Architecture

Fig.8, 9 and 10 shows the proposed system of transmitter receiver and packet format. The proposed system is developed with a based on IEEE802.11a circuit. The bandwidth of the proposed system is extended from 20MHz to 30MHz. The proposed system is improved data rate from 54Mbps to 81Mbps.

3.1 Impulse Noise Estimator

Generation timing of impulse noise can be expected if you know the timing of the triangular wave and frequency(f) of the triangular wave voltage command(η)

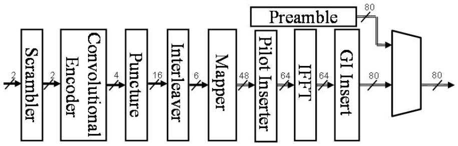


Fig. 8. Proposed Transmitter

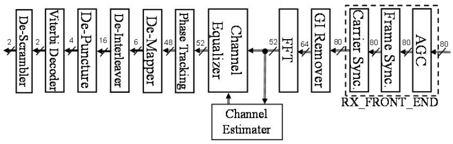


Fig. 9. Proposed Receiver

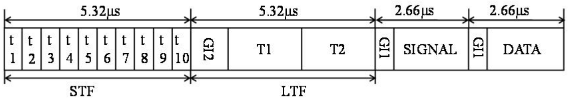


Fig. 10. Packet Format

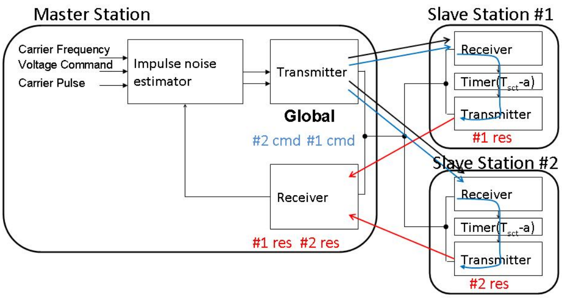


Fig. 11. Diagram of a power supply overlaid communication system

value. Equation.1 indicates the non-impulse noise time interval, T_{sca}: Safety Communication Area.

$$T_{sca} = (1 - \eta)/2 \times 1/f_c - \pi t_r \tag{1}$$

This equation can be derived useful starting time for communication from the peak and valley of the triangle wave. Equation.2 estimates useful starting time for communication by the peak and valley of the triangle wave, T_{sct}: Start Communication Timing.

$$T_{sct} = 1/(2 \times f_c) - (1 - \eta)/2 \times 1/2f_c + \pi t_r \tag{2}$$

T_{sca} is required 24.03μsec according to the Fig.10. Voltage command (η) derive ≤ 0.38 at 10kHz and ≤ 0.75 at 4kHz. Fig.11 shows a configuration diagram of a power supply overlaid communication system proposed. Master station is located on the controller, the slave station is placed in the actuator unit.Slave station 1 is in the actuator 1. Slave station 2 is in the actuator 2. Fig.12 shows the communication protocol of the proposed system. The first signal indicates multicast

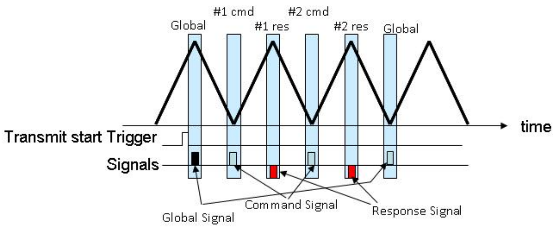


Fig. 12. The proposed system of protocol

frame. The second signal(♯1 cmd) indicates the command to the slave station 1. The third signal(♯2 cmd) indicates the command to the slave station 2.The signal(♯1 res) indicates response to the master station from the slave station 1. The signal(♯2 res) indicates response to the master station from the slave station 2. These behaviors are described in the following issues.Master station estimates the communication time(T_{sct}) from the voltage command and carrier frequency, whenever the carrier pulse is input to the impulse noise estimator.T_{sct} time after starting from the peak or valley of career, master station transmits a signal to the global time zone that is not the generation of impulse noise.When receiving the global signal, the slave station sets the T_{sct} the internal timer.Then, the master station receives a time period that does not occur in the impulse noise from the impulse noise estimator, it transmits a command(♯1 cmd)to the slave station 1. The slave station 1 received command signals, and then it starts the internal timer.The time is reached not generated the impulse noise, the slave station 1 responds signals(♯1 res) to the master station.Even if other slave station is there, data communication of this command response is carried out.The proposed system performs cyclic communication in this step. In this paper, a method of activation timing of this cyclic communication is proposed.

4 Evaluation System

Fig.13 shows an outline of the developed transmission line emulator system. The developed system consists of a transmitter unit and receiver unit and channel simulator unit and two selector units. The transmitter unit and the channel simulator unit are connected by the left side selector, and that the channel simulator unit and the receiver unit are connected by the right side selector. The transmitter unit and receiver unit functions are achieved by MATLAB®/Simulink®, or Verilog HDL simulator, or the circuit board. Fig.14 shows construction of channel simulator unit in Fig.13. Channel simulator unit is composed of back-end unit and transmission line unit and front-end unit. Back-end unit convert the real signal component from the complex signal that is output from the transmission unit. Transmission line unit achieves the characteristics of any channel, and add the Gaussian noise according to SNR and impulse nose. Fig.15 shows the measured values used for impulse noise model. Front-end unit convert the complex signal from the real signal component. By switching the selector, the combination of transmit and receive units are determined. Channel simulator unit construct of a complex signal to real component signal processing back-end unit that signal is output from the transmission unit.

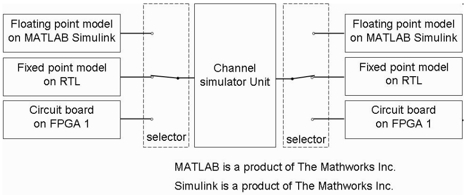


Fig. 13. Transmission Line Emulator System

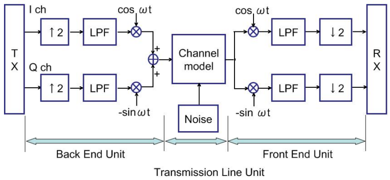
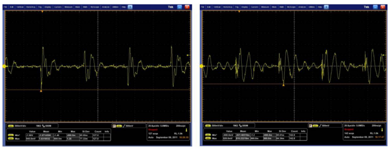


Fig. 14. Channel Simulator Unit

Cable Length	Motor Rating			
	50W		750W	
(m)	Max(v)	Min(v)	Max(v)	Min(v)
50	1.28	-1.46	0.98	-1.20



a) 50W a) 750W

Fig. 15. Impulse noise

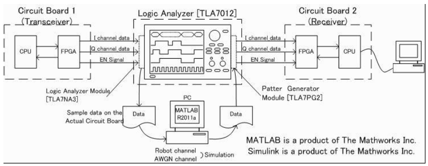


Fig. 16. Transmission Line Emulator System Using FPGA

Fig.16 shows the construction of the transmission line emulator system using the circuit board. The system consists of two circuit boards, instrument, and PC. The circuit boards 1 and 2 mount FPGA and CPU chips. Transmitter and receiver of the proposed communication system have implemented in the circuit boards 1 and 2, respectively. The CPU mounted on the circuit boards 1 and 2 takes control of the FPGA. The instrument (TLA7012) consists of the logic analyzer unit (TLA7NA3) and data generator unit (TLA7PG2). The logic analyzer unit is sampling the signal output from the FPGA of the circuit board 1.We treated the signal from the circuit board 1 and inputted the signal into the FPGA of the circuit board 2. The signal processing is applied to the channel characteristics (AWGN, Robot power line) and noise transmission path by the channel simulator unit. This signal processing was simulated using the MATLAB®/Simulink® simulator on the PC in the middle of Fig.16.

5 Performance Examination

We verified the real-time and reliability communication performance of the proposed system. The proposed system was verified real-time performance and reliability performance by actual circuit and transmission line emulator System.

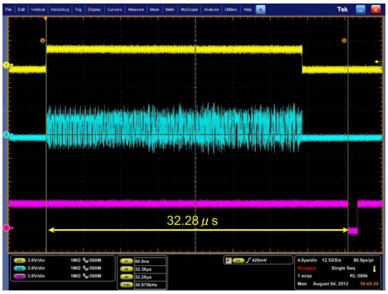


Fig. 17. Real Time Result (Transmit and Receive Time)

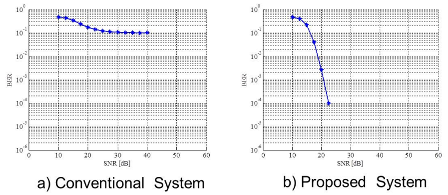


Fig. 18. Simulation Result (AWGN Channel)

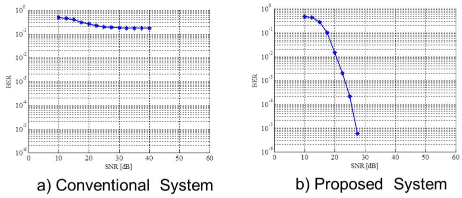


Fig. 19. Simulation Result (Robot Power Line Channel)

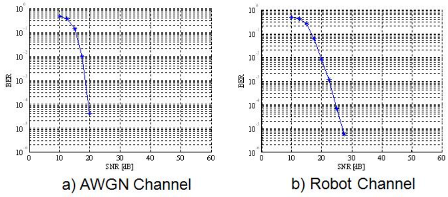


Fig. 20. Simulation Result (without impulse noise)

Fig.17 shows real-time performance of the proposed system. Ch1 signal indicates the signal of the start of transmission, ch2 is a communication signal, ch3 is a signal indicating that reception has completed. Time to complete the start of transmission received from 32.28 μsec is understood.

From Fig.18 to Fig.20 shows the results when the simulation model to a floating point number in the proposed system. Fig.18 shows the characteristics of AWGN channel. Fig.19 shows the characteristics of robot power line channel characteristics. Fig.20 shows the characteristics of AWGN channel and robot power line channel without impulse noise. Three validations carried out a hard decision Viterbi decoding circuit in error correction circuit.

As a result of the verification, It was confirmed that the proposed system is superior performance the conventional systems on BER vs SNR. On the AWGN channel, conventional systems are pulling the floor in the performance of BER=10^{-1}, at SNR = 25dB, the proposed system is BER=10^{-5} or less. On the robot power line channel, conventional systems are pulling the floor in the performance of BER=2.0×10^{-1} at SNR = 25dB, the proposed system is BER=2.0×10^{-4} or less. On the non-impulse noise channel, AWGN showed the performance of BER=4.0×10^{-5} at SNR = 20dB and the robot power line channel showed the performance of BER=7.0×10^{-5} at SNR = 25dB. It can be seen that conventional system can not communicate in impulse noise environment. However, the proposed system was found to be a communication performance similar to the non-impulse noise conditions. Fig.4 shows amplitude frequency

Table 2. Simulation Parameter

Parameter	Value
Band Width	$30[Mbit/s]$
Carrier Frequency	$15[MHz]$
Data Rate	$81[Mbit/s]$
FFT point	64
Modulation	64-QAM
Coding Rate	3/4
Transmitted bit	$10^8[bit]$
Channel	AWGN or Industry Robot Power Supply Line
Noise	AWGN

response of robot channel model. This channel model is identified by measured value of actual robot power supply line reflective characteristic. Simulation parameter is showed in Table 2.

6 Conclusion

We proposed a power supply overlaid communication system for industrial robot control. The system can reduce PWM noise. Then, we reported on the feasibility study of power supply overlaid communication system, using the transmission line emulator system. We verified real-time communication performance and that real-time μsec order could be confirmed. The proposed system is able to communicate BER=2.0×10^{-4} SNR=25dB on the robot power line channel. In the future, we plan to examine a method to bring maximum voltage command.

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