DESIGN OF A LOW-COST SYSTEM WITH BUILT-IN-GPS AGRICULTURAL MACHINERY
/
种基于嵌入式的低成本农业机械GPS 导航定位系统设计

Assoc. Prof. Ms. Lin Hanhui[1], Assoc. Prof. Ph.D. Cai Ken[2], Eng. Zeng Zhaofeng[3]
[1] Center for Educational Technology, Guangdong University of Finance and Economics, Guangzhou / China;
[2] School of Information Science and Technology, Zhongkai University of Agriculture and Engineering, Guangzhou / China;
[3] Department of Mathematics and Computer Science, California State University, East Bay/ U.S.A
Tel: +8634172680; Email: icken@126.com

Abstract: *Intelligent agricultural machinery is a key component in developing precise and intellectual agriculture. However, achieving the accurate operation of intellectual agricultural equipment depends on precisely sensing the field position. This study adopts built-in technology and integrates wireless communication and Global Positioning System (GPS) stand-alone positioning to obtain low-cost and high-precision positioning in production. Information collection and transmission by the low-cost agricultural machinery are realized to implement overall management, monitoring, and scheduling. Test results show that the measured and actual errors can be stabilized to less than 3%, and the accurate position of an agricultural vehicle can be obtained. The system exhibits good expandability, functional implementation, and stable performance. It is significantly useful in engineering applications.*

Keywords: *agricultural machinery, GPS, built-in system, wireless communication*

摘要: *智能农业机械是发展智慧农业和精准农业的关键设备，然而要实现农业装备的精确作业取决于对农田位置的精确定位。为了解决低成本和高精度定位的目的，本论文采用全球卫星定位系统(GPS)单机定位方式，并综合无线通讯、嵌入式技术等先进技术手段，实现了一种低成本高精度的农业机械定位信息的采集、传输，从而完成了对农业机械的综合管理、监控和调度。试验测试结果表明使用该系统对收割面积进行计算其平均统计误差能稳定在 3%以下，也能准确获取农用车辆行驶过程中的位置信息。该系统可扩展性强，功能实现良好，性能稳定，具有重要的工程应用价值。*

关键词: *农业机械；GPS；嵌入式系统；无线通信*

INTRODUCTION

The 20th century is the development period for agricultural mechanization, which is actually the integration of agricultural machinery with modern hydraulic, instrumentation and control, modern microelectronics, sensor (including 3S), and information technologies. This integration then evolves into intelligent, mechanical, and electrical integrations [4,5,7]. The application of GPS and information technology (IT) to agricultural machinery was initially implemented in the information management system of farming office personal computers (PC) and mobile machinery via wireless communication, which enables the system dispatching center to transmit data between field-operation machinery and crop-growing environment [1]. The central computer, with its functions of information storage, processing, expert knowledge base and management decision-making panel, can create detailed agricultural operation and navigation operation plans from the data collected from the field operation. Such plans are utilized to instruct field-operation agricultural machinery, being widely applied in the USA [2,3,11]. GPS is the core technology in navigating agricultural machinery or equipment. How to improve the overall performance of agricultural machinery and equipment with related technology is currently under development. Therefore, the study of the navigation application of agricultural machinery and equipment is necessary and significant in realizing the modernization of China's agricultural machinery [12]. This study aims to design a low-cost system with built-in-GPS agricultural machinery through the use of IT, built-in technology, and GPS technology. Such system can receive GPS real-time data through serial ports and receive and send data in a Wi-Fi

引言

二十世纪是农业机械化发展的时期，这实际上是农业机械与现代液压技术、仪器仪表控制技术、现代微电子技术、传感器技术（包括 3S 技术）和信息技术的整合。同时它也是智能化、机械化、电子化的整合[4,5,7]。运用 GPS 和信息技术（IT）的农业机械已开始应用于农业办公的个人计算机（PC）中的信息管理系统和通过无线网络连接的移动终端设备，这些系统和移动终端设备能够和系统调度中心进行通信，并使其控制在田间进行作业的农业机械和农作物生长环境之间的数据交互[1]。另外，具有信息存储功能、处理功能、专家知识库和管理决策模块的中央计算机，可以实施控制具体的农业作业操作和利用从现场收集回来的有效数据指导导航操作计划。这些指导农业现场作业计划的方法已广泛应用于美国等国家的农业机械中[2,3,11]。GPS 是农业机械或设备导航的核心技术，如何提高农业机械和相关设备的整体性能目前还处于发展阶段，因此，研究应用于农业机械与设备的导航技术就显得相当的必要，其对实现中国的农业机械现代化具有重要意义[12]。本文的目的是设计使用信息技术、嵌入式技术和 GPS 技术的低成本农业机械导航定位系统，这样的系统可以通过串口接收 GPS 的实时数据，并在 Wi-Fi 环境下接收和发送数据，从而实现农业机械的导航和定位，在提高农

environment to achieve navigation and positioning of the machinery, thereby improving efficiency while lowering the operation cost and increasing economic and ecological benefits in agricultural production.

业作业效率的同时降低运营成本，提高农业生产的经济效益和生态效益。

MATERIALS AND METHODS

Overall Design of the System

The controlling system is the most vital part of agricultural navigation and positioning system; the former is directly relevant to the latter's intellectual level. The controlling system consists of lithium battery power supply, GPS, electric machine control, and wireless communication modules. In the typical design, each hardware and software should be independent of each other as much as possible, as shown in Figure 1, to allow for future updating.

材料与方法

系统总体设计

控制系统是整个农机导航定位系统设计中最重要的部分，直接关系到系统的智能化程度。该系统主要包括：锂电池供电模块、GPS 模块、电机控制模块、无线通信模块。如图 1 所示。在具体的设计中，控制系统的每个硬件模块和软件部分以相对独立的方式进行设计，这样做的目的是为以后的更新升级提供便利。

Fig.1- System structure

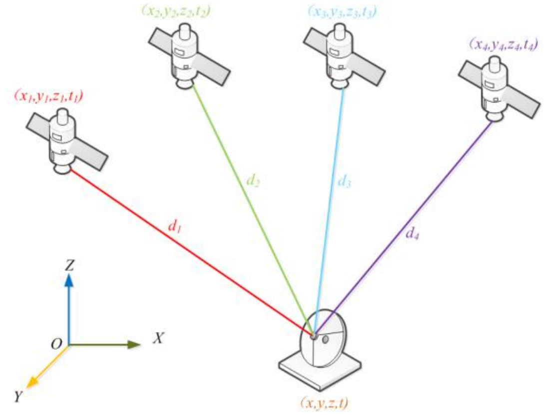

Fig.2- GPS positioning principle

GPS Positioning Principle

The basic principle of GPS positioning is using ΔTIME to calculate the distance between the receiver's antenna and satellite [8]. The message received by the satellite is decoded and generated into the 3D position of the receiving antenna. The GPS satellite constantly sends navigation messages that include position information (x_i,y_i,z_i) with the time stamp of each position attached. As the receiver receives the messages, the satellite time (t_i) and the receiver's internal time (t) are extracted to obtain transmission $\Delta t_i = t - t_i$, which multiplies the speed of wireless wave (c) which is light speed. The distance between the antenna and satellite ($d_i = \Delta t_i \times c$) is obtained with the following equation.

GPS 定位原理

GPS 定位的基本原理[8]就是利用时间差的方式来测量接收机天线到卫星之间的距离，然后通过解析接收到的卫星导航电文数据来计算出接收机天线的三维位置。GPS 卫星不断的发送导航电文，导航电文不仅包括了卫星的位置信息(x_i,y_i,z_i)还附加了电文发送的时间戳 t_i。接收机接收到电文时，通过提取的卫星的时间 t_i 与接收机内部的时间 t，便可得到电文在空中的传输时间差 $\Delta t_i = t - t_i$，再乘以无线电波传输速度 c(即光速)，就可以得到接收机天线到卫星的距离为 $d_i = \Delta t_i \times c$，于是就可以得到下面的方程组：

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} = c \times \Delta t_i, i = 1,2,3,4 \quad (1)$$

The position (x,y,z) of the receiver's antenna is obtained when the equation is solved (as shown in Figure 2).

This equation only has three unknown numbers, which means only three satellites are required to fully acquire the position of the antenna. However, in actual situations, three satellites are insufficient. Four or more are required to acquire the position precisely because c is a large value, and d (distance) is obtained by Δt, which multiplies c (light speed), and can be magnified numerous times by even a small error of Δt. The error of Δt originates from the receiver because the timing device in the receiver is not as expensive as the cesium atomic clock in GPS satellites. Therefore, adding another satellite is the best solution to minimize the error when considering the receiver's internal time (t) as a variable value.

根据上面的方程可得到接收机天线的位置(x, y, z)(如图 2 所示)。

上面的方程组中只有三个未知数，求解它们只需要三颗卫星即可。但是实际应用中，必须要四颗或更多卫星。因为上面方程组右边距离 d 是由时间差 Δt 和光速 c 相乘得到，而光速 c 的值很大，时间差 Δt 一个很小的误差就会被放大很多倍。然而 Δt 的误差主要来源是接收机，因为 GPS 卫星上是通过铯原子钟来计时，但接收机不可能配备昂贵的精确时钟，为了降低成本一般都是通过增加一个卫星的方式来减小误差，也就是将接收机内部的时间 t 也看成变量，于是式(1)变为下式：

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} = c \times (t - t_i), i = 1,2,3,4 \quad (2)$$

A more accurate position (*x*,*y*,*z*) of the receiver can be obtained by solving the equation above. Different interfering factors may cause errors during GPS positioning, and each interference may generate a different effect on the accuracy of GPS positioning. This factor should be considered when designing the GPS.

这样，通过解公式(2)就可以获得在时间 *t* 的相对更为精确的接收机的位置 (*x*,*y*,*z*)。当然 GPS 的定位精度还受其他各种因素干扰，不同因素的影响程度也不同，因此在进行 GPS 的相关设计时都需要考虑。

Design of the Hardware in the System

Micro-controller module

The agricultural navigation and positioning system should complete data collection, processing, and transmittance, and an algorithm should be adopted. Therefore, the core processor must have high processing speed. The STM32F103RBT6 chip manufactured by ST Microelectronics is utilized as the core processor of the core controller of this machine to complete information collection and processing from the sensor and control the machine. The STM32F103RBT6 chip is ARM Cortex-M3 32 digit reduced instruction set computing (RISC) with a working frequency of 72 MHz. It can achieve high-speed operation. It has 128 Kb flash memory, 20 Kb static random-access memory, and a large number of enhancement mode I/O ports.

系统硬件平台的搭建

微控制器模块

农机导航定位系统需要完成数据的采集、处理、传输等功能，并涉及到一些算法的设计，因此要求系统的核心处理器具有比较快的运行和处理速度。本论文选择 STMicroelectronics公司的STM32F103RBT6 芯片作为系统的核心处理器来完成各类外围设备的信息采集和处理。STM32F103RBT6是ST公司推出的高性能 ARM Cortex-M3 32 位精简指令集计算机(RISC)内核芯片，工作频率是 72MHz，能实现较快速度的运算。其内置128Kb的闪存存储器、20Kb 的静态随机存储器，以及大量的增强型 I/O 端口。

Fig.3- NEO-6M GPS module

GPS module

The task of the GPS module is to capture the signal of the satellite to be measured at a certain drag angle of the satellite height and keep the track of such satellite. It transforms, magnifies, and processes the received GPS signals to obtain the transmission time from the satellite and the receiver's antenna, decode the navigation message sent by the GPS satellite, and calculate the real-time 3D position, 3D speed, and time. NEO-6M is adopted as the GPS module in this study because it has high performance and low power consumption. It is an intelligent satellite signal-receiving module with complete functions of a satellite positioning receiver; it meets the strict requirements of professional positioning and individual consumption. The shape of the GPS module is shown in Figure 3. The NEO-6M mode GPS module is based on the No. 0183 Act of the National Marine Electronics Association, which stipulates that the sentence transmission format of a GPS navigation message should have "$" illustration as its frame header, followed by data segments that are separated by "," and end with pressing “enter to line feed.”

GPS 模块

GPS 模块的任务是能够捕获到按一定卫星高度截止角所选择的待测卫星的信号，并跟踪这些卫星的运行，对所接收到的 GPS 信号进行变换、放大和处理，以便测量出 GPS 信号从卫星到接收机天线的传播时间，解译出 GPS 卫星所发送的导航电文，实时地计算出测站的三维位置，甚至三维速度和时间。本论文采用的 GPS 模块为 NEO-6M，该模块是一个高性能、低功耗的智慧型卫星接收模块，具备完整的卫星定位接收器的功能，能满足专业定位的严格要求与个人消费需求。GPS 模块外形如图 3 所示。NEO-6M 型 GPS 模块遵循美国国家海洋电子协会(National Marine Electronic Association)所制定的 0183 标准协议。NMEA-0183 规定的 GPS 导航电文的语句传输格式是以“$”加语句类型说明作为帧头，其后为各数据段，各数据段以“，”分开，最后以回车换行标志结束。

Wi-Fi module

The Wi-Fi circuit is designed to enable the users to retrieve the GPS information and data in the Wi-Fi environment. S2W-M02 ports that transmit to the Wi-Fi module are adopted to facilitate hardware design. S2W-M02, produced by Beijing Simple-WiFi Co.Ltd, contains low-cost built-in ports of Ethernet to the Wi-Fi module. It is based on universal serial ports, Wi-Fi built-in module, and TCP/IP protocol stack to perform data transmission of serial and Wi-Fi ports. The serial port data can be transferred into Internet data and transmitted via the S2W-M02 module. Through this process, the hardware can support the UART ports and facilitate the Wi-Fi circuit. The Wi-Fi module in this study operates under the client end, which is connected to the external router via Wi-Fi. With software configuration, the ports of the data field can be mutually transferred and transmitted through Wi-Fi. The Wi-Fi LAN structure is shown in Figure 4. S2W-M02 is connected to the exterior router via Wi-Fi and connected to the microprocessor via the UART port. S2W-M02 is utilized as Station (STA) to connect to the router and form a wireless network. The router is the center of the wireless network, and the communication between the Wi-Fi module and the PC is achieved via the router. The S2W-M02 module transmits the data through unvarnished transmission, and the TCP handshake protocol should be added to ensure the reliability of data transmission.

Wi-Fi 模块

Wi-Fi 电路的设计目标是能够方便用户在无线网内方便访问系统的 GPS 信息和数据。为了方便硬件设计，选用了 S2W-M02 串口转无线网模块。S2W-M02 是 Beijing Simple-WiFi Co.Ltd 推出的低成本嵌入式串口-以太网-无线网模块。它是基于通用串行接口和无线 Wi-Fi 网络标准的嵌入式模块，内置 TCP/IP 协议栈，能够实现串口和无线网（Wi-Fi）之间的数据转换。通过 S2W-M02 模块，串口数据可转化为 Internet 网络传输数据。这样系统在硬件上支持 UART 接口就可以方便的实现 Wi-Fi 电路。在本论文中，Wi-Fi 模块工作于客户端模式，通过 Wi-Fi 连接到外部路由器，通过软件配置，即可实现数据域的串口与 Wi-Fi 的互转换传输。Wi-Fi 局域网结构如图 4 所示。S2W-M02 模块通过 Wi-Fi 和路由器连接，通过 UART 接口和微处理器连接，S2W-M02 模块做为 STA 连接到路由器上，组成一个无线网络，以路由器做为无线网络的中心，Wi-Fi 模块与 PC 之间的相互通信都通过路由器转发完成。S2W-M02 模块数据传输采用透传模式，在软件设计中增加 TCP 握手协议保证数据传输的可靠性。

Fig.4 - Wi-Fi LAN structural diagram

Solar power supply module

The power supply is an integral part of this agricultural navigation positioning system. Solar modules and a rechargeable battery are adopted to supply power because solar energy is clean energy; it can be easily obtained and has zero emission. The lithium battery is charged by solar energy from the solar modules. The energy is stored in the battery to power the navigation system. The solar power supply diagram is shown in Figure 5.

太阳能供电模块

电源系统是农机导航定位系统设计的重要组成部分。本论文采用的供电方式是太阳能电池板和可充电电池结合的方法，太阳能是一种清洁能源，自获取、零排放。太阳能电池获取能量之后给锂电池充电，锂电池将能量存储起来给导航定位系统供电。太阳能供电系统如图 5 所示。

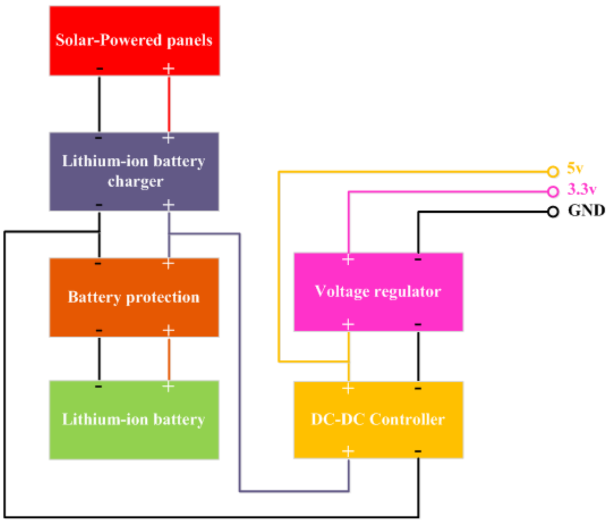

Fig.5 - Power supply diagram of solar power

(1) The solar module consists of 10 polycrystalline solar cells that are connected in parallel. The working voltage is 5 V, and I_{max} is 1.3 A.

(2) The rechargeable battery pack includes four sets of 18650 lithium batteries manufactured by Samsung Korea. Each battery is 2600 mAH, with a rechargeable voltage of 4.2 V, nominal output voltage of 3.7 V, and minimum output voltage of 2.8 V. The advantages of a lithium battery are small size and large capacity. It can also be repeatedly recharged and re-discharged.

(3) The controlling circuit of the solar module consists of CN3063 and its external circuits. CN3063 is employed as the battery recharging chip to control each single set of lithium battery in this solar power supply system. Inside the chip is an eight-digit analog–digital conversion circuit that can automatically adjust the recharging current according to the output capacity of the current from the input voltage source. Considering the worst situation is unnecessary. Hence, the output current from the input voltage source can be fully used. This solution is ideal for recharging solar energy.

(4) The voltage booster circuit of the system consists of CN5136 and its exterior circuits. CN 5136 is a DC–DC converter with high-efficiency pulse frequency modulation (PFM), and its I_{max} can be 500 mA. Power transistors are integrated inside CN5136 to minimize the number of external components. The output voltage from CN5136 can be set via the external resistance. The high-precision voltage reference guarantees the accuracy and low-temperature drift of the output voltage. The working voltage of CN5136 ranges from 2.7 V to 6 V, which is applicable for lithium batteries.

(5) The protection module of lithium batteries is a crucial part of the design. The module protects the battery from being over-charged or over-discharged and from experiencing short circuit and over-current caused by the integration of the G3PU chip with IM8205.

(6) The core processor of this system is STM32F103RBT6 powered by +3.3 V. The 5 V power should be converted to 3.3 V so that the micro-processor can be utilized. AS1117-3.3 is also applied in this study. It is a linear voltage regulator with low drop-out performance. It provides protection from over-current and over-heating to ensure the stability of the chips and power supply. Amendment technology is adopted during its manufacture, thereby ensuring that output voltage and reference source accuracy is within ±1%.

The power supply circuit is shown in Figure 6.

（1）系统所采用的太阳能电池板由十块“多晶硅太阳能环氧树脂滴胶板”并联构成，工作电压为5V，最大电流为1.3A。

（2）锂电池采用四节韩国三星18650锂电池并联供电，每节电池容量为2600mAH，充电电压为4.2V，标准输出电压为3.7V，最低输出电压为2.8V。锂电池具有体积小、容量大等优点，并且可以反复充放电。

（3）太阳能充电控制电路主要由CN3063及其外部电路组成，CN3063是可以用于太阳能电池供电的单节锂离子电池充电管理芯片。该器件内部包括8位模拟-数字转换电路，能够根据输入电压源的电流输出能力自动调整充电电流，不需要考虑最坏情况，可最大限度地利用输入电压源的电流输出能力，非常适合太阳能充电。

（4）系统的升压电路主要由CN5136及其外部电路组成，CN5136是一款高效率的脉冲频率调制型(PFM) DC-DC转换器，最大输出电流能力可以达到500mA。CN5136内部集成有功率晶体管，大大减少了外部元器件的数目。CN5136的输出电压可以通过外部电阻设置。片内高精度的电压基准源保证了输出电压的精度和低温度漂移。CN5136的工作电压范围为2.7V-6V，非常适合锂电池供电的应用。

（5）锂电池保护模块电路是本设计中的关键部分，此部分主要用集成电路芯片G3PU与IM8205组合搭建，负责锂电池的过充保护、过放保护、短路保护以及过流保护等功能。

（6）系统采用的核心处理器STM32F103RBT6是由+3.3V供电的，因此需要将升压得到的5V电源转化成3.3V以供微处理器使用。本论文采用AS1117-3.3这款芯片，它是一款低压差的线性稳压器，提供完善的过流保护和过热保护功能，确保芯片和电源系统的稳定性。同时在产品生产中应用先进的修正技术，确保输出电压和参考源精度在±1%的精度范围内。

电源模块电路图如图 6 所示。

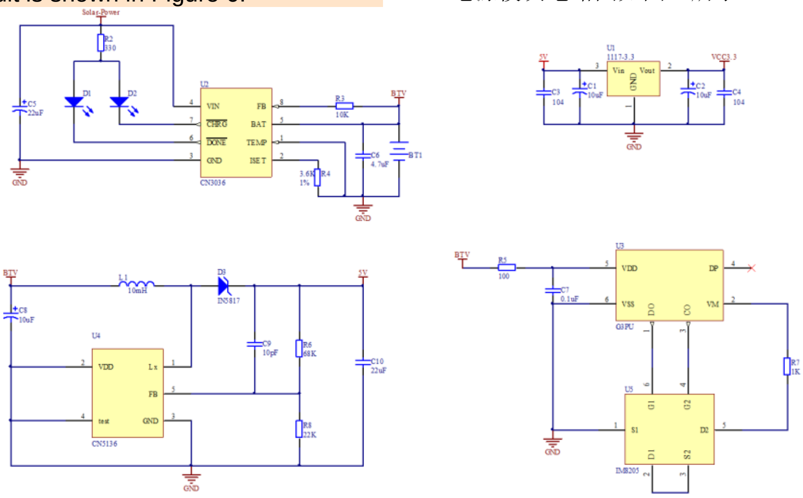

Fig.6 - Power circuit diagram

Design of PWM driving circuit

PWM control, a technology that modulates pulse length, modulates the duty circle to smoothly control the speed of electronic machinery. The developed system employs PWM technology to control electronic machinery. However, the amplitude voltage of the PWM signal reaches only 3.3 V in the micro-controller of this system. The electronic machinery can only be controlled when transferring level and improving the driving ability of the signal. Therefore, the abutment of a photon-coupled insulator and electronic machinery modules are adopted in this study.

Design of the Software in the System

GPS data processing

The GPS module and STM32 are connected by serial ports. The GPS module sends a standard NMEA-0183 instruction to serial ports each second. The program can handle received data during this period. When processing the positioning and navigation, time and latitude–longitude are the only required information. Instruction GPRMC includes all positioning-required data. Therefore, collecting GPRMC instruction and selecting requisite information based on the meaning of each segment data are the only tasks we need to perform. Figure 7 shows the collection and disposal process of GPS data.

PWM 驱动电路设计

PWM控制就是对脉冲宽度进行调制的技术即通过调制其占空比实现对电机转速的平滑控制。本系统就是采用PWM技术对电机进行控制。然而系统采用的微控制器输出的PWM信号的幅值电压只有3.3V，需要进行电平转换并提高信号的驱动能力才能控制电机的运转，因此在论文中采用光耦隔离器件和电机驱动模块进行对接。

系统软件设计

GPS 数据处理

GPS 模块与 STM32 之间通过串口进行通，GPS 模块每隔一秒向串口发送一条 NMEA-0183 标准的语句，程序可以在这个周期内将接收到的数据进行处理。在进行定位和导航处理中，只需要用到时间、经纬度信息。GPRMC 语句完整的包含了定位所需的所有数据信息。因此，只需要对 GPRMC 语句进行采集，然后根据各段数据的意义，提取出需要的数据信息。图 7 所示为 GPS 数据采集和处理流程。

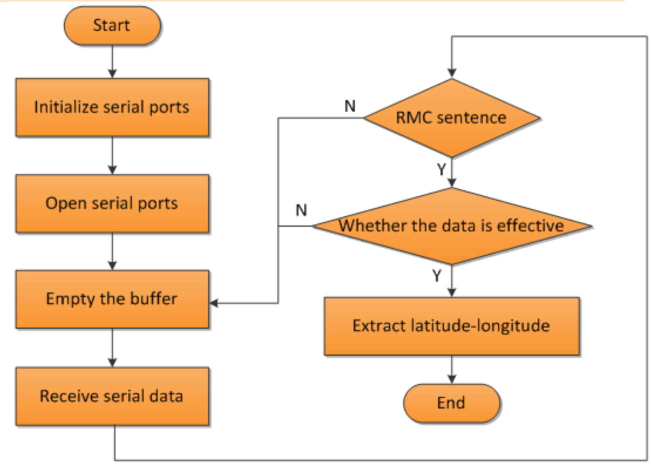

Fig.7 - GPS data processing

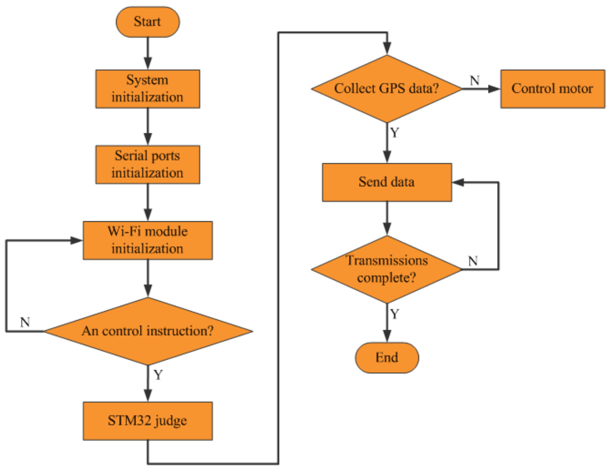

Fig.8 - Wireless data processing

Given that the standard NMEA-0183 instruction selects $GPXXX as the initial sign with enter or line break as a completed sign for each instruction, data can be judged whether they are RMC instructions as soon as they are written in buffer. The principle is to search RMC in strings. If it can be found, the next step is to return to the position where RMC is and if not, return to −1. If it is an RMC instruction, the next step is to judge whether the data are effective. Two standards are employed to judge whether the data are effective. The first standard is whether the data are complete, which can be judged by data length. The second standard is whether the locator data are effective, which can be judged by a specific data segment. V represents ineffective locator data, and A represents effective locator data. Information on latitude and longitude will be extracted if the data are effective. The first data segment after the initial sign is time. Following it are the positioning state, latitude, direction of latitude, longitude, and direction of longitude. Other data are of no importance because they are useless in positioning.

由于NMEA-0183标准的语句是以$GPXXX作为每条语句的起始标志，以回车或者换行符作为语句的结束标志，因此读入一行数据到缓冲区后，就可以判断这行数据是否是所需要的RMC语句，这主要通过在字符串中查找RMC，如果找到就返回RMC在的位置，否则返回-1。如果是RMC语句，则进行下一步判断，判断数据是否有效。数据是否有效有两个标准：第一，这行数据是否完整，这个可以通过判断数据长度来确定。第二，数据中有一个数据段专门用来表示这行数据是否为有效定位数据，V表示无效定位数据，A表示有效定位数据。如果数据有效，则进行经纬度等信息的提取。起始标志之后的第一个数据段是时间，接着是定位状态、纬度、纬度方向(N或S)、经度以及经度方向(W或E)，再之后面的数据不需要关心，因为在定位中用不到。

此外，从GPS模块中提取出来的时间和日期信息均为

Meanwhile, the information of time and date extracted from the GPS module is UTC time. Converting UTC time into local time is necessary. UTC time is similar to that of Greenwich's. Beijing time is adopted in China. Beijing belongs to the East Eight time zone, which is ahead of UTC time by eight hours. Eight hours should be added to UTC time when changing the time zone to obtain the local time. If UTC time is after 1600, Beijing time is in the next day, and the date should be changed.

UTC时间，因此需要将其转换为本地时间。UTC时间和格林威治时间相同，在我国，都采用北京时间，北京在国际时区中位于东八区，领先UTC时间8小时，因此在转化的时候，需要将UTC时间加上8小时获得本地时间。需要注意的是，如果UTC时间在16点之后，此时北京时间已经是第二天了，需要改变日期。

Wireless data transmission

Data form is called data frame when the Wi-Fi network is used. When performing serial transmission, byte throttling is implemented. Data from the terminal can be successfully transferred to the controller STM32 only when the system changes the form of data. The constraint mechanism of the Wi-Fi module S2W-M02 used in this study includes the fully automatic mode and the length of automatic framing. The forms of data can be freely transferred using this constraint mechanism to achieve data transmission between the serial port and the wireless network. The flowchart is shown in Figure 8.

无线数据传输程序设计

Wi-Fi 网络传输时，数据形式为数据帧；在串口传输时，为字节流。基于此，系统就需要先转换数据形式，才能将终端的数据成功地传输到 STM32 控制器。本文选用的 Wi-Fi 模块 S2W-M02 的约束机制中，包含“全自动方式”，和“自动组帧长度”，通过这种约束机制，可以成功地实现数据类型的转换，从而实现数据在串口和无线网络之间的传输。其传输流程图如图 8 所示：

Coordinate Transformation

The coordinate system WGS-84 (World Geodetic System) can directly obtain latitude–longitude from the GPS receiver, but most electronic maps do not use this coordinate system. Unifying coordinate systems is necessary to meet the requirements of the display of positioning points in electronic maps [9, 10]. In China, the coordinate systems of many electronic maps of cities are based on the elliptical coordinate system of Beijing 54 (BJ-54). Therefore, the WGS-84 coordinate must be converted into the BJ-54 coordinate. The Bursa–Wolfe model is used in coordinate transformation in this study [13]. The formula of the model transformation is as follows:

坐标转换

从 GPS 接收机得到经纬度属于 WGS-84 坐标系统 (World Geodetie System 1984)，而大多数的电子地图并不是采用 WGS-84 坐标系统。为满足电子地图显示定位点的需要，有必要统一坐标系统[9,10]。中国的许多城市电子地图的坐标系统是基于北京 54 的椭圆坐标系（北京-54）。因此，WGS-84 坐标必须被转换成北京 54 坐标。在本文中，使用 Bursa-Wolf 模型进行坐标变换[13]。模型的变换公式可列为：

$$\begin{bmatrix} X_{54i} \\ Y_{54i} \\ Z_{54i} \end{bmatrix} = \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} + (1+\mu)\begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} + \begin{bmatrix} 0 & \varepsilon_Z & -\varepsilon_Y \\ \varepsilon_Z & 0 & \varepsilon_X \\ \varepsilon_Y & \varepsilon_X & 0 \end{bmatrix}\begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} \quad (3)$$

where X_0, Y_0, and Z_0 are translational transformation parameters; ε_X, ε_Y, and ε_Z are rotation parameters; and μ is the zoom scale transformation factor. Seven parameters are used in the above-mentioned formula. Therefore, three or more common points and their coordinates in two coordinate systems are required when calculating transformation parameters. When only three common points are available, the translation, rotation, and zoom scale parameters in the formula can be directly calculated with the plane coordinates of two common points. When more than three common points are available, seven parameters can be calculated according to the principle of least squares. Formula (3) can then be written as follows:

其中X_0，Y_0，Z_0为平移转换参数，ε_X，ε_Y，ε_Z是旋转参数，μ为缩放尺度变换因子，上式中共7个参数，因此，一般说来，需要有三个或三个以上的公共点，利用它们在两个坐标系中的坐标来求出转换参数。当只有三个公共点时，式中的平移、旋转和尺度缩放参数，可由两个公共点的平面坐标直接求得。当公共点个数多于三个时，可以按最小二乘原理求解七参数，这时(3)式可写成如下形式：

$$\begin{bmatrix} X_{54i} \\ Y_{54i} \\ Z_{54i} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & X_{84i} & 0 & -Z_{84i} & Y_{84i} \\ 0 & 1 & 0 & Y_{84i} & Z_{84i} & 0 & -X_{84i} \\ 0 & 0 & 1 & Z_{84i} & -Y_{84i} & X_{84i} & 0 \end{bmatrix}\begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \\ \mu \\ \varepsilon_X \\ \varepsilon_Y \\ \varepsilon_Z \end{bmatrix} + \begin{bmatrix} X_{84i} \\ Y_{84i} \\ Z_{84i} \end{bmatrix} \quad (4)$$

$$C_i=\begin{bmatrix}1&0&0&X_{84i}&0&-Z_{84i}&Y_{84i}\\0&1&0&Y_{84i}&Z_{84i}&0&-X_{84i}\\0&0&1&Z_{84i}&-Y_{84i}&X_{84i}&0\end{bmatrix} \quad (5)$$

$$B_i=[X_{84i}-X_{54i},Y_{84i}-Y_{54i},Z_{84i}-Z_{54i}]^T \quad (6)$$

Coordinate Transformation

The coordinate system WGS-84 (World Geodetic System) can directly obtain latitude–longitude from the error equation can be obtained, and its matrix form is as follows:

坐标转换

从GPS接收机得到经纬度属于WGS-84坐标系统(World

则可以列出误差方程，其矩阵形式为：

$$V=AR+L \quad (7)$$

where $R=[X_0,Y_0,Z_0,\mu,\varepsilon_X,\varepsilon_Y,\varepsilon_Z]^T$, $V=[V_X,V_Y,V_Z]^T$, $L=[B_1,B_2,...,B_n]^T$, and $A=[C_1,C_2,...,C_n]^T$.

If each measurement is supposed to be equal in accuracy, the least square solution of the transformation parameter can be expressed as

其中 $R=[X_0,Y_0,Z_0,\mu,\varepsilon_X,\varepsilon_Y,\varepsilon_Z]^T$，$V=[V_X,V_Y,V_Z]^T$，$L=[B_1,B_2,...,B_n]^T$，$A=[C_1,C_2,...,C_n]^T$。

若认为各观测量是等精度的，则可得转换参数的最小二乘解为：

$$R=(A^TA)^{-1}A^TL \quad (8)$$

Finally, the computing result is *R* with seven transformation parameters. After transforming the coordinates through the above mentioned models, the WGS-84 coordinate can be transformed into the BJ-54 spatial rectangular coordinate. Gauss projection is then conducted, and the spatial coordinates are transformed into plane coordinates that are compatible with electronic maps. The process flowchart is shown in Figure 9.

最后解得 *R*，求得 7 个转换参数。再利用上述模型进行坐标转换，就可以把 WGS-84 坐标转换到北京 54 空间直角坐标系下，然后进行高斯投影,把空间直角坐标转换成电子地图所用的平面坐标系中。其程序流程图如图 9 所示。

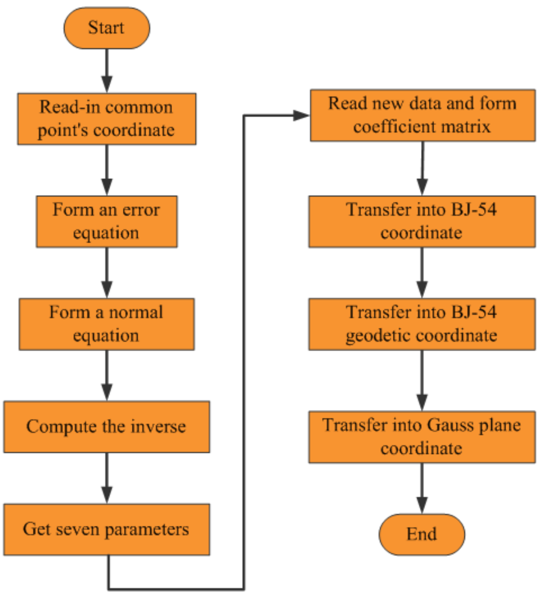

Fig.9 - Coordinate transformation

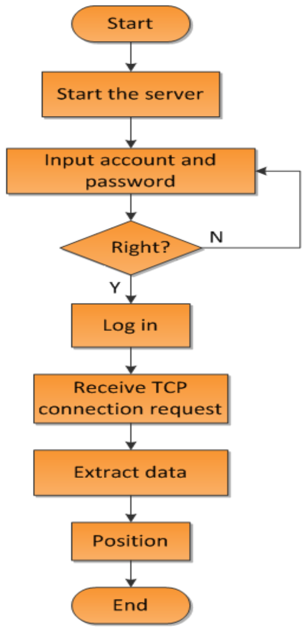

Fig.10 - Sever data processing

Server design

The program of TCP/IP agreements employs the client–server model. In server-side programs, data from the client side are received as soon as connection request data are found. The corresponding positions are displayed on maps. Figure 10 shows a flowchart designed for servers.

服务器设计

TCP/IP 协议的程序使用的是客户端/服务器模式。在服务器端的程序中，通过监听本地主机的一个端口，一旦有客户端的连接请求，就接收来自客户端的数据，并在地图上显示出相应的位置，图 10 为服务器设计流程图。

RESULTS

A low-cost system with built-in-GPS agricultural machinery is developed in this study according to the abovementioned principles of operating the software and hardware. The hardware system is shown in Figure 11.

结果

根据前面所述的软硬件原理，本文开发了一套低成本的农机 GPS 导航定位系统，其硬件系统如图 11 所示。

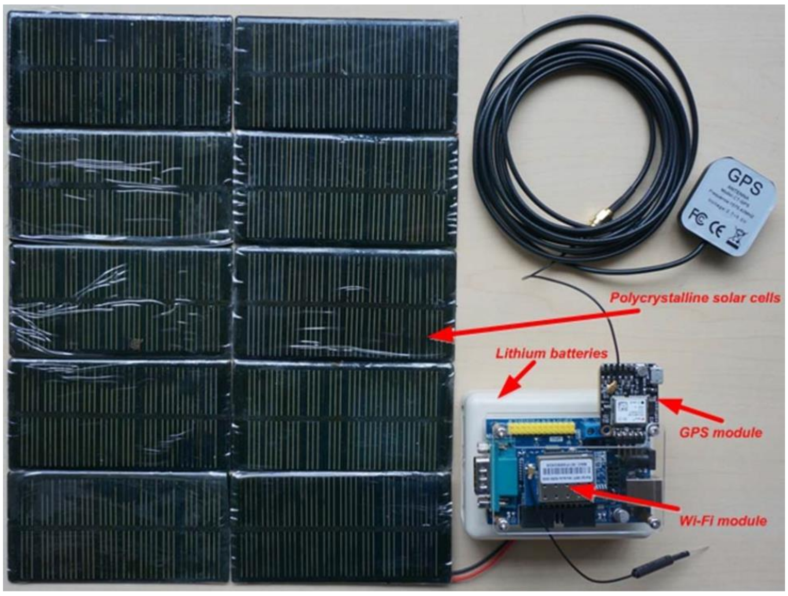

Fig.11 - Hardware system

Two experiments are conducted to verify the navigation precision of the designed system. The first experiment aims to measure the reaping area [5], and the second one aims to obtain the location of the agricultural machine. In Experiment 1, the reaping pitches range from 112 m^2 to 2166 m^2. Most pitches are rectangular, and several are irregularly shaped. A comparison of the measured reaping and actual areas is shown in Table 1.

为了验证该系统的定位精度，本论文通过两种实验进行测试验证，一种是通过测量收割面积[5]，一种是获取农机行车位置信息。实验 1，通过对实际的田间收割地块进行测量，收割地块大小从 112m^2到 2166 m^2，地块区域大多数是矩形，有些是不规则形。将测量得到的收割面积与地块实际面积的对比统计如表 1 所示。

Table 1

Area measurement table

No.	Measurement area(m^2)	Actual area(m^2)	Error (%)
1	131.14	112.00	1.70
2	466.03	408.37	1.41
3	903.19	763.82	1.82
4	1329.83	1321.57	0.62
5	1883.58	1873.98	0.51
6	2174.98	2166.32	0.39

The measured and actual errors can be stabilized to less than 3%, as shown in Table 1, which meets the requirement of within the 5% error standard. Table 1 shows that the error between the statistic area of the relatively large area and the actual reaping area is small (less than 1%).

The server interface is designed with Qt. The multi-threaded approach is applied to enhance system performance. A thread is responsible for processing wireless data. Another thread mainly processes the map display and user input. The interface is shown in Figure 12.

从表1所列的系统所得的收割面积与实际收割面积之间的误差一般能稳定在3%以下，符合现行农机跨区收割时对收割面积统计所允许的5%的误差要求。而且从表中可以看出，在收割较大面积时系统的统计面积与实际收割面积的误差相对较小，一般在1%以下。

服务器界面采用 QT 进行设计。为了提高系统的性能，本论文使用多线程的方法。一个线程负责处理无线给的数据。另一个线程主要处理地图显示和用户输入。其界面如图 12 所示。

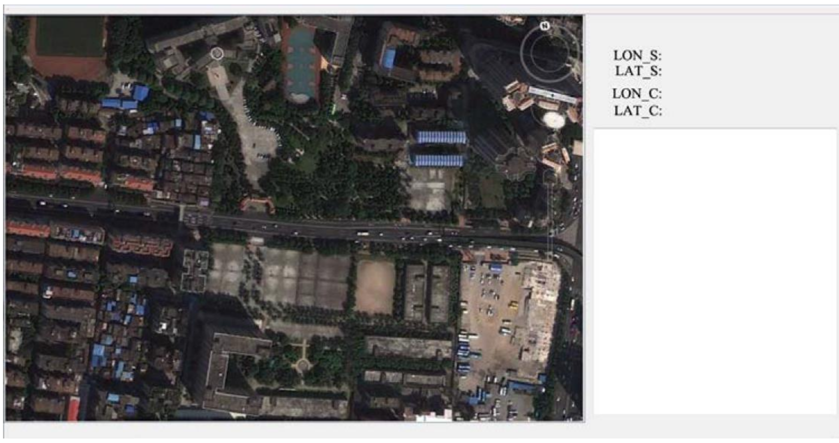

Fig.12- Server interface

In Experiment 2, an agricultural university is selected as the experimental area. This area is from (113° 16′ 28.00″ E to 113° 16′ 45.7″ E) to (23° 06′ 81.02″ N to 23° 06′ 34.12″ N). The experiment adopts real-time field data. The position of the agricultural vehicle is accessed by GPS, and the data are sent to server-side maps via Wi-Fi to test the system's accuracy and reliability. The result (shown in Figure 13) indicates that the accuracy of locator data satisfies the operating qualification of the system but has errors when matched with real maps. Such errors are probably caused by the difference between the database of electronic maps and orientation modules. Corrections should be made on positioning data in the late stages of development.

实验 2 以某农业院校为实验区域，这一区域为东经 113° 16′ 28.00″ 到东经 113° 16′ 45.7″，北纬 23° 06′ 81.02″ 到 23° 06′ 34.12″，采用实地实时采集数据，利用系统中的 GPS 模块获取农用车辆行驶过程中的位置信息，然后将采集的数据通过 Wi-Fi 的方式传到服务器端的地图进行显示，从而验证系统的准确性和可靠性，其结果如图 13 所示。测试结果表明，定位数据的精度满足了系统的使用要求，但是和实际电子地图之间的匹配有一定的误差，这可能是电子地图的数据库和定位模块之间存在的系统的差异，在后期的开发中，需要对定位的数据作出修正。

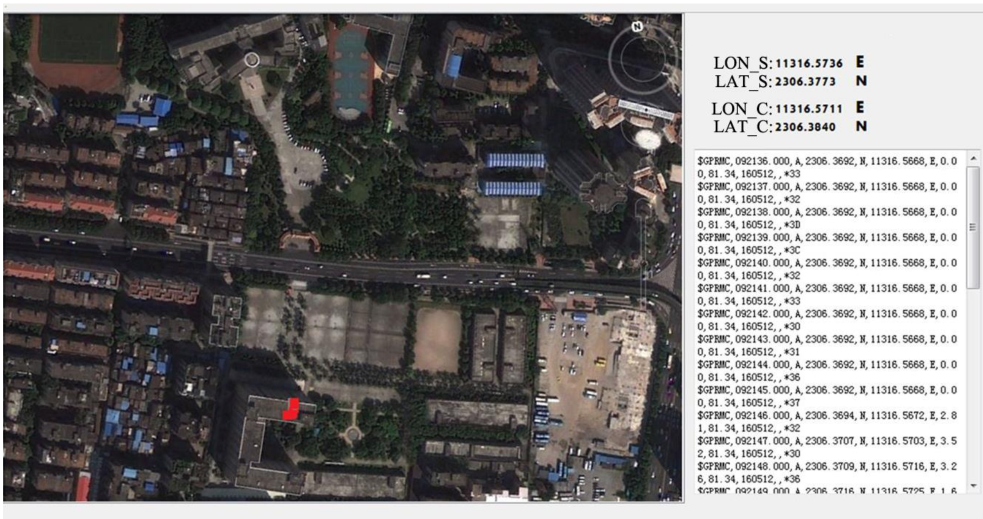

Fig.13 - Demonstration of agricultural machinery positioning

CONCLUSIONS

Intelligent agricultural machinery, which is driven and supported by modern science and technology, is an integral part of precision agriculture and development of intelligent agriculture. On one hand, it can improve working efficiency and production output. On the other hand, it can minimize labor intensity and injury. In the operation process of intelligent agricultural machinery, the intelligent function depends on how precisely the machine can locate and navigate in farming fields. GPS is the first option in sensing the location. At present, the common agricultural GPS facility is the double-satellite

结论

现代科学技术支撑的智能农业机械被认为是精准农业和智慧农业发展的关键设备，发展智能农业机械一方面可以提高生产效益和劳动生产率，另一方面可以大大减轻在农业实施过程中农民的劳动强度和减少对农民的安全伤害。然而农业机械的智能化作业其功能往往在依赖于它在农田中的精确定位导航。一般来说，对农田位置的精确感知，GPS 是的首选设备。目前，常见的农用 GPS 设备往往是

double-frequency high-cost receiver, which hinders the popularization and application of such systems. Agricultural navigation specialists also integrate inertial navigation with GPS to increase the locating precision. However, the inertial navigation device increases the cost of the system. Therefore, a low-cost system with built-in-GPS agricultural machinery was designed in this study based on the actual demand for low cost and high precision in agricultural production. The key software and hardware technology was analyzed and applied to the built-in-GPS agricultural machinery, and all the functions were accomplished to satisfy the requirements of agriculture location and realize automation and modernization.

双星双频接收机，但由于其价格高昂成为 GPS 精确定位在农业生产领域普及应用的障碍。除此以外，为了提高定位精度，还可以把惯性导航设备与 GPS 进行结合，但惯导设备的引入也大大增加了系统的定位成本。因此，本文从农业生产中低成本高精度定位的实际需求出发，开发基于低成本 GPS 设备的农机导航定位系统。通过对软硬件的关键技术进行了系统学习和理论研究，并将结果应用到嵌入式农机 GPS 导航定位系统的设计与功能实现中，最终完成系统的功能，满足农田定位精度要求，实现了农业机械的自动化和现代化。

ACKNOWLEDGEMENT

This study was funded by Guangdong Natural Science Foundation (No.S2013040014993), State Scholarship Fund (CSC No.201408440326), Pearl River S&T Nova Program of Guangzhou (No. 201506010035), and University-sponsored Research Project of Guangdong University of Finance and Economics(No. 14GLL63001).

致谢

本论文得到广东省自然科学基金资助（项目号：No.S2013040014993），国家留学基金资助（项目号：CSC No.201408440326），广州市珠江科技新星专项资助（项目号：No. 201506010035），广东财经大学校级科研项目资助(项目号：No. 14GLL63001)。

REFERENCES

[1]. Backman J, Oksanen T, Visala A. (2012) - *Navigation system for agricultural machines: Nonlinear Model Predictive path tracking*, Computers and Electronics in Agriculture, vol. 82, pp. 32-43;

[2]. Bora G C, Nowatzki J F, Roberts D C. (2012) - *Energy savings by adopting precision agriculture in rural USA*, Energy, Sustainability and Society, vol. 2, no. 1, pp. 1-5;

[3]. Darr M. (2012) - *CAN Bus technology enables advanced machinery management*, Resource: Engineering and Technology for Sustainable World, vol. 19, no. 5, pp. 10-11;

[4]. Huang G, Han L, Liu X, Yang Z. (2012) - *Establish of evaluation system for integrated agricultural mechanization engineering technology*, Transactions of the Chinese Society of Agricultural Engineering, vol. 28, no. 16, pp. 74-79;

[5]. Ji B, Li J, Yang Y, Zhang S. (2012) - *A Real-time Measurement Based on GPS Which Was Designed for Calculating the Harvest Area of Combine*, Chinese Agricultural Mechanization, no. 6, pp. 89-92.

[6]. Kic P, Zewdie R. (2013) - *Agricultural mechanization in sub Saharan Africa for a better tomorrow*, AMA, Agricultural Mechanization in Asia, Africa and Latin America, vol. 44, no. 1, pp. 73-84;

[7]. Oni K C. (2013) - *Promoting agricultural mechanization in Nigeria through the intervention of Japanese Government*, AMA, Agricultural Mechanization in Asia, Africa and Latin America, vol. 44, no. 4, pp. 25-26;

[8]. Ozsoy K, Bozkurt A, Tekin I. (2013) - *Indoor positioning based on global positioning system signals*, Microwave and Optical Technology Letters, vol. 55, no. 5, pp. 1091-1097;

[9]. Philip Chen C L, Zhou J, Zhao W. (2012) - *A real-time vehicle navigation algorithm in sensor network environments*, IEEE Transactions on Intelligent Transportation Systems, vol. 13, no. 4, pp. 1657-1666;

[10]. Shi Y, Wang L, Zhou Y. (2011) - *Coordinate transformation based on projection plane between three-dimension geocentric coordinate system and regional*

参考文献

[1]. Backman J, Oksanen T, Visala A. (2012) - *农业机械导航系统:非线性模型预测行车路径*, 农业中的计算机和电子技术, 第 82 卷, 32-43;

[2]. Bora G C, Nowatzki J F, Roberts D C. (2012) - *在美国采用精准农业实现农村节能*, 能源，可持续发展和社会, 第 2 卷, 第 1 期, 1-5;

[3]. Darr M. (2012) - *采用 CAN 总线技术提高机械管理先进性*, 资源:农业工程与技术, 第 19 卷, 第 5 期, 10-11;

[4]. 黄光群, 韩鲁佳, 刘贤, 杨增玲. (2012) - *农业机械化工程集成技术评价体系的建立*, 农业工程学报, 第 28 卷, 第 16 期, 74-79;

[5]. 季彬彬, 李俊, 杨玉萍, 张森. (2012) - *基于 GPS 的联合收割机收割面积实时统计方法*, 中国农机化, 第 6 期, 89-92。

[6]. Kic P, Zewdie R. (2013) - *为了更好的明天在撒哈拉以南非洲发展农业机械化*, 亚洲非洲和拉丁美洲农业机械化, 第 44 卷, 第 1 期, 73-84;

[7]. Oni K C. (2013) - *日本政府推动下的尼日利亚农业机械化*, 亚洲非洲和拉丁美洲农业机械化, 第 44 卷, 第 4 期, 25-26;

[8]. Ozsoy K, Bozkurt A, Tekin I. (2013) - *基于全球定位系统的室内定位*, 微波和光学技术快报, 第 55 卷, 第 5 期, 1091-1097;

[9]. Philip Chen C L, Zhou J, Zhao W. (2012) - *一种在传感器网络环境下的实时车辆导航算法*, IEEE 智能交通系统汇刊, 第 13 卷, 第 4 期, 1657-1666;

[10]. 施一民, 王丽华, 周拥军. (2011) - *基于投影面由三维*

coordinate system, Journal of Tongji University, vol. 39, no. 1, pp. 121-123, 128;

[11]. Wakabayashi K, Imou K, Li M, Sumida N, Inoue H, Ibuki T. (2013) - *Positional measurement of an agricultural vehicle at different speeds using omnidirectional vision*, Applied Engineering in Agriculture, vol. 29, no. 2, pp. 289-294;

[12]. Wei L, Zhang Q, Yan H, Liu Y. (2011) - *GPS automatic navigation system design for XDNZ630 rice trans-planter*, Transactions of the Chinese Society of Agricultural Machinery, vol. 42, no. 7, pp. 186-190;

[13]. Yao Y, Huang C, Li C, Kong J. (2012) - *A new algorithm for solution of transformation parameters of big rotation angle's 3D coordinate*, Geomatics and Information Science of Wuhan University, vol. 37, no. 3, pp. 253-256.

地心坐标系到区域性坐标系的转换, 同济大学学报, 第 39 卷, 第 1 期, 121-123, 128;

[11]. Wakabayashi K, Imou K, Li M, Sumida N, Inoue H, Ibuki T. (2013) - *使用全方位视觉测量不同速度下的农用车辆位置*, 农业应用工程, 第 29 卷, 第 2 期, 289-294;

[12]. 伟利国, 张权, 颜华. (2011) - *XDNZ630 型水稻插秧机 GPS 自动导航系统*, 农业机械学报, 第 42 期, 第 7 卷, 186-190;

[13]. 姚宜斌，黄承猛，李程春，孔建. (2012) - *一种适用于大角度的三维坐标转换参数求解算法*, 武汉大学学报(信息科学版), 第 37 卷, 第 3 期, 253-256.