Experimental Verification of Robot Hand Operation using The Power Packet Dispatching System

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A power packet dispatching system for a robot hand operation is proposed in this paper. The power packet dispatching system is a power distribution system in which DC voltage is delivered with an information tag in the same power line. To include the information in the packet, the switching speed of the switching device should be over the megahertz range. A SiC or GaN device is an attractive solution to realize a power packet system. The operation of a robot hand using the power packet dispatching system is designed and evaluated in this study. Wi-Fi feedback control is introduced to provide feedback of the pressure sensor information of each finger. The design concept to interface the power and information simultaneously is described and the proposed method is evaluated.

Keywords: FPGA, power packet, robot arm, robot hand, routing

1. Introduction

A power packet dispatching system is an advanced power distribution system for an information-technology based society. To realize a highly integrated power distribution system, a highly reliable and efficient power distribution system is required. Information technology is a key issue, not only regarding network technology but also in the field of power electronics. The concept of an open-electrics energy network was proposed in (1), in which the power flow is controlled using multiple electric routers, and power is treated as a packet, similarly to network information. The data transfer latency for the power converter is very fast compared with the switching speed of the power modules. It has been difficult to realize a power packet dispatching system owing to the limitation of the switching device capability. Recently, however, power semiconductor devices with a wide bandgap began to be released in the consumer market, such as SiC and GaN devices (2). Such devices have the potential to switch to high power within the megahertz range with low switching losses. A power packet dispatching system can be realized using these new semiconductor devices.

Hikihara proposed such a concept for a DC power distribution system (3)–(7), and experimental verifications were carried out for various applications (8)–(10). Using the latest equipment, power packet dispatch equipment has been built using GaN devices, and the fundamental operation of a power distribution system was confirmed (9) and (10). The DC voltage source is delivered using the information tag through a mixer and router. The power and information can be delivered simultaneously in one common power line, and the different DC power levels can be delivered to the different loads. In addition, synchronization between the mixer and router without synchronization clock wiring has been achieved (10).

A robot system is an attractive application for a power packet dispatching system. To operate a robot system, a sufficient amount of power to activate the actuator and the control information are both required. In a conventional robot system, many wires are required, which prevents a high-density integration of the system. If a power dispatching system is adopted in a robot system, the power and control information lines can be combined into the same wiring, and a downsizing of the robot system can thus be realized.

In this study, a power packet dispatching system was applied to a robot hand operation. A robot hand with four fingers was applied for verification, the power packet dispatching system was combined with the power line of the robot hand, and the control information for the robot hand operations was delivered to the servo motor of each finger using the same power line. The destination of the packet and the rotation reference were included in the header of the power packet in the Mixer. In the Router, the operation signal was generated for each actuator based on the header information. The pressure sensor information was transmitted through Wi-Fi communication to the Mixer, which can generate a power packet corresponding to the pressure value of the hand (11). Using a conventional method, a power supply and motor with different ratings are connected to each other using exclusive power lines, and the control signal is also sent from the controller through different cables. However, with the proposed method, the wiring between the Mixer and Router can be realized using only one wire for the different voltage ratings, and the control information can be included in the same wire. In the power packet dispatching system, the header information should be designed to fit the applications and thereby minimize the header length. In the Router, the received information has to be adjusted to operate the submodules, and an interface circuit between the Router and submodules should be designed. Applying the power packet dispatching system to the robot hand control, the wiring of the actuators of the

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robot hand can be minimized. Reducing the size of the Mixer and Router equipment in the future, the wiring of the robot system is simplified.

The design concept of the proposed robot hand system with a power packet dispatching system is described. The interfaces among/between the robot hand controller and Mixer and/or the Router of the power packet dispatching system were implemented. Experiments were carried out to verify the basic operation of the robot hand system. A new power distribution system for a robot hand operation with a single power line was verified.

2. Power Packet Dispatching System

The power packet dispatching system is applied to the power supply between the power source and load. As shown in Fig. 1, the power packet is the unit of pulsed power information, and the power itself is the unit of the payload. In this research, one packet consists of a header, payload, and footer. The header is assumed to be the start of the packet information, and consists of information required for the Router and load. The footer is assumed to be the end of the packet information. The pulsed power information is treated as the information header of the packet. The power packet dispatching system consists of a mixer and router.

To avoid an excessive ripple of the load voltage, the header length needs to be minimized, and the refresh rate of the packet for each module should be considered. In the proposed system, the switching frequency for 1 bit was settled at 1 MHz, and the control calculation frequency was settled at 20 kHz, whereas to measure the pressure sensor value 50 times during a single control period, the length of one packet was settled at 100 bits. The rotation bit represents the rotation operation, and the direction bit indicates the direction of the rotation.

An INASTOMER Elastomer sensor was used as the pressure sensor to feed the finger pressure back to the Mixer. The maximum load of this pressure sensor is 50 N. To operate the finger according to the pressure sensor information, an Arudino sensor was used to feed the pressure information back to the Mixer. When the pressure is 2 N or less, the motor is rotated in the forward direction. At 2 N or more and at less than 5 N, the motor is stopped, and in the case of 5 N or more, the motor is rotated in the backward direction to bend the finger.

As shown in Fig. 2, the Mixer generates the power packets from the supplied voltage and transmits them to the Router. The transmitted packets are distributed to the load by the Router. The configuration of the Mixer circuit is shown in Fig. 3. The control signal generated by the controller is connected to the gate drive circuit, and the switching device is driven according to the packet information. The header, payload, and footer of the power packet are generated using this switching device. An FPGA (XC3S250E) is used as the controller, and a GaN (EPC 2014) is used as the switching device. In addition, a clock signal is transmitted from the Mixer to the Router. The power packet created by the Mixer is transferred to the Router. The configuration of the Router circuit is shown in Fig. 4. The Router consists of switching devices, a gate driver, a controller, and an isolator. The isolator consists of a Zener diode and a photocoupler, and when an input voltage is higher than the threshold value of the Zener diode, the controller recognizes the input as “1”, whereas in other cases, the input is treated as “0.” When the Router reads the header information, the switch selects the storage, and the switch of the selected output regenerates the information tag based on the header information. In addition, the Mixer and Router have a communication module to transmit and receive the information to and from other controllers. Figure 5 shows the appearance of the Mixer and Router.
3. Robot Hand Operation using Power Packet Dispatching System

Figure 6 shows the appearance of the robot hand. The robot hand consists of four fingers, and a total of five linear servo motors are incorporated, four for each finger and one for controlling the position of the thumb. To control each finger, four servo motors are controlled using the power packet dispatching system. Figure 7 shows the control block diagram of the robot hand. This system is composed of a Mixer, Router, robot hand, pressure sensor, and wireless module integrated using XBEE and Arduino devices. Arduino was used for A/D conversion of the pressure sensor value and transmit the sensor information to the Mixer. The construction of the robot hand with a power packet dispatching system is shown in Fig. 8. The Arduino device generates the rotation reference, which is transmitted to the servo motor by the power packet dispatching system and controls the motor for each finger. In this system, to control the robot hand, the Arduino device determines the rotation direction of the servo motor through wireless feedback of the pressure sensor attached to each finger. Therefore, the header consists of the control and start information. The connection from the Mixer to the Router uses only a single power line.

The appearance of the linear servo motor [PQ12-100-6-R] is shown in Fig. 9, and the specifications are indicated in Table 1.

As shown in Fig. 9 and Table 1, because the input voltage of the servo motor is 6 V, a 6 V power supply is connected to the Mixer, and power is supplied to each motor. The control input specifications of this motor are shown in Fig. 10. The PQ12-100-6-R is expanded by applying 5 V pulses of 1 ms,
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and is contracted by applying 5 V pulses of 2 ms, both for a duration of 20 ms.

For the pressure sensor, a pressure-sensitive conductive rubber sensor whose resistance increases according to the pressure is used. The maximum load of this pressure sensor is 50 N. Because the purpose of this system is to allow a single finger to move according to the pressure, such pressure, which is the threshold value required to touch an object, is set to 2 and 4 N, and the pressure is judged using an Arduino sensor based on a partial pressure with a resistance of 33 k. When the pressure is 2 N or less, the motor is rotated in the forward direction, whereas with a pressure of 2 N or more and less than 4 N, the motor is stopped, and for a pressure of 4 N or more, the motor is rotated in the reverse direction, allowing the finger to bend and realize three actions required in grasping an object and extending a finger.

Figure 9. Linear Servo Motor

Table 1. Specifications of PQ12-100-6-R

| Parameter  | Value |
|------------|-------|
| Stroke     | 20 mm |
| Rated voltage | DC 6.0 V |
| Rated current | 550 mA |

Fig. 10. Control signal of linear servo motor

Table 2. Specifications of robot arm control

| Power Packet | Specification |
|--------------|---------------|
| Header       | start signal: 3 [bit] |
|              | motor selection: 2 [bit] |
|              | rotation selection: 2 [bit] |
| Payload      | 90 [bit] |
| Footer       | end signal: 3 [bit] |
| Packet control cycle | 400 [µs] |

4. Experiment

Figure 11 shows an overview of the experimental setup, and the experimental conditions are listed in Table 2. As the experimental equipment, the wiring between the Mixer and Router is realized using only a single pair of wires. For the Router, the power packet and control information are delivered to each sub-model.

Through this verification, to check the power transmission operation and deliver the control signal, the waveform was measured using the power supply destination as a resistive load.

Figures 12, 13, 14, and 15 show the experimental results according to the conditions listed in Tables 3 and 4.

The output voltage waveforms of the Mixer and Router are shown in Fig. 12, whereas Fig. 13 shows an enlargement of the Mixer output waveforms during each state of the motor.

Figure 14 shows the Mixer output waveforms when the motor rotates in the normal and reverse directions, and Fig. 15 shows the output and control signal output waveforms of the power transmission section of the Router.

The first waveform of Fig. 12 is for the Mixer output, and the second, third, fourth, and fifth waveforms are for the Router output. From the first waveform, it can be confirmed that the power packet is sequentially transmitted to the motors of the four fingers every 400 µs. From the second waveform, the power transmission to each motor is realized based on the
Figure 13 shows an enlarged waveform of the header part of the power packet transmitted to the motor for the thumb operation. According to the value of the pressure sensor, the Mixer generates the rotation command in the header information. The three types of header information are the forward, stop, and backward operations.

From Figs. 14 and 15, it can be seen that control signals of 1 and 2 ms are generated within 20 ms from the Router output, and the rotation direction of the motor can be controlled. It was therefore confirmed that all control information was delivered to the robot hand, and the power packet dispatching system was connected to the robot hand.

Figure 16 shows the robot hand operation for gripping/opening operations using a power transmission from the Router and outputting control signals through pressure sensor feedback. From Fig. 16, it can be confirmed that a proper operation of each finger was realized.

5. Conclusion

A power packet dispatching system for use in a robot hand was proposed. The design concept used to apply the power packet dispatching system to the robot hand was described. The destination of the packet and rotation reference are included in the header of the power packet of the Mixer. In the Router, based on the header information, an operation signal destination information of the power packet.

Table 3. Experimental Condition

| Parameter | Value | Header | Output |
|-----------|-------|--------|--------|
| Source1   | 6.0 V | 10100X | Load1  |
| Source1   | 6.0 V | 10101X | Load2  |
| Source1   | 6.0 V | 10110X | Load3  |
| Source1   | 6.0 V | 10111X | Load4  |
| Load1,2,3,4 | 100Ω | -      | -      |
| 1bit  | 1 MHz | -      | -      |

Table 4. Motor status of header

| Motor state | Output |
|-------------|--------|
| CW          | 01     |
| Stop        | 10     |
| CCW         | 11     |

The moving operation of each finger is shown in Fig. 16.
is generated for each actuator. The pressure sensor information is transmitted to the Mixer through Wi-Fi, and the Mixer can generate a power packet corresponding to the pressure of the hand. Thus, applying the power packet dispatching system to the robot hand control, the wiring for the actuators of the robot hand can be minimized. The power packet dispatching system applied to the robot hand system was realized, and the basic operation was confirmed.

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