Construction and experiment of phenotyping system based on field wheat

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Abstract. In response to the actual needs of informatization of the collectors engaged in the whole process of field wheat production, this paper constructed a phenotyping system based on field wheat, which was of great significance to improve the efficiency of data collection and reduce the labor intensity of the collectors. Based on the collection and management of phenotyping traits data from sowing to harvesting, combined with barcode recognition, database technology and mobile terminal APP technology, a field wheat phenotyping system was designed and developed, and the data was compared with collection efficiency by manual collection methods. The system was composed of the phenotyping trait collection system APP and the phenotype trait management system Web. The APP development architecture used client/server (C/S), the development language used Java, and the phenotyping traits were collected. As the core, upload collected data to the Web to realize data exchange and sharing between APP and Web; Web development architecture used browser/server (B/S) to realize the distribution of test tasks in the wheat production process, data management, report generation center, and statistical analysis. Compared with the manual data collection method, the application of APP could improve the data collection efficiency by 72%. This system had been realized the rapid collection, efficient management and automatic analysis of wheat phenotyping traits, which ensured the standardization of data collection and management, and improved the efficiency of data collection and utilization. The system could support the phenotyping collection and management of other crops, and it is also suitable for field phenotyping surveys in various industries such as fruits, vegetables and so on.

1. Introduction

Henan Province is the main wheat producing area in my country. In the past five years, the planting area has stabilized at more than 566.7 hectare, accounting for nearly a quarter of the country’s total wheat planting area, with a total output of 375.3 kilogram, which is of great importance to the task of maintaining my country’s food security [1]. Since the formation of wheat yield is closely related to phenotyping traits, the development of a field wheat phenotyping system has important reference value...
for improving the efficiency of data collection and reducing the labor intensity of collectors. In actual production, the collection and management of wheat phenotyping traits have the following problems: 1) The collection methods still generally use manual measurement, paper records, empirical decision-making and other work methods, and then return to the room for secondary data collation. Problems such as backward collection methods, time-consuming and labor-intensive collection of data, large human errors, and difficult storage of paper records; 2) The management method is generally based on Excel spreadsheets, and there are problems such as irregular data management and inconsistent standards; 3) The analysis methods have the problems of large data volume and low data utilization rate, data statistics results can’t be obtained quickly; 4) The existing collection system of some scientific research teams does not match the actual needs very well, which leads to cumbersome operation and low utilization rate. Aiming at the above-mentioned problems in the collection and management of phenotyping traits, how to quickly and accurately obtain wheat phenotyping traits is still a hot topic for scientists.

With the in-depth development of crop phenotyping technology, the collection of crop phenotyping traits has been developed to a certain extent, but it hasn’t yet been able to meet the actual needs of crop research [2-7]. In recent years, domestic and foreign experts and scholars have carried out research and discussion on performance data collection systems. Zang et al [8] developed a wheat agronomic traits data collection and management system, which realized the rapid collection, management and analysis of test materials. Zhang and Li [9] designed a wild plant data collection system based on distributed locations, uploading plant photos from the established plant library to a cloud server for identification. Crescente J M et al [10] developed the Phenobook open source software for remote data collection and mobile phenotyping data collection, such as Web-based experimental design and data input. Scholars at home and abroad have explored the acquisition of field crop phenotype information, and have been initially applied to the research of crop ridge number, plant height, leaf area index, ear test species, and disease image extraction [11-13]. In summary, the above systems have conducted a lot of research on the mobile terminal field data collection and query. At present, there are few reports on the field wheat phenotyping system under different cultivation and breeding experiments. Such research is very important for wheat in Henan Province. Efficient collection, management and analysis of phenotyping traits have important application value. In view of this, the research combines the actual needs of informatization in the whole process of wheat production, with the goal of changing the traditional data collection method and improving the efficiency of phenotyping trait management, and constructs a field wheat phenotyping system to realize the digital collection of phenotyping information, standardized management and science chemical analysis and other functions, so as to solve many problems and deficiencies in the collection and management of traditional phenotyping traits, and provide references for the collection and management of phenotyping traits of other crops.

2. SYSTEM DESIGN

In this study, according to the information demand of collection and management of phenotypic traits in wheat production, a field wheat phenotyping system was designed based on multiple field surveys, combined with the author’s years of field wheat experiments. The system adopts a mixed architecture of C/S and B/S. APP is installed on the mobile terminal PDA, and the Web is accessed by a PC browser; the APP data interface on the mobile terminal PDA is connected to the management software of the Web. The overall structure of the system is shown in figure 1.
2.1. Data Layer
The data layer is located in the database server, which provides data services for the business logic layer. The Web is composed of basic information data and business data uploaded at various test stations, and the assigned test tasks are updated to the server in real time. The APP can obtain test tasks issued by the Web in real time, phenotyping traits were collected according to the test tasks, and upload the collected data to the server to provide data sources for the Web and barcode printers.

2.2. Business logic layer
The business logic layer is mainly used for business logic processing, which is the core part of system function realization. In this system, the user submits a form operation on the browser page, sends a request to the server, the server receives and processes the request, and then returns the data requested by the user (webpage files, pictures, sounds, etc.) to the browser. The APP receives user tasks from the server and uploads the collected data to the server wirelessly to provide the required data for the Web.

2.3. User layer
User layer is the window for user to interact with the system, which is used to receive user input, display and operate data layer data.
3. System Implementation

3.1. Development Environment
The APP development framework adopts the C/S structure, Android Studio as the development platform, and using network interaction and annotation framework technology to realize data interaction with the Web. The web development architecture adopts the B/S structure, Microsoft Visual Studio 2017 is used as the development platform, the MVC structure framework is adopted, C# is written, the development environment uses Eclipse, and the website services and databases are accessed through lambda expressions.

3.2. Database design
Database design is an important guarantee for system data storage and business data processing. It is necessary to strictly follow the security design principles to ensure data security. The database includes system management data tables, basic data tables and phenotyping character data survey tables. The system management data table includes the user table and the user group table, which are mainly used for user login and the administrator to manage the user role data table. The basic data table includes administrative area data table, test station management data table, wheat information data table, variety data table, trait management data table, etc. The phenotyping character data questionnaire includes the phenological period record form, the stress resistance record form, the disease and insect pest questionnaire, the main character questionnaire, the yield characteristic questionnaire, etc.

3.3. System implementation

3.3.1 Implementation of APP
In order to realize the collection of wheat phenotyping traits, the main functions of the APP include six modules: template selection, scanning code positioning, electronic labeling, data entry, data upload and test layout. 1) The traits need to be collected for the test, it can be quickly added from the trait indicators, and the selected traits form the template of the test. The template is named after the date of the day. 2) Scanning code positioning: Identify the bar code information on the wheat plant through the laser scanning gun that comes with the mobile terminal, and enter the trait indicators that need to be collected. 3) Electronic tags: The electronic tag binding function is provided in the test layout, and the phenotyping traits of wheat plants can be collected through the UHF that comes with the mobile terminal. 4) Data entry: Phenotypic traits were collected according to the test requirements, and the data could be modified, viewed and saved in real time. 5) Data upload: It includes data query, upload, and upload of phenotyping character collection data to the Web. 6) Test layout: It takes the test plot as a unit, the field layout is automatically generated according to the test task.

The APP is deployed on the mobile terminal and is mainly used for real-time collection of field observation and observation trait data to realize the rapid positioning, collection and query of wheat plants. At the same time, the App’s collection of traits templates can be customized, allowing users to add traits and view the field layout at any time. In terms of data entry methods, it supports offline collection of trait data, realizing the dual choice of voice recognition entry and manual entry; after APP data collection, upload the collected data to the Web through wired or wireless methods.

3.3.2 Implementation of Web
Web is the main program. In addition to receiving the data collected by APP, it includes accurate management, query and statistical analysis from the beginning to the end of the wheat experiment design. Through the test design module, the tasks undertaken by each test site are synchronously distributed to the APP, the data collected by the APP is uploaded to the Web, and the data uploaded by the APP is reviewed, inquired and analyzed by the Web. The system is deployed on the data center computer and is the core part of the entire system. The data center exchanges data with the APP, and the collected data is stored in the user's local server to prevent data tampering.
According to business logic and demand analysis, Web is divided into five major functional modules: system management, experiment design, data management, report center, and statistical analysis. 1) System management: including administrative area, character management, user management and user group management. The administrative area is used to select the province, city, and county area where the experiment is located; the trait management is used to customize the addition of various quantitative and qualitative traits; the user management is used to set the role permissions of various users; the user group management is for users Role permissions are managed. 2) Test design: including basic test information, plot layout and test tasks. The basic information of the test uses the test plot as a unit to record the basic soil fertility, meteorological data, field management and other information; the plot layout is based on the different test purposes, and the field layout is automatically generated according to the test task; the test task has the characteristics of the test collection. It can realize the real-time distribution of multi-point test tasks and synchronize them to the APP. 3) Data management: including all data summary tables, quantitative trait summary tables and qualitative trait summary tables. By setting query conditions, you can view different types of collected trait data for the test, with data query, review, modification, retrieval, export, and printing functions. 4) Report center: It associates the information contained in the report with the database, and automatically completes the statistics and summary of the information according to the template provided by the management unit, and generates the corresponding report. It has functions such as data query, retrieval, export, and printing. 5) Statistical analysis: Select the test name and data collection time to be analyzed, and output a list of phenotyping traits measured in the test within a certain period of time to realize statistical analysis of various phenotyping traits.

4. Test Verification

4.1. Manual and APP data collection test plan
In order to test the efficiency of mobile terminal APP data collection, manual and mobile terminal tests were used to compare the data collection efficiency. The main target is the field front-line personnel engaged in wheat experiments. Technical training and actual operation and other tracking services are provided before application to ensure standardized collection and standardized management of wheat agronomic traits data, while establishing scientific and standardized case demonstrations. The following is an example of data collection during the mature period of wheat regional trials at the Modern Agricultural Science and Technology Experimental Demonstration Base of Henan Academy of Agricultural Sciences in May 2020. Each wheat variety is planted in 6 rows, the row length is nine metre, the row width is 1.5 metres, the row spacing is twenty centimeter, the planting density is 2.7 million/hm2, three repetitions, random block arrangement, according to the test requirements, each plot is in order perform phenotyping trait collection. The phenotyping trait indicators collected this time are not affected by the weather and can be directly collected. The eight phenotyping traits (variety number, maturity period, plant height, maturity phase, panicle type, panicle length, grain color, image) commonly measured in the experiment were selected as the data collection objects, and were produced by Chengdu Fuliye Electronic Technology Co., Ltd. Fu Liye C7 mobile terminal is used as a data collection device. The data format includes common forms such as text, value and photo. The character measurement standard refers to the "Technical Regulations for Agricultural Wheat Variety Test-Wheat". In response to the actual needs of users, six front-line personnel engaged in wheat field trials were selected. After thirty minutes of on-site practical operation training, they were randomly divided into three groups with two people in each group. A total of six experimenters were collected manually, randomly divided into three groups, two people in each group, collected according to the character collection standard, one person measured the selected eight phenotyping trait data, took pictures, entered Excel tables and renamed pictures, one person recorded test time for collecting the eight phenotyping traits. The test takes the average time consumed to complete the data collection of 8 phenotyping traits of a single plant as the measurement standard, and the test results are averaged.
4.2. Time-consuming comparative test of manual and APP data collection
Manual data collection mainly includes the following four operating procedures: (1) Record observation data in a notebook; (2) Take photos with a camera; (3) Record the data in the notebook into Excel for archiving; (4) Record The captured photos are exported and renamed. When the APP collects wheat phenotyping traits, it only needs to record the data to the device, and the other three steps are synchronized to the Web and automatically completed. It can be seen from Table 1 that the average time for the three groups of people to manually collect data is 612.3 s, which saves an average of 39.6% of the time in the data recording link, and the average time of entering the data in the logbook into Excel saves 38.4%. The average time for the same group of people to collect data using APP is 171.3 s. Compared with manual data collection, the application of APP not only eliminates the need for photographing, data entry and picture renaming, but also improves data collection efficiency by 72%.

| Acquisition steps | Average time used by manual recording/s | Average time used by APP recording/s |
|-------------------|----------------------------------------|-------------------------------------|
|                   | Group 1 | Group 2 | Group 3 | Group 1 | Group 2 | Group 3 |
| Data recording    | 234     | 251     | 243     | 167     | 176     | 171     |
| Photograph        | 78      | 71      | 69      |         |         |         |
| Data entry        | 229     | 245     | 232     |         |         |         |
| Professional rename | 62    | 59      | 64      |         |         |         |
| Total             | 603     | 626     | 608     | 167     | 176     | 171     |

4.3. Application of the system
Since 2017, the field wheat phenotyping system has been promoted and applied in scientific research institutions, institutions of higher learning, etc. In the process of using APP, it can receive real-time collection of multiple test tasks at the same time, and support multiple people to share the same collection template, which greatly improves the efficiency of data collection and eliminates the most time-consuming secondary input process of traditional manual data collection. According to the requirements of collection tasks in the field, the data exchange content with the web can be flexibly adjusted to improve the efficiency of data collection. Web can flexibly adjust the collection fields and thresholds of phenotyping traits according to user needs, reducing human error and intervention. At present, the data collected from the wheat experiment in 2021 is continuously being added, and the system is operating stably. After long-term testing and continuous updating, the system has a reasonable design, simple interface operation and convenient use. However, some shortcomings have been found in practical applications, for example, a large number of collected pictures can only be viewed and retrieved, without deep excavation. Therefore, in future research, we will focus on applying machine vision and deep learning technology to this system, so as to improve the efficiency of data utilization. Further research and discussion are needed in the future.

5. Discussion and Conclusion
Traditional test data is often managed and analyzed based on Excel, and it is impossible to perform preprocessing such as batch correction and logical judgment on a large number of test data. This brings great hidden dangers to the accuracy of later variety evaluation and decision-making [14]. The system development in this study is based on the existing wheat varieties test technical regulations and data standards, and focuses on the actual needs of data collection and management informationization in the whole process of wheat production, and realizes the accurate collection of phenotyping traits data of wheat from sowing to harvesting. The problems of data collection and management in the whole process
of wheat production were effectively solved. It is consistent with the client APP, which realizes the unification of data collection and storage standards, and provides a good foundation for data sharing, analysis and utilization.

Huang and Li [15] designed and developed a breeding field information collection system based on mobile smart devices. They mainly discussed the rapid entry of breeding field data, dynamic configuration forms, data validity verification and methods to ensure data security. Li and Yang [16] designed a wheat breeding information management system for effective management, comprehensive analysis and utilization of wheat trait data and other related information, which realized the scientific management of wheat breeding information. Zhang et al [17] developed a pear breeding information management and collection system based on the pear germplasm resource data standard, which realized the rapid collection and transmission of pear breeding information in the field. The above research is a field crop breeding information collection and management system based on a single software, but there are deficiencies in voice recognition, test layout, multiple test task reception, and collection template sharing. The client APP designed in this research supports the functions of scanning code positioning, offline data collection, data uploading, etc., and realizes the data exchange and sharing between the client APP and the Web; the Web browser realizes the real-time distribution of multi-point test tasks, which is convenient for many years. The collection of multi-point regional test data and the generation of the report center provide a good foundation for data analysis and utilization.

With the rapid development of machine vision technology and artificial intelligence technology, the field wheat phenotyping technology has been greatly enriched and perfected. Based on this, the actual needs of informatization around the whole process of field wheat production, this study designed a field wheat phenotyping system. It has the following characteristics:

1) APP adopts C/S development architecture, which has the characteristics of simple deployment, convenient operation, flexible setting and friendly interface. Users can quickly and real-time collect wheat phenotyping traits through the APP anytime and anywhere, which solves the problems of backward data collection methods in the whole process of wheat production and time-consuming and labor-intensive data recording.

2) Web adopts B/S development architecture, which has the characteristics of stable operation, convenient maintenance, good compatibility and strong cross-platform capabilities. Users can log into the Web site to realize the distribution of test tasks in the wheat production process, data management, report center generation and statistical analysis of data. It provides a good foundation for data analysis and utilization.

3) Compared with traditional manual data collection, the application of APP significantly improves the data collection efficiency by 72%, and eliminating the need to enter the recorded data into Excel for archiving. Compared with the photos taken by the camera, the photos taken with the mobile terminal APP can automatically mark the shooting time and name it after the cell number, which is convenient for the post-processing and utilization of the image data.

4) The system can be extended to other types of wheat, such as crop, fruits, vegetables, etc. According to different wheat phenotyping traits, through the module management function, different collection indicators and collection method standards can be customized, which is suitable for the general version of convenient collection and management of other wheat phenotyping traits, it greatly improves the efficiency and efficiency of wheat test data collection.

5) During the use of the system, different crops have different personalized needs in business functions. Therefore, it is the focus of the next step to improve the system to set up functional permissions with crops as the unit, a variety of wheat data collection methods are added, and bring more different types of crops into the system, and more different types of crops are included in the system.

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