Design of a Synchronous Control System for Mobile Lift Based on Wireless Network

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Abstract. The lift used in automobile maintenance industry is usually installed in a place permanently. It occupies the place, and also has poor adaptability to vehicles with different size. Furthermore, there exists physical connection between lifting columns, which affects maintenance operation. To solve these problems, a mobile hydraulic lift control system based on wireless network has been designed. It uses the STM32F103 microcontroller and nRF905 wireless communication module to form a control network for several mobile lifts. The height of each lift is measured with laser displacement sensors, and synchronously controlled through the wireless control network. The control system was verified by lifting the Jinlong bus with wirelessly connected four lifts. The lifting process is stable, which demonstrates a bright prospect for practical usages.

1. Introduction
Automobile lift is a vehicle lift equipment used in the process of vehicle maintenance. When the vehicle is driven to the lifting machine, it can be lifted to a certain height by manual operation, which is convenient for vehicle maintenance. It is a necessary equipment for garage. In recent years, car ownership in China has been on the rise, and the corresponding demand for car maintenance has also risen sharply, resulting in a very strong market demand[1]. The traditional lift has column type, shear type, trench type and other structures. The technology is relatively mature, but there are also obvious shortcomings. Take the double-column lift as an example, two vertical columns are fixed and installed in the maintenance site, and there is a fixed pipeline connection between the vertical columns to achieve synchronous lifting. Its disadvantages are as follows:

(1) The fixed installed column and the pipeline connecting the column occupy the valuable space of the maintenance site. When there is no maintenance task, the station cannot be used for other purposes;

(2) Once the column is installed, the maximum size of the vehicle it can lift will be limited, and the flexibility is poor;

(3) The connected pipeline between the columns is easy to trap the maintenance personnel, which is a potential safety hazard.

The mobile lift can overcome the above disadvantages of the traditional lift. A mobile lift corresponds to a freely movable lift column. The power is provided by battery, and through wireless communication, a number of lifting columns can be netted for operation on site. Through precise state detection, communication and control, multiple lifting columns can be simultaneously lifted (for example, 2 lifting units can lift family cars, 4 lifting units can lift common buses and trucks, and 6
lifting units can lift heavy-duty trucks). This is convenient to meet a variety of vehicle maintenance operations.

The related studies reported in the literature mainly involve traditional lifts, such as mechanical design, hydraulic design, PLC control and other technologies [2-6]. There are few reports on mobile lifts. Literature [7] reported the design of a mobile lift, and analyzed the mechanical model and hydraulic system. However, the control system only mentioned the lifting function and safety protection control, and did not further explain the implementation issue. In this paper, a wireless network-based synchronous control system for mobile lift is designed. The network control of four mobile lifts is realized, and a bus has been used as the load to successfully carry out the experimental verification.

2. System scheme
The lift studied in this paper uses hydraulic transmission with a 24V battery for power supply. The normal lifting speed is 3.5cm/s. The design requires that the maximum height deviation of each lift during lifting is less than 2.5cm, so as to maintain the stability of the lifted vehicle. The synchronous lifting working mode of the mobile lift for networking operation is shown in figure 1. The wireless network is composed of several lifts (4 lifts in the figure). One of them is set as the host lift, which is used to collect the information of each lift in real time, make decisions, and transmit control instructions to the slave lift. In order to meet the requirement of maximum height deviation, a high-precision displacement sensor is installed on each lift. The height is detected synchronously according to the command of the host lift and sent to the host lift in turn. The host lift makes judgment according to the height data collected. If the maximum height deviation reaches the speed regulation threshold, it will start the speed regulation program. If it is less than the stop speed threshold, it will stop the speed regulation program.

The schematic diagram of the hydraulic speed regulation system of a single lift is shown in figure 2. In the figure, YA1 branch is the main branch with a large flow. YA2 branch is speed regulation branch with small flow. During normal lift operation, both YA1 and YA2 are turned on. When speed regulation is required, YA2 is closed to reduce the speed. If the motor is started, and YA3 is turned off, the lift moves up. If the motor is stopped, and YA3 is turned off, the lift stops. If the motor is stopped, and YA3 is turned on, the lift moves down.

![Figure 1. Schematic diagram of wirelessly grouped lifts](image1)

![Figure 2. Schematic diagram of hydraulic speed regulating system of a single lift](image2)
Each lift is equipped with a controller, which can be configured by the user into stand-alone mode or networking mode on the job site as required. The power supply of the controller comes from 24V battery, and all the control is realized by microcontroller programming. Considering the real-time requirements of motion control for data processing, the 32-bit microcontroller STM32F103 is selected as the processing core with the highest clock frequency of 72MHz. Wireless communication uses nRF905 wireless transceiver module working in ISM (Industrial Scientific Medical) frequency band. Height measurement is made using laser displacement sensor. The lifting control and speed regulation signals are sent to YA1, YA2 and YA3 through relays. The touch screen is used to display the necessary status information and receive the parameter input during networking and other operation steps. The mechanical key inputs are set corresponding to the up, down, and stop command, respectively. The overall structure of the controller is shown in figure 3.

![Controller block diagram](image)

**Figure 3.** Block diagram of the controller

### 3. Controller circuit design

#### 3.1. Power circuit
The operating voltage of each module of the controller is not completely consistent, which requires 5V and 3.3v. In this paper, the switching power supply circuit is used to convert the 24V DC input voltage into 5V, and then the linear voltage regulator is used to convert the 5V voltage into 3.3v. The circuit uses conventional technology and is not repeated here.

#### 3.2. Wireless communication
The wireless communication module uses nRF905 wireless transceiver chip of Nordic company, and only a few peripheral circuits are needed to complete the wireless communication task. This is suitable for industrial applications [8][9], whose carrier frequency is 433MHz/868MHz/915MHz. The band can be used without license, with 512 bands and a wireless communication rate of 50kbps. SPI interface is used to connect to the microcontroller. The operating voltage is 1.9v-3.6v, and 3.3v is used in this paper. Its data frame can contain up to 32 bytes of user data. According to the size of user data, the time required to complete a frame of data communication is about 1.3ms-6.4ms.

#### 3.3. Height measurement
Height can be measured by means of draw-wire displacement sensor, laser displacement sensor, etc. Considering that the measurement error of draw-wire displacement caused by the internal rewinding mechanism is apt to be large, the laser displacement sensor is selected for the height measurement. A laser displacement sensor with ±1mm accuracy and 30Hz measurement frequency has been selected. In other words, it takes about 33ms to complete a measurement, and the lifting distance of the corresponding lift is 3.5cm/s x 33ms = 0.115cm. In the worst case, if a lift is in the stop state and the other lifts rise normally, the height deviation of each lift will increase by 0.115cm after one measurement, which is far less than the allowable maximum deviation value.

#### 3.4. Input and output module
The input and output module includes key, touch screen and relay output part. Keys are used to receive input signals such as up, down, stop and networking. Common key circuit structure is adopted.
The General Purpose Input Output (GPIO) port of MCU is directly connected to the key input signals. The touch screen is used to display working status information and provide necessary input interface in networking and other operation steps. The relay output is used to control the hydraulic valve and the input is from the MCU GPIO pin. The rated current of relay coil is about 15mA. In order to match the driving ability, a driving circuit is designed. The driving circuit of the corresponding relay of YA1 is shown in figure 4. The control signal from MCU controls the on-off state of transistor Q1, and then drives the relay U1 to the corresponding state. In the figure, diode D1 is used to provide a path for the current in relay coil to flow during the transition of Q1 being turned off.

3.5. Main control chip
The main control chip uses the 32-bit microcontroller STM32F103, which is made by the ST Microelectronics Company. It uses advanced RISC architecture, with built-in rich peripherals and large capacity FLASH storage space. The highest working frequency is 72MHz, which can meet the requirement of high-speed data processing, so as to make a quick response to all kinds of emergencies during the lifting process. The designed controller is shown in figure 5.

4. Control method and software design
4.1. Wireless communication and networking control
The data frame of wireless module nRF905 includes four fields, as is shown in figure 6[10]. The preamble is automatically added by the hardware during transmission, and the address is used for the receiving end to match the transmitting end. The payload is the actual user data to be transmitted, and the CRC is used to verify the data. Time On Air (TOA) of a frame can be estimated as

\[ TOA = t_{\text{startup}} + t_{\text{preamble}} + N_{\text{addr}} + N_{\text{payload}} + N_{\text{CRC}} \]

Where, \( t_{\text{startup}} \) is the RF startup time, and its value is 550μs for the switching of receiving and transmitting modes; \( t_{\text{preamble}} \) is the preamble time, which is 200μs; \( N_{\text{addr}} \), \( N_{\text{payload}} \) and \( N_{\text{CRC}} \) are the binary bits of address, payload and CRC check code, respectively; BR is baud rate, which is fixed at 50kbps. In this paper, \( N_{\text{addr}} \) takes 4 bytes. The data to be transmitted each time mainly includes command encoding and height data, including reserved fields. The total length is 10 bytes. \( N_{\text{CRC}} \) is set to 1 byte. According to figure 6 and formula (1), the value of TOA is 3150μs.

![Figure 4. Relay interface circuit](image1)

![Figure 5. The designed controller](image2)

![Figure 6. nRF905 data frame format](image3)
that the network address will not overlap. In the practical operations, it may happen that other irrelevant devices using the nRF905 module with the same address will disturb the function of the grouped lifts. To prevent it, additional information used for authentication is added in the user data field. During the rising or falling process, the host lift sends the broadcast command firstly, and each lift receives the command at the same time to measure the height. Then the host lift communicates with each slave lift in turn, and commands each slave lift to upload height data in turn. Finally, the host lift makes decision whether to start the speed adjustment process based on the collected height value. The time $t_{cycle}$ required for the grouped lifts to complete a round of communication is

$$t_{cycle} = t_{broadcast} + (n - 1) \cdot (t_{down} + t_{up})$$ \hspace{1cm} (2)$$

In the formula, $t_{broadcast}$, $t_{down}$ and $t_{up}$ are the time of broadcasting command, downloading command and uploading data, respectively; $n$ is the number of grouped lifts. In a worst-case scenario, $t_{broadcast}$, $t_{down}$ and $t_{up}$ are all set as 3150μs of the maximum TOA value. If $n = 4$, then $t_{cycle} = 22050μs$, or 22.05ms. It is less than the time the height sensor takes to measure for one time.

4.2. Speed regulation
Two thresholds, $t_{start}$ and $t_{stop}$, are used for speed regulation. When the maximum height deviation is greater than $t_{start}$, the speed regulation program is started. For the lift in the speed regulation state, when its height deviation is less than $t_{stop}$, speed regulation is stopped.

There is a delay $t_d$ from issuing the command to the speed actually being regulated. The delay consists of air transmission time TOA, relay response time, solenoid valve and hydraulic response time, program processing time and other parts. The response time of the relay in the design is about 10ms. Solenoid valve and hydraulic response time cannot be accurately measured. It is generally in tens to hundreds of milliseconds. In the study, a harsh case of 500ms is used for estimation. The program executing time is at the microsecond level, which is relatively small and negligible. The resulting $t_d$ value is 513.15ms. During the $t_d$ period, each lift moves at the original speed, and the maximum deviation is required to be less than the allowable value $h_{max}$, then

$$\Delta v \cdot t_d < h_{max} - h_{start}$$ \hspace{1cm} (3)$$

In the formula, $\Delta v$ is the speed deviation between the lifts, which is due to the influence of manufacturing process deviation, load difference and other factors. It is difficult to obtain $\Delta v$ accurately. In this study, 30% of the rated speed of 3.5cm /s is taken, that is 1.05cm /s. The $h_{max}$ is 2.5cm according to the design requirements. According to formula (3), $h_{start} < 1.96cm$ can be obtained.

The determination principle of speed regulation threshold $t_{stop}$ is similar to that of $t_{start}$, with the purpose of avoiding excessive regulation and forming new deviation. The calculation of $t_{stop}$ can be expressed as

$$\Delta v \cdot t_d < h_{start}$$ \hspace{1cm} (4)$$

The calculated result is $t_{stop} > 0.54cm$. Under the premise that the values of $t_{start}$ and $t_{stop}$ meet the above calculation requirements, the closer to the conditional boundary, the easier it is to meet the requirements of non-deviation. However, the solenoid valve switches more frequently if the two thresholds are close to the condition boundary.

4.3. Program design
The working mode of the controller is divided into the host and the slave. The host mode needs to manage the lift in the whole network, and the software flow is shown in figure 7. Firstly, the hardware is initialized. Before the first synchronous lifting, all the lifts in the wireless network are adjusted to the same level and the height value is saved. Then the program enters key query state. when the "up" or "down" key is pressed, the host controller will send broadcast command to all slaves to query the height. At the same time, the host lift height is detected, and the status information of each slave height is queried successively. Then the host controller determines whether to start the speed regulation program. When the "up" or "down" key is released or the "stop" key is pressed, the host controller will send a broadcast to all the slaves, and command them to stop. The host lift is also stopped at the same time.
In slave mode, the controller performs corresponding actions according to the received host commands, and its software flow is shown in figure 8. It firstly initializes the hardware, then enters receive mode and waits for the wireless command from the host. After receiving the command, the command is parsed and the corresponding operation is completed. The slave remains in receive mode after executing the command to wait for the wireless command from the host.

5. Experimental results
After the completion of the controller design, it is mounted into the control cabinet of the lift, and connected with the electrical and hydraulic systems. The following experimental tests have been conducted.

(1) Wireless communication test in the working environment: Two controllers are placed across a bus and continuously send and receive 1000 frames of data through the wireless module to test the communication stability. The experimental results show that the communication is smooth and the frame loss rate is zero.

(2) Repeatability test: Four lift units are grouped to lift 20 times with even load of 4 tons, and the total number of repeated experiments is 200 times after battery charging. During the experiment, the control system behaves normally.

(3) Partial load test: Two lifts are grouped, one lift with a load of 3.3 tons and the other with a load of 1.1 tons. In the process of lifting, the lift operates smoothly with the height deviation being within 2.5cm.

(4) Actual working condition test: Four mobile lifts are used to carry out the lifting test on the bus outdoors, as is shown in figure 9. The experimental result shows that the control system works correctly. As can be seen from the figure, the mobile lift has low requirements for the working site and is flexible and convenient to use.
6. Conclusion
This paper analyzes and designs the wireless networking, communication, speed regulation and synchronous control of mobile lifts by using ISM band wireless communication technology. The corresponding circuit and program are designed to realize the information interconnection and synchronous control of several mobile lifts. And it has been applied for lifting the bus outdoors. The experimental results show that it is feasible to realize the network operation and synchronous control of mobile lift based on wireless communication and microcontrollers. In this paper, only the networking control of 4 sets of lift has been tested experimentally. In the future, the networking operation of more sets of lift can be studied to meet the needs of a wider range of applications, such as lifting ultra-long vehicles.

7. References
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