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LTE-based humanoid robotics system

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ABSTRACT

Although the robots integrated with communication module can provide various functions, there is intrinsic limitation because of the instable wireless connection, restricted bandwidth and limited coverage of network. Fortunately, assisted by LTE (Long Term Evolution) techniques, the robots can be deployed more widely to support bandwidth-intensive applications. Hence, this paper proposes a LTE-based robotics system integrated with cloud computing to enhance the capability of data transmissions and intelligence for providing higher quality and more friendly services. Furthermore, we develop a robot with emotional recognition and feedback for improving Quality of Service (QoS) and Quality of Experience (QoE), and design a testbed for verifying system's feasibility and performance.

1. Introduction

With the advances in microprocessor, communication, and computer science, there has been a significant development in of robot techniques over the past decade. Generally, conventional robot technology based on automatic and computer technology is independently deployed in industrial control systems [1], which can only fulfill some simple control functions due to the limited resources. Although the robots integrated with communication module can be connected into a group for providing more M2M (machine-to-machine) functions, they can only work in a certain situation because of the instable connection, restricted bandwidth and limited coverage.

Fortunately, as the 4G-LTE (Long Term Evolution) is promoted and popularized, the robots can be deployed more widely. Moreover, the emerging technologies, such as machine learning, big data and cloud computing, promote industrialization and commercialization of household robot which can provide higher quality, more intelligent, and more friendly services to address the following issues:

- Enhanced communication capability: LTE-based robot can provide enhanced transmission in various applications. For example, LTE-based health-care robot cannot only collect physiological data, but also provides real-time video communications for emergency response. Specially, in some certain conditions without wired connection, LTE-based robot can provide considerable support.
- Extended intelligence: Through LTE, the sensory data collected by robot can be transmitted to cloud, which provides strong ability of storage and computation. Hence, assisted by LTE, the intelligence of robot is extensively stretched by remote cloud.

Hence, this paper proposes a LTE-based approach for robot system integrated with cloud computing and big data. Furthermore, we develop a robot with emotional recognition and feedback for QoS provisioning and QoE enhancement.

The rest of this paper is organized as follows. Section 2 presents related works. The LTE-based mobile robot structure is presented in Section 3. Section 4 describes the hardware of robot, while the software is described in Section 5. Finally, Section 6 concludes this paper.

2. Related work

Along with the significant improvement of wireless communication, some advanced techniques has been implemented in the robot field. In [2], Hille et al. designed an outdoor robot, which is

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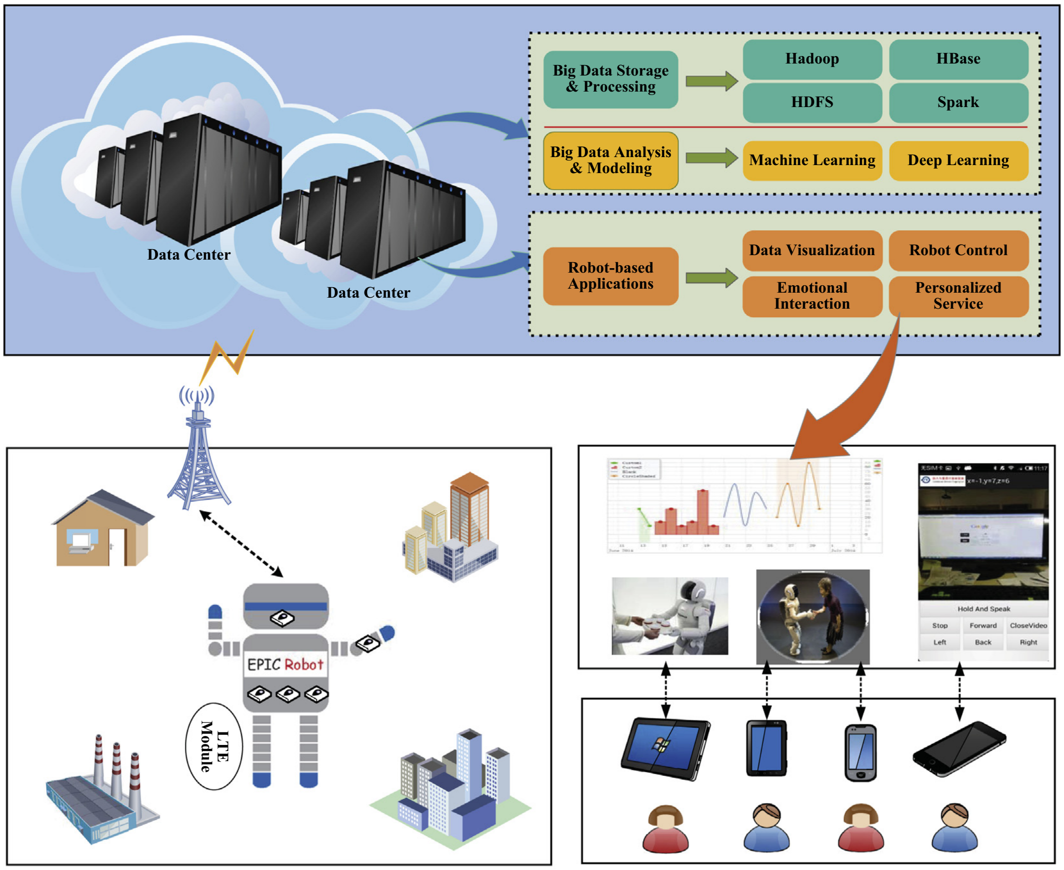


Fig. 1. LTE-based mobile robot framework.

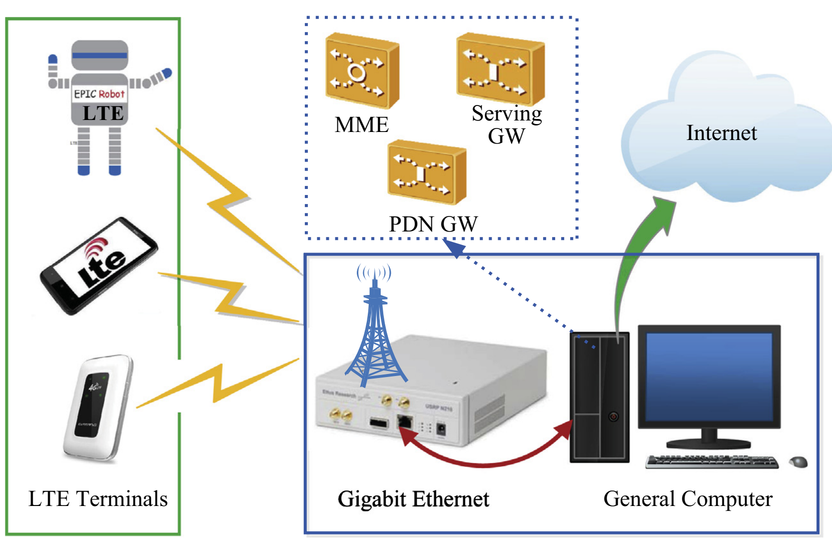


Fig. 2. LTE-based testbed for robot communication.

integrated with WiFi module to provide real-time video transmission. However, the mobility of robot will be restricted because of the coverage and bandwidth of WLAN. In [3], Lin et al. proposed that a camera-enabled interactive learning robot assisted by 4G LTE, which provides high date rate, low bandwidth and high mobility.

Generally, the software control of robot is mostly based on embedded system (i.e. Embedded Linux, ucos, WinCE). In recent years, along with the rapid improvement of Android system, Android-based robot has also been widely implemented. In [4], Deng et al. proposed an Android household robot integrated various sensors (including temperature, humidity, smoke, etc.), but its intelligence is insufficient. In [5], Moon et al. developed a robot platform based on Android, which can be controlled remotely by a smart phone and provide real-time image transmission through 801.11x wireless WLAN. In [6], Myeong et al. developed an Android-based

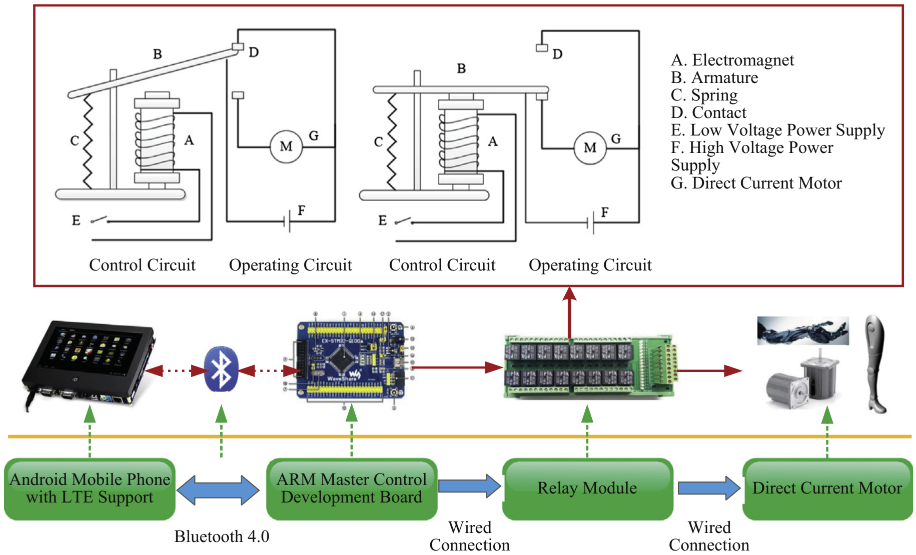


Fig. 3. Robot control system.

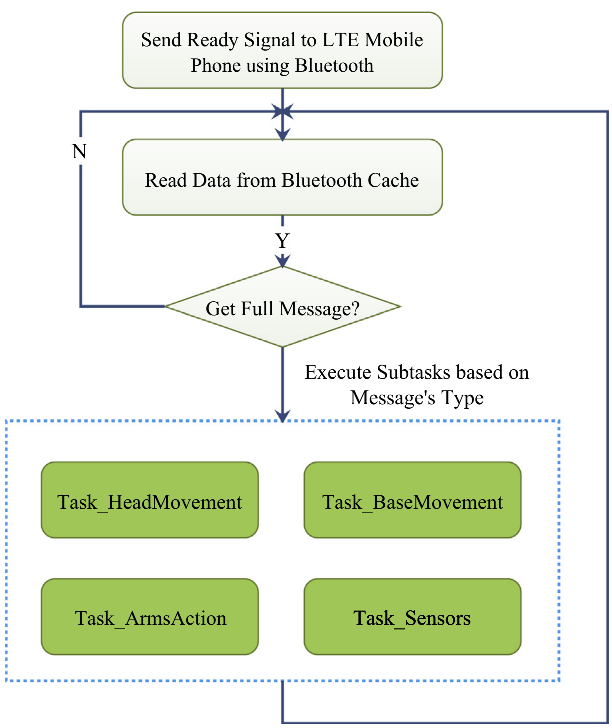


Fig. 4. Robot control flow chart.

education robot based on Android integrated with by ultrasonic sensor and radio frequency module to provide pure education services.

For improving the intelligence of robot, cloud computing is deployed [7]. With cloud computing, sufficient resources are provided to robot for complete computation-intensive tasks, such as emotional emotional recognition and feedback, which can extensively improve robot intelligence and user experience. In 2010, Kuffner firstly proposes the concept of Cloud Robotics for addressing the restricted resource [8]. In [9] Dyumin et al. proposed a structure for Cloud Robot, while in [10] Ma proposed a household healthcare robot integrated with motion sensor and camera.

In a word, the robot integrated with 4G LTE, Android, cloud computing has gradually become hotspot in this field. Although there have been a few research achievements, it still lack of a standard system structure. In this paper, we propose a comprehensive robot system structure.

3. The robot system architecture

Along with the development of mobile communication and artificial intelligence, networking, mobility and intelligence have become the trends in robot development. In this paper, we propose an intelligent mobile robot structure based on 4G LTE mobile communication technology, cloud computing, big data and machine learning. As shown in Fig. 1, the robot system structure includes the following module:

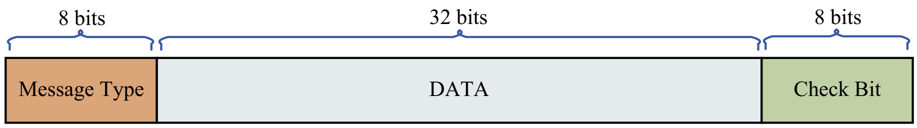
- Humanoid robot: works for the front-end of user interaction, including hardware components, micro-processor, various sensors, 4G LTE communication module and software functions based on Android.
- 4G LTE network: provides considerable bandwidth for sensory data transmission, and reliable connection between robot, terminal and cloud.
- Smart control terminal: receives data from robot via bluetooth, remote control robot via 4G LTE.
- Cloud platform: provides adequate resources for storage and computation to enhance the ability of robot. Moreover, data analysis and machine learning are integrated in cloud to improve the man–machine interaction of robot.

4. Hardware structure

4.1. Functional components of humanoid robot

The humanoid robot body mainly consists of the following components:

- Head: consists of 5 LED lights and 2 rotation motors.
- Arm: consists of 7 rotation motors to control 7 joints, while each motor contains 2 relays.
- Leg: is a fixed proportion of 2 joints to imitate human walking which is controlled by magnetic field signals.
- Controller: is a STM32 high-performance low-power chips, which is integrated with bluetooth module to receive control command.

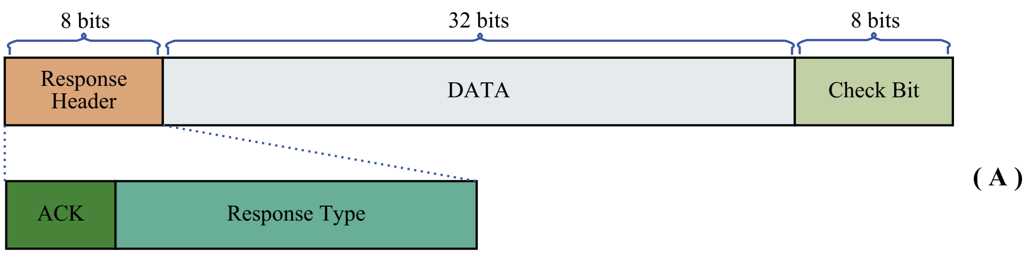


Message Type (8bits)	Description
0001xxxx	Biped Walking Control
0010xxxx	Head Movment Control
0011xxxx	Sensor Control
0100xxxx	Hands Movement Control

DATA	Description
32bits	Sensor Data or Cmd Detail

Check Bit	Description
8bits	Message Checksum

Fig. 5. Robot message protocol.



(B)

ACK (1bit)	Response Type (7bits)	DATA	Description
0	0000001	Integer	Infra-red Sensor
1	0000000	All-Zero	Command Success (No Error, No Data)
1	0000001	Float	Temperature Sensor
1	0000010	Float	Humidity Sensor
1	0000011	Int	Smog Sensor
1	1111111	ErrorCode	Error occurred

(C)

Error Code	Error Name	Description
0	ERROR_UNKNOWN_CLASS_CODE	Command Type Code Error
1	ERROR_UNKNOWN_CMD_CODE	Command Code Error
2	ERROR_INVALID_CHECK_SEQ	Checksum Error
3	ERROR_OSSEM_PEND_FAULT	System Error (Request Singal Error)
4	ERROR_OSSEM_POST_FAULT	System Error (Send Singal Error)
5-11	ERROR_INTERNAL_FAULT_{5-11}	Internal Error

Fig. 6. Response message protocol.

4.2. LTE communication system

Considering the advantage of less network latency, higher transmission speed, larger system capacity and better safety measures, LTE technique is deployed in our system to provide reliable communication between robot, remote terminal and cloud. Furthermore, real-time monitoring is available that high definition video can be prompt transmitted via LTE networks for real-time video analysis, human emotion analysis, etc.

In order to verify the network feasibility and performance, considering the compatibility for major LTE terminals, a testbed based on Amari LTE is designed as illustrated in Fig. 2. The software of this testbed mainly includes LTE base station (LTE eNB) as LTE access network and LTE mobile management entity (LTE MME) software as LTE core network involving Service Gateway (SGW), Packet Data Network Gateway (PGW) and Home Subscriber Server (HSS), etc. And the hardware consists of radio frequency unit, high performance computer and LTE terminal.

4.3. Robot control system

The control system is an ARM demoboard to control the motors via relay groups on the robot. In order to reduce the complexity and error rate of the wiring inside, the communication between the upper computer of robot and all kinds of main control chips of bottom control motors is based on bluetooth as shown in Fig. 3.

Specifically, the movements of robot is driven by motors which are switched on or off via the electromagnetic relays. Because the great number of motors on the robot, we use two groups of relays to control all the motors.

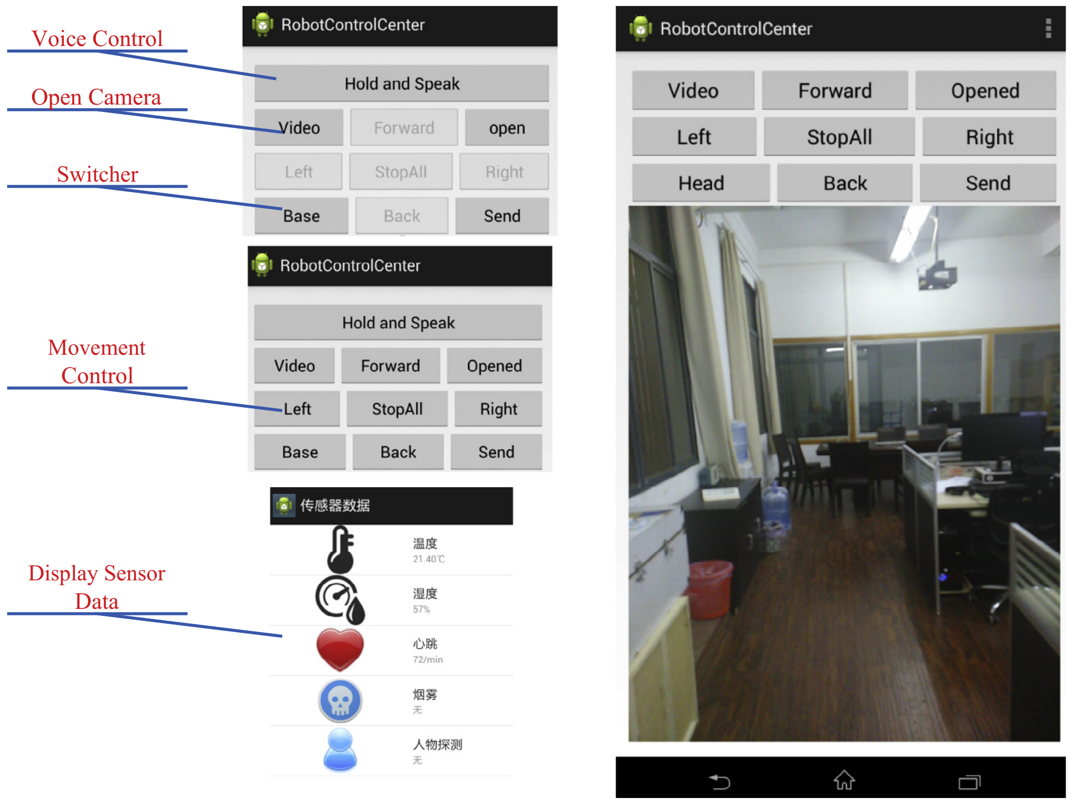


Fig. 7. Application software for remote control.

Moreover, the Bluetooth module on the robot main controller is used to communicate with the upper computer. In order to reduce development cost and improve development effect, LTE Mobile Phone is used as upper computer, which is integrated with 4 core ARM processor, LTE communication, high definition camera. Once LTE Mobile Phone receives the control commands via LTE network, it will send the commands to the main controller by bluetooth to achieve the remote control.

5. Software system

The robot software system includes underlying control software and high-level application software.

5.1. Underlying control software

The underlying control software is developed based on the $\mu C/OS - II$ embedded system which is widely applied to military defense, consumer electronics, network communication and industrial control because the characteristics of portability, solidifiability, tailorability, multi task preemptive real-time kernel. It is applicable to various micro-processors, micro-controllers and digital processing chips, and it can shorten the control software developing period with a bottom hardware abstraction as operating system.

As shown in Fig. 4, the flow chart of robot control includes the following procedures:

1. Task Daemon sends ready signal to LTE Mobile Phone via bluetooth to inform the control system is started.
2. LTE Mobile Phone immediately sends control signal to the bottom layer or hold in suspense.
3. The task goes to an endless loop, inquiring about whether buffer of bluetooth for receiving data has received complete message, and recognizing the control command according to the message content.
4. After accomplishing corresponding control task, it will enter the next loop.

The communication between LTE Mobile Phone and ARM is based on Robot Message Protocol as shown in Fig. 5, which is mainly used for sending control command from upper computer to ARM, and sending sensory data from ARM to upper computer. As shown in Fig. 5(A), Robot Message is composed of 6 bytes. Specifically, Message Type consists of ClassCode and CmdCode, which are both 4 bits. As shown in Fig. 5(B), ClassCode is used for identifying commend category including bipedal walking, head movement, hand movement, sensor, etc., while CmdCode is used for identifying the detailed content according to ClassCode.

Furthermore, the master control board must send execution results via response mechanism to upper computer. The format of Robot Response Message is illustrated in Fig. 6(A), while detailed Response Type is shown in Fig. 6(B), and ErrorCode is presented in Fig. 6(C).

5.2. High-level application software

The high-level application software is developed on Android platform. Because of open source and considerable portability, it is convent to develop bottom hardware driver and up application of the robot.

In this paper, we develop application software for local operation and remote control: (1) local operation is used for receive remote control command and forward to robot; (2) remote control is used for providing communication between user's smart mobile terminals and robot via LTE networks, which includes the following modules as shown in Fig. 7: user interface, robot control, voice recognition, sensory data processing, video transmission and display.

6. Conclusion

In this paper, we propose a mobile humanoid robot architecture based on LTE, including detailed hardware and software design and development. Furthermore, we develop an emotion-aware robot based on the proposed architecture and a testbed for verifying the system feasibility and extendibility.

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References

[1] Y. Liu, G. Nejat, Robotic urban search and rescue: a survey from the control perspective, J. Intell. Robot. Syst. 72 (2) (2013) 147–165.
[2] C. Hille, A. Nasir, A. Abreu, et al., Development of an outdoor mobile robot for teleoperation as an agent for a robot network, World Congr. 19 (1) (2014) 9732–9737.
[3] B. Lin, W. Tsai, C. Wu, et al., The design of cloud-based 4G/LTE for mobile augmented reality with smart mobile devices, in: Proceeding of IEEE 7th International Symposium on Service Oriented System Engineering (IEEE SOSE 2013), 2013, pp. 561–566.
[4] D. Zhi-Hui, Z. Yun-hang, The design and implement of household Robot based on Android platform, in: Proceeding of IEEE Workshop on Advanced Research and Technology in Industry Applications (WARTIA), 2014, pp. 449–452.
[5] S.W. Moon, Y.J. Kim, H.J. Myeong, et al., Implementation of smartphone environment remote control and monitoring system for Android operating system-based robot platform, in: 2011 8th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI), IEEE, 2011, pp. 211–214.
[6] H. Myeong, Y. Yoon, N. Cha, et al., User tracking of an educational robot with android operating system based robot platform, in: Proceeding of IEEE 9th International Conference on Ubiquitous Robots and Ambient Intelligence (URAI 2012), 2012, pp. 132–135.
[7] K. Goldberg, B. Kehoe, Cloud Robotics and Automation: A Survey of Related Work, EECS Department, University of California, Berkeley, Tech. Rep. UCB/EECS-2013-5, 2013.
[8] J. Kuffner, Cloud-enabled robots, in: IEEE-RAS International Conference on Humanoid Robotics, Nashville, TN, 2010.
[9] A. Dyumin, L. Puzikov, M. Rovnyagin, et al., Cloud computing architectures for mobile robotics, in: 2015 IEEE NW Russia Young Researchers in Electrical and Electronic Engineering Conference (EIConRusNW), IEEE, 2015, pp. 65–70.
[10] Y. Ma, Y. Zhang, J. Wan, et al., Robot and cloud-assisted multi-modal healthcare system, Clust. Comput. (2015), http://dx.doi.org/10.1007/s10586-015-0453-9.

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