Design of Communication Interface and Control System for Intelligent Humanoid Robot

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ABSTRACT: Currently, robot applications have been fast expanding to many areas such as entertainment, home task, security, medical care, etc. With an increasing robot demand, the development of highly reliable and low-cost robot control system has become a hot research field in recent years. However, most robot control system requires special interface design or suffers from complexity or high cost. This phenomenon poses a great difficulty for students to learn such a robot development knowledge from a traditional classroom. Accordingly, this paper aims to propose a simple but reliable robot communication interface and local-loop control system based on RS232 and 8051 microprocessor, suitable use as lecture material for various kinds of robot control. In this proposed scheme, the robot action commands stored in the database using C++ Builder can be transmitted from the command-transmission microprocessor (CTM) and then received by the individual authorized action-processing microprocessor (APM) via RS232. Every APM is responsible to its respective robot’s joint so that there are up to tens of modules to be operated for a variety of robot actions simultaneously and independently. Real-time implementation results are presented to demonstrate the effectiveness of the proposed approach in terms of robust, simple, flexible, and efficient performance. © 2010 Wiley Periodicals, Inc. Comput Appl Eng Educ 17: 1–14, 2010; Published online in Wiley InterScience (www.interscience.wiley.com); DOI 10.1002/cae.20413

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INTRODUCTION

Due to the prospective global robot market, some big enterprises around the world have started to get into the robot field and opened related projects. One of the most well-known cases is that Microsoft has announced the robot development platform, for example, Microsoft Robotics Studio 2006, Microsoft Robotics Developer Studio 2008, the second-generation robot SPC-101C, etc. With the robot development trend, the research in the robot communication interface and control system is increasing significantly in recent years [1–35]. Although in nowadays the robot development is much faster than before, most of robot control systems and interfaces relied on the special platform such as Microsoft products, or special robot languages such as ACT-R cognitive-modeling language, Extensible Markup Language (XML), or special controllers such as SAMSUNG ARM S3C2410, etc. [5, 7, 25]. These tools may cause a barrier for students to apply their school-based learning knowledge to robot system directly. From the view of teaching, it is thus indispensable to establish a helpful example for robot system studying, particularly in communication interface and control system.

This study proposes a communication interface and local-loop control system for Intelligent Humanoid Robot with open architecture based on a RS232 and the microprocessor, that is, Intel 8051 [36–38]. Every robot action can be carried out using the predefined commands combining with independent hardware modules. Hence, a variety of robot actions can be achieved simultaneously and rapidly. This paper is organized as follows. The second section introduces a profile of the proposed system architecture, focusing on the hardware system. In the third section, the software system based on C++ Builder database is introduced. The fourth section presents the real-time...
experimental results with both basic and advanced robot actions. Conclusions and recommendations for further applications are given in the fifth section.

ARCHITECTURE OF SYSTEM

Figure 1 depicts the profile of general interface communication methods [1–14]. The Intelligence Computer is assumed as the core processing center, and the other peripheral facilities or signal sources can communicate with it via different interfaces. For instance, PDA uses a wireless communication for data transferring and receiving information from the Intelligence Computer. Also, RS232 is used as a bridge between the Intelligence Computer and Sound, Robot’s Head, Power System, etc. Based on Figure 1, the Action Computer that receives the commands from the Intelligence Computer is responsible for performing the robot actions.

The objective of this study is to construct a communication interface via RS232 and develop a local-loop control system. The block of the proposed scheme is shown in Figure 2. Once the computer receives external signals, it will soon access the database to obtain the responsible commands that are then transmitted to the command-transmission microprocessor (CTM), where the database is built up using C++ Builder. The action-processing microprocessor (APM) receiving the commands from the CTM is designed to control the robot actions by the proposed Motor Control System with DC motor.

The sketch of Humanoid Robot in this study is shown in Figure 3, where M1–M24 is the robot’s joint controlling motor. The proposed hardware architecture is shown in Figure 4. When external signals such as image, sound, ultrasonic, temperature, photoelectric, or other facilities are received by PC, the responsible action commands can be therefore determined and transmitted to the CTMs, that is, 8051(A), 8051(B), 8051(C), 8051(D), via COM1, COM2, COM3, and COM4, respectively. The commands in the CTM, for example, 8051(A), can be identified by each APM (89C2051(1)–89C2051(12)). The robot action is controlled by its responsible APM so that there are up to 48 local-loop robot action control modules that can be activated simultaneously and independently.

For easy demonstration, Figure 5 only illustrates the hardware module in the case of 8051(A)-linked system. Note that the other modules keep the same structure as Figure 5. The main facilities for implementing the proposed system are
concluded in Table 1. The command obtained from the database is first sent to the port 1 of 8051(A), and it is then read by the APM (89C2051(1)–89C2051(12)). Once any APM confirms its recognized command, the respective motor control system will be soon operated via its output of port 3. Also, the robot joint movement status is detected by the position-limited circuit, and its feedback signal will be received by the APM for necessary processing like stop or brake.

The port 1 bits in the APM is designated to receive the command from the CTM. Its highest four bits \((0100****...1111****)\) represent the specific motor driving operation with pulse width modulation (PWM), for details listed in Table 2. On the other hand, the motor ID (joint identification) is defined using the lowest four bits \((****0000...****1111)\). Additionally, two bits from the port 3 are used to generate control signals for the two-input motor driver (TA 7257P) to control the DC motor, shown in Table 3. Figure 6 depicts 4-speed PWM signals.

**SYSTEM SOFTWARE**

**Database Access and Transmission Processing**

The flowchart of the database access and transmission is shown in Figure 7. Firstly, the action command is read and checked if it is predefined in advance. Once the command is confirmed, a sequence data stored in the database will be transmitted to the CTM. Note that the sequence data are composed as the action command according to the definition in Table 2. More detailed discussion is presented in the Experimental Results Section.

Figure 8 shows the further detailed procedure for the data transmission from PC to the CTM. Initially, set up the Relational Database System using C++ Builder, that is, MySQL database. The TXD and RXD of the serial port, for example, COM1, are employed to transmit data. The data ready for transmission are hold in the Transmission Holding Register (THR) temporarily until it has been transmitted completely. Note that the Bps (Baud rate per second), for example, 9,600, must match the 8,051 receiving rate. The checking code, that is, 10H, is sent out prior to the data transmission. This procedure guarantees that the command can be received by the CTM without data loss.

The main programming procedure is briefly described as follows:

(a) Set up MySQL database connection.
(b) Read the command (a sequence data) from the database. Some examples of command codes are given in Table 4.
(c) Transmit the checking number (10H) to the CTM.
(d) Delay 0.01 s.
(e) Transmit the data to the CTM.
(f) Delay 0.01 s.
(g) Go back to step (b) until the transmission is complete.

**Action Command Receiving**

The CTM is to receive the action commands from PC database, and it must coordinate with the PC data transmission as above. Its programming flowchart is shown in Figure 9. The main procedure is briefly described as follows:

(a) Set COM1 as the serial communication. SCON is set to as transmission mode 1, and TMOD is set as timer mode 2, set as Table 5.
(b) Read the data and check if it is 10H, received from the PC and regarded as a checking code. If yes, delay 0.1 s, read the command, and forward it to the port 1 of CTM. Otherwise, continue next step.
(c) Delay 0.01 s.
(d) Go back to step (b) until the system stop is requested.

**Action Command Processing**

A case study is given to demonstrate the action command processing, where the motor ID number is assumed as 0001,
that is, $p_1 = \text{abcd0001}$, and “abcd” is an arbitrary binary code. Once the APM has read the command from the CTM and confirmed the ID number, the motor control program in the APM starts to operate the responsible motor, as shown in Figure 10.

The main programming procedure is briefly described as follows:

(a) **Reset the system**: Check if the LS0 (limit switch) is touched ($p_{3.2} = 1$). If yes, brake the motor ($p_{3.0} = 1, p_{3.1} = 1$). Otherwise, reverse the motor using 1/4 speed until the LS0 is touched.

(b) **Read the command from the CTM**.

(c) **Check if the motor ID is the authorized number**, that is, $p_1 = \text{abcd0001}$. If yes, continue next step. Otherwise, go back to step (b).

(d) **Select its predefined procedure according to the value of “abcd.”**

(e) **Check if the LS0 or LS1 is touched** ($p_{3.2} = 1$ or $p_{3.3} = 1$). If yes, brake the motor. Otherwise, the motor will be driven continuously until a new command, that is, abcd0001, is received. Then, the procedure will go back to step (d).

Please note that the motor stops whenever the $p_1 = \text{0000****}$, and the motor brakes if the $p_1 = \text{1111****}$ during the process of step (d).

**EXPERIMENTAL RESULTS**

In order to verify the effectiveness of the proposed approach, both basic and advanced robot actions were fully investigated. Every
Figure 5 Hardware of robot action control module.

Table 1 Main Facilities for the Robot Action Control System

<table>
<thead>
<tr>
<th>Item num.</th>
<th>Instrument name</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PC</td>
<td>CPU: E6550 2.33G/1333FSB</td>
</tr>
<tr>
<td>2</td>
<td>Microprocessor</td>
<td>Intel 8051</td>
</tr>
<tr>
<td>3</td>
<td>Microprocessor</td>
<td>Intel 89C2051 TA 7257P: full bridge</td>
</tr>
<tr>
<td>4</td>
<td>Motor driver</td>
<td>DC motor driver</td>
</tr>
<tr>
<td>5</td>
<td>PC 817</td>
<td>Opti-transistor</td>
</tr>
<tr>
<td>6</td>
<td>Limit switch</td>
<td>15A 1/2HP</td>
</tr>
<tr>
<td>7</td>
<td>Buffer</td>
<td>IC7407</td>
</tr>
<tr>
<td>8</td>
<td>DC motor (M1–M24)</td>
<td>12 V</td>
</tr>
</tbody>
</table>

Table 2 Definition of Motor Operation

<table>
<thead>
<tr>
<th>High bits of port 1</th>
<th>Motor operation</th>
<th>Speed (PWM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0100</td>
<td>Reverse</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>0101</td>
<td>Reverse</td>
<td>2/4 speed</td>
</tr>
<tr>
<td>0110</td>
<td>Reverse</td>
<td>3/4 speed</td>
</tr>
<tr>
<td>0111</td>
<td>Reverse</td>
<td>4/4 (full speed)</td>
</tr>
<tr>
<td>1000</td>
<td>Forward</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>1001</td>
<td>Forward</td>
<td>2/4 speed</td>
</tr>
<tr>
<td>1010</td>
<td>Forward</td>
<td>3/4 speed</td>
</tr>
<tr>
<td>1011</td>
<td>Forward</td>
<td>4/4 (full speed)</td>
</tr>
<tr>
<td>0000</td>
<td>Stop</td>
<td></td>
</tr>
<tr>
<td>1111</td>
<td>Brake</td>
<td></td>
</tr>
</tbody>
</table>
Table 3  Motor Operation With PWM Speed

<table>
<thead>
<tr>
<th>Input signal</th>
<th>Motor function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brake</td>
</tr>
<tr>
<td>0</td>
<td>PWM signal Reverse</td>
</tr>
<tr>
<td>PWM signal</td>
<td>Reverse with PWM speed</td>
</tr>
<tr>
<td>0</td>
<td>Forward with PWM speed</td>
</tr>
<tr>
<td>0</td>
<td>Stop</td>
</tr>
</tbody>
</table>

Figure 6  Four-speed PWM signals.

Figure 7  Flowchart of database access and transmission.
robot action is defined in advance in the database so that the robot can act as desired. Some of action commands are shown in Figure 11. For instance, the robot can rise up its left arm using the predefined function labeled as "Left arm side rise up" with 1/4 speed motor operation.

**Basic Robot Action**

The first basic action, that is, Head nodding, was carried out by a sequence data (command) from the database, as shown in Table 6. In the table, the type "A" means the robot action, and the type "D" is the delay time (ms). The waveform of the robot’s head nodding is shown in Figure 12. The first waveform is the PWM signal. The second waveform is the motor (M13) voltage, and the third one shows its current waveform. The robot firstly bends down its head 90° using the reverse motor direction. The action continues 1 s, and the robot’s head then rises up back to the original position with the forward direction. From the outcome, it can be seen that the motor current direction is opposite between above two actions. Additionally, the head rising time is a little longer than the head lowering time due to the gravity weight. It also indicates that the reverse transient current always occurs whenever the motor just stops, no matter what motor rotating direction is.

Similar to the robot’s head nodding control, Table 7 provides the command for the head turning action. Firstly, the head starts to turn right 30° from the middle location, that is, original point, until the right limited switch is touched. Then, the head turns left 60°, and it stops when the left limited switch is touched. Finally, the head turns right 30° back to the original point. Figure 13 shows the action waveform of the head turning. The first waveform is the PWM signal. The second waveform is the motor (M14) voltage, and the third one presents its current waveform.

**Advanced Robot Action**

The hand waving is illustrated as the first advanced robot action. Its sequence commands are listed in Table 8. The right arm motor (M2), right arm rotating motor (M1), and right hand elbow motor (M4) are used to complete this action at the same time. The main action sequence is as follows. Right arm rises — right hand rotates forward — right hand elbow rotates forward — right hand elbow rotates reversely — right hand elbow rotates forward — right hand elbow rotates reversely — right hand rotates reversely — right arm descends. Following up the above procedure, the arm will return to the original position at the last stage. This action shows that the right arm begins to rise up and then rotates 90°. The elbow then moves to right and left sides twice. As above, the hand waving action is complete. The waveform results are shown in Figure 14. The first waveform is the right arm motor (M14) voltage, and the third one presents its current waveform.

<table>
<thead>
<tr>
<th>Command code (Hex)</th>
<th>Operation</th>
<th>PWM speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>81</td>
<td>Left arm side rise up</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>51</td>
<td>Left arm side rise down</td>
<td>1/2 speed</td>
</tr>
<tr>
<td>B2</td>
<td>Left arm side rise up</td>
<td>Full speed</td>
</tr>
<tr>
<td>02</td>
<td>Left arm rise brake</td>
<td>Brake</td>
</tr>
<tr>
<td>B3</td>
<td>Left elbow bend down</td>
<td>Full speed</td>
</tr>
<tr>
<td>84</td>
<td>Left elbow bend in</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>04</td>
<td>Left elbow bend brake</td>
<td>Brake</td>
</tr>
<tr>
<td>86</td>
<td>Head nod up</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>76</td>
<td>Head nod down</td>
<td>Full speed</td>
</tr>
<tr>
<td>B7</td>
<td>Head wag up</td>
<td>Full speed</td>
</tr>
<tr>
<td>A8</td>
<td>Right arm side rise up</td>
<td>3/4 speed</td>
</tr>
<tr>
<td>68</td>
<td>Right arm side rise down</td>
<td>3/4 speed</td>
</tr>
<tr>
<td>09</td>
<td>Right arm brake</td>
<td>Brake</td>
</tr>
<tr>
<td>0A</td>
<td>Right elbow bend brake</td>
<td>Brake</td>
</tr>
<tr>
<td>92</td>
<td>Right wrist bend in</td>
<td>1/2 speed</td>
</tr>
<tr>
<td>43</td>
<td>Right thigh back</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>87</td>
<td>Right ankle up</td>
<td>1/4 speed</td>
</tr>
<tr>
<td>5A</td>
<td>Left elbow turn counter-clockwise</td>
<td>1/2 speed</td>
</tr>
<tr>
<td>51</td>
<td>Right foot drive backward</td>
<td>1/2 speed</td>
</tr>
<tr>
<td>82</td>
<td>Left foot drive forward</td>
<td>1/4 speed</td>
</tr>
</tbody>
</table>
In the second case, the sequence commands for the hand pointing to robot itself are listed in Table 9. This action requires four motors, that is, right arm rotating motor (M1), right arm motor (M2), right hand elbow motor (M4), and right wrist motor (M6), to be operated simultaneously. Its main action sequence is as follows: right arm rotates forward → right arm rises → right hand elbow rotates forward → right wrist rotates forward → right wrist rotates reversely → right hand elbow rotates reversely → right hand rotates reversely. Accordingly, the action for the hand pointing to robot itself is complete. The waveform results are shown in Figure 15. The first waveform is the right arm rotating motor (M1) voltage. The second one is the right hand elbow motor (M4) voltage, and the third one shows the total supply current required to operate this action. Obviously, we see that different joint operations can be performed at the same time. This situation is particularly clear during the last period of time, where more current is required. Note that for the simplification the waveform of right arm motor (M2) voltage does not appear in Figure 15.

The third case is to demonstrate the robot’s two-foot walking using the right-foot motor (M24) and left-foot motor (M20). Its sequence commands from the database are listed in Table 10, and its performance result is shown in Figure 16. The first waveform indicates the right-foot motor voltage. The second one is the left-foot motor voltage, and the third one shows the total supply current required to operate this action. Firstly, the robot’s two feet move forward simultaneously in order to drive the robot walking along a straight line. In the next stage, the robot’s right foot turns left 45°, and the left foot remains immobile. The robot’s left foot then turns right 90° while the right foot remains immobile. This stage indeed drives the robot to move back in the opposite direction. Soon after the robot turns back, it starts to move backward. The results confirm that the robot is capable of implementing walk and turning performance well.

**CONCLUSIONS**

The proposed system has presented a simple communication interface and local-loop control system for real-time robot action successfully. Each serial communication port can continuously send various action commands to the CTM that is connected to 12 independent APMs. All predefined commands stored in the database can be thus called out to work with the local-loop control system for achieving the desired robot actions. Accordingly, up to tens of robot actions can be carried out independently at a time.
Figure 10  Flowchart of main control program.
Figure 11  Command definition in the database.

Figure 12  Head nodding waveforms: (1) PWM signal, (2) motor voltage, and (3) motor current.

Figure 13  Head turning (1) PWM signal, (2) motor voltage, and (3) motor current.

Table 6  Head Nodding Command in the Database
Table 7  Head Turning Command in the Database

<table>
<thead>
<tr>
<th>ActionNo</th>
<th>SerialNo</th>
<th>Type</th>
<th>Command</th>
<th>Port</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>1</td>
<td>A</td>
<td>135</td>
<td>1</td>
<td>Head wag up</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>D</td>
<td>300</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>A</td>
<td>7</td>
<td>1</td>
<td>Head wag brake</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>A</td>
<td>71</td>
<td>1</td>
<td>Head wag down</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>D</td>
<td>500</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>A</td>
<td>7</td>
<td>1</td>
<td>Head wag brake</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>A</td>
<td>135</td>
<td>1</td>
<td>Head wag up</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>D</td>
<td>300</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>A</td>
<td>7</td>
<td>1</td>
<td>Head wag brake</td>
</tr>
</tbody>
</table>

Table 8  Hand Waving Command in the Database

<table>
<thead>
<tr>
<th>ActionNo</th>
<th>SerialNo</th>
<th>Type</th>
<th>Command</th>
<th>Port</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>3001</td>
<td>1</td>
<td>A</td>
<td>159</td>
<td>1</td>
<td>Right arm rise up</td>
</tr>
<tr>
<td>3001</td>
<td>2</td>
<td>D</td>
<td>3000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>3</td>
<td>A</td>
<td>9</td>
<td>1</td>
<td>Right arm brake</td>
</tr>
<tr>
<td>3001</td>
<td>4</td>
<td>A</td>
<td>168</td>
<td>1</td>
<td>Right arm side rise up</td>
</tr>
<tr>
<td>3001</td>
<td>5</td>
<td>D</td>
<td>2000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>6</td>
<td>A</td>
<td>8</td>
<td>1</td>
<td>Right arm side rise brake</td>
</tr>
<tr>
<td>3001</td>
<td>7</td>
<td>A</td>
<td>170</td>
<td>1</td>
<td>Right elbow head down</td>
</tr>
<tr>
<td>3001</td>
<td>8</td>
<td>D</td>
<td>3000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>9</td>
<td>A</td>
<td>106</td>
<td>1</td>
<td>Right elbow head up</td>
</tr>
<tr>
<td>3001</td>
<td>10</td>
<td>D</td>
<td>800</td>
<td>0</td>
<td></td>
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<tr>
<td>3001</td>
<td>11</td>
<td>A</td>
<td>10</td>
<td>1</td>
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<tr>
<td>3001</td>
<td>12</td>
<td>A</td>
<td>170</td>
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<td>Right elbow head down</td>
</tr>
<tr>
<td>3001</td>
<td>13</td>
<td>D</td>
<td>800</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>14</td>
<td>A</td>
<td>10</td>
<td>1</td>
<td>Right elbow head brake</td>
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<tr>
<td>3001</td>
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</tr>
<tr>
<td>3001</td>
<td>16</td>
<td>D</td>
<td>2000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>17</td>
<td>A</td>
<td>8</td>
<td>1</td>
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<tr>
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<td>18</td>
<td>A</td>
<td>72</td>
<td>1</td>
<td>Right arm rise down</td>
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<td>19</td>
<td>D</td>
<td>1000</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3001</td>
<td>20</td>
<td>A</td>
<td>8</td>
<td>1</td>
<td>Right arm brake</td>
</tr>
</tbody>
</table>

Figure 14  Hand waving waveforms: (1) right arm motor voltage, (2) right arm rotating motor voltage, (3) right hand elbow motor voltage, and (4) total DC supply current.

Figure 15  Hand pointing to robot itself: (1) right arm rotating motor voltage, (2) right hand elbow motor, (3) right wrist motor voltage, and (4) total DC supply current.
reality of the multiple speed options has made the proposed system be operated more smoothly and robustly. Particularly, this paper presented a good lecture material for students to learn their school-based knowledge to be applied to a robot interface and control system design. The paper also demonstrated its potential capability for extension to a variety of development and applications in the robot discipline. For further applications, the proposed scheme can be easily extended to perform an instant multi-motor control in related robot control systems or automated industry.

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REFERENCES


BIographies

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