Remote driving technology based on 5G

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Abstract. Relying on the 5G development wave, this project realizes human-vehicle interaction in the simulated cockpit in an innovative way, and remotely controls vehicle-like robots (unmanned vehicles). It aims to build a vehicle remote control system with a lower cost and a more stable way, and develop a remote driving robot based on 5G communication for distribution, disinfection or more precise tasks.

Keywords: 5G, remote driving, human-car interaction.

1. Introduction (Heading 1)

Based on the current achievements and development of 5G communication technology at home and abroad, this project proposes a 5G-based remote control system for unmanned vehicles, which is used to realize human-vehicle interaction and remote real-time control through the 5G network in the simulated cockpit. The function of unmanned vehicles (vehicle robots) to complete specified operations. Compared with the immature autonomous driving and limited manual driving technology in the field of unmanned vehicles, this project reduces the environmental requirements of unmanned vehicle operations, enhances the working capability and stability of unmanned vehicles, and enables them to be used in harsh conditions. Remote unmanned precise distribution and high-precision (manual precision) disinfection operations in the environment.

This project researches the remote driving technology of motor vehicles that is currently in the experimental stage. The simulated cockpit used is a motor vehicle console, and the technical standards adopted are all motor vehicle driving standards. The content of the realization also has a certain level of research on L4 autonomous driving. The driving effect of

2. Research content

2.1. Collect operation console control action information

In this part, in order to collect the driver's motion information at the remote console, in the collection of the steering wheel rotation angle, taking into account the zero cumulative error of the incremental encoder, and the existence of poor anti-interference, the receiving device needs to be powered off memory. Turning on should find the zero or reference position, we choose the absolute encoder to convert the steering wheel's rotational position into binary gray code stably and reliably. The pedal quantity is realized by pressure-sensitive components with corresponding analog-to-digital conversion circuit. Finally, the collected information is output as a digital signal, reducing the difficulty of subsequent operations.
2.2. Use 5G network to realize information transmission

In order to simulate the environment where the robot is located, we set up three display screens at the console to receive the real-time pictures taken by the robot's camera. The console used in the experiment is shown in the figure below.

![Fig. 1 Operation console for experiment](image)

As this project requires video images with high definition and low latency, it is necessary to develop a real-time video streaming technology based on 5G for the return of remote driving robot visual data. During the driving of the vehicle robot, the video stream will be transmitted to the screen of the console through the 5G module in real time, and the video playback on the device is required to be synchronized or nearly synchronized. Since in the real-time transmission of video streams, each device only needs to cache a small part of the video stream to maintain a stable playback rate, so the cache space of these devices does not need to be very large. On the contrary, real-time video streaming requires strict end-to-end delay between devices. The shorter the delay, the more real-time the video stream received by the end user.

This section discusses the problem of video transmission when multiple operating stations operate multiple vehicle-like robots, and formulates this problem as how to select neighboring devices to maximize real-time, as shown in Equation 1.

\[
\text{Min} \sum_{i \in N} X_i D_i + \sum_{i \in N} X_i J_i - \sum_{i \in N} X_i H_i
\]

Optimal conditions:

\[
\sum_{i \in N} X_i \leq A
\] (2)

\[
\sum_{i \in N} X_i D_i \leq T
\] (3)

Among them, \(H_i\) represents the latest video chunk in user i; \(D_i\) indicates the delay of the i user; \(J_i\) indicates the jitter of user i; \(T\) represents chunk timestamp; \(A\) indicates total capacity. \(X_i \in \{0, 1\}\), If user i participates in the chunk request, the parameter value is 1, Otherwise 0. \(R_i \geq 0\) ndicates the
total number of users who have cached chunk \( j \). \( B_{i,j} \in \{0,1\} \). If user \( i \) caches chunk \( j \), the parameter value is 1, otherwise it is 0.

The above is the optimization function, the function is to identify the neighboring devices that have cached the latest block, and at the same time minimize the change of the video delay and the block receiving delay. Equations 2 and 3 are the conditions that need to be met for optimization. Equation 2 represents the limitation of link capacity, ensuring that only a few devices request the video chunk. Equation 3 ensures that the requested chunk can arrive on time.

At the same time, this part should also realize the accurate transmission of control instructions to the console. This project requires a total of two 5G modules. One of them is connected to the serial port and camera of the single-chip microcomputer on the robot, and the other is connected to the video and instruction transmission port of the console. Both modules need to realize the input/output data through the interface protocol. The specific information transmission flowchart is as follows.

![Flow chart of information transmission](image)

**Figure 3.** Flow chart of information transmission
2.3. Real-time and precise control and drive of the vehicle robot chassis

After pre-preparation, the encapsulation of basic action commands for vehicle robots such as start, braking, acceleration, deceleration, gear shifting, and steering has been realized. At the same time, it supports CAN control and remote control, and the chassis drive can be controlled through the embedded control unit. Considering the large number of chassis modules (more demand for IO port resources) and 5G modules have certain requirements for serial ports, we choose STM32 series single-chip microcomputers to control the chassis modules (the internal circuit is shown in Figure 3). The working process of CAN bus and CAN module in STM32 is introduced below.

![Figure 4 CAN bus basic topology](image)

The CAN communication module in STM32 has three working modes, namely the initialization of the CAN module, the normal working mode of the CAN module and the sleep mode of the CAN module.

The initialization of the CAN module of STM32 is completed by software setting. Setting the INRQ bit of the CAN_MCR register to 1 and setting 0 can make the CAN module enter initialization and exit initialization respectively. When the CAN communication module is in the initialization state, the message reception and transmission on the bus are prohibited. The CANTX pin outputs a recessive bit, which is a high level.

The CAN module of STM32 enters the normal working mode after initialization. At this time, the software synchronizes the CAN bus to send and receive messages normally. When the software clears the INRQ bit to 0, the CAN module enters the normal working mode. After the CAN bus is synchronized, that is, after the bus is idle, the CAN communication module can send and receive messages normally.

The sleep mode of the CAN module of STM32 is achieved by setting the INRQ bit of the CAN_MAR register to 1. After entering this mode, although the CAN clock is stopped, the software can still access the mailbox register. If you need to adjust the CAN module in sleep mode to initialization mode, in addition to setting the INRQ bit of the CAN_MCR register to 1, you also need to clear the SLEEP bit to 0 at the same time. If you want to exit from sleep mode, you need to clear the SLEEP bit to 0, or the hardware can detect the activity of the CAN bus. The following is the schematic diagram of the STM32 CAN module communication interface.
Another key point is the one-to-one correspondence between the data sent by the console and the instructions sent by the embedded, so that the console can send corresponding information to the embedded control unit, and then the embedded control unit can control the robot.

**Figure 5** Schematic diagram of the CAN module communication interface of STM32

**Figure 6** Sending process

3. Feasibility Analysis

3.1. Basic structure and mathematical principles of 5G communication network

The communication system is mainly composed of three parts: a core network (Core Network), a macro base station (MBS), and a small base station (SBS), and its structure is shown in Figure 7.

**Figure 7** 5G communication network structure
The core network is the "brain" of the communication system, responsible for the control of the system and the transmission of information and data, and connects calls or data requests from different ports to the corresponding network.

The macro base station is the "central nerve" of the communication system. It is connected to the core network through optical fiber or microwave, and the transmission power through radio waves is generally greater than 10W, and the coverage radius is generally greater than 200m.

Micro base stations are the "terminal nerves" of the communication system. They are the collective term for small base stations, which have been gradually applied in the 4G communication era. Micro base stations have low transmit power and small coverage radius. The coordinated coverage of a large number of micro base stations can ensure signal strength in various areas and increase wireless connection density.

In the wireless communication between macro base stations, micro base stations and users, the transmission rate of information is affected by multiple factors such as channel bandwidth and signal-to-noise ratio. The upper limit of the rate is determined by the famous Shannon formula (4):

\[ C = W \log_2 (1 + \frac{S}{N}) \]  

In the formula: C is the maximum transmission rate, bps; W is the channel bandwidth, Hz; S is the signal power, W; N is noise power, W; S / N indicates the signal-to-noise ratio.

3.1.1. 5G communication core features. 5G communication has the characteristics of high reliability, low latency, high speed, high capacity, etc. The specific indicators are shown in the following table.

| Indicators                        | Targeted values                      |
|-----------------------------------|--------------------------------------|
| Peak data rate /Gbps              | Uplink:20; Downlink:10               |
| User experienced data rate/Mbps   | Uplink:100; Downlink:50              |
| Bandwidth/MHz                     | >100                                 |
| Connection density/km²            | 1000000                              |
| Area traffic capacity/(Mbps/m⁻)   | 10                                   |
| Reliability                       | 0.001% packet loss (32 bytes/ms)     |
| Latency/ms                        | 1                                    |
| Mobility/(km/h)                   | 500                                  |

Figure 8. 5G core features

4. Technical route and system construction
This product needs to use many current new technologies and integrate them. Modularization is selected when the system is constructed. After the individual debugging of each module is completed, the system integration and overall debugging of the entire system are carried out. Considering multidimensional considerations such as R&D progress and time, this flowchart is drawn up. The sequence of the flowchart is the order in which the functions of each module are realized.
Get the underlying code encapsulation of each device

Debug the communication module to realize data transmission

Debug the console and determine the interface protocol

Load the embedded control unit, debug the robot chassis and conduct instruction encapsulation

Connect the embedded control unit in robot chassis with communication module through protocol

Connect the communication module with the console by protocol

Try to develop unmanned vehicle program, control directly with Ros or embedded code and achieve certain functions

Transmit images from the camera mounted on the robot to the console screen

Transmit commands from the console to the robot chassis

Transform the control of the console into encapsulation of control instructions for robot chassis

Read out for remote driving

**Figure 9** System construction flow chart

5. Innovation and project features

Based on this epidemic environment, this project has improved the functional unmanned vehicle system, and developed a remote driving robot based on 5G communication, filling the gap outside the scope of unmanned vehicle operation, keeping up with current events, and having practicality, Targeted. Compared with the current 5G remote driving technology, it has the advantages of cost economy, high equipment stability, and high universality of the solution. At the same time, this project introduces vehicle-type robots as the control object, which has pioneering and enlightening significance in the field of unmanned robots and remote driving.

In the commercial field, all hardware such as the materials and equipment of this project are easily available devices, with strong practicability, simple maintenance, strong overall system stability, and considerable commercial prospects; in the scientific and technological field, the 5G communication module used in this project is currently The mainstream trend of communication algorithms and the debugging of communication hardware are in line with the current main research, which is of reference value for the current remote driving and unmanned driving research. Moreover, the technical solution of this project is highly portable. The system architecture of this project can be directly applied to multiple application scenarios such as unmanned distribution, unmanned cleaning, and unmanned disinfection.

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