Smartphone based precise monitoring method for farm operation

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Abstract: Although Global Navigation Satellite System (GNSS) terminal has been widely used for fleet management, it cannot satisfy the need of managing changes of laborer and implement during farm operation, which are important for social service cooperatives comparing to family farms in China. The objective of this study was to explore a precise, low cost and easy-to-use method for vehicle fleet management of large scale farm machinery cooperatives. A smartphone based application software (APP) named Precise Monitoring System (PMS) was developed to record the farm operation information including tractor, implement and laborer by scanning their Quick Response codes (QR codes), and obtain real time GNSS positions by using built-in GNSS chip of smartphone. Considering the convenience usage for farmers, only two buttons, "start/pause/continue" and "stop" were designed to record farm operation status. Finally, IDs, positions and operation status were combined and transferred to the server through GPRS/3G/4G. Two kinds of experiments were designed and conducted to verify the PMS. The results showed that PMS can realize the basic functions such as precise and real-time monitoring, operation quality tracing, operation mileage and operation area calculating, and U-turn processing. The method and APP could record complex combination of production factors precisely and accurately, which is suitable for the management of vehicle fleet, and can replace GNSS terminal to some extent.

Keywords: smartphone, agricultural machinery, farm operation, monitor, method, system
DOI: 10.3965/j.ijabe.20160903.2154

Citation: Wu C C, Zhou L, Wang J, Cai Y P. Smartphone based precise monitoring method for farm operation. Int J Agric & Biol Eng, 2016; 9(3): 111－121.

1 Introduction

With the quick development of farm machinery social service nowadays, precise and accurate method to monitor fleet operation is needed. In China, both land transferring and farm machinery social service are encouraged currently[1]. Farm machinery cooperative must sign service contracts with small farm owners in order to hire temporary drivers to work for them. Under this circumstance, fields, crop, tractors and implements do not belong to the driver, and this is different from classical family farms which own everything. Therefore, cooperative and employer of temporary drivers should be responsible for operation progress and operation quality[2]. It is necessary to monitor the whole operation progress of farm machinery to collect information of tractor, implement, and laborer.

Commercial GNSS terminals, usually called "black box"[3], are widely used for vehicle fleet management nowadays[4,5]. The GNSS terminal is usually equipped on farm machinery to capture real-time positions, productivity information of the vehicle fleet[6,7] and the public Controller Area Network (CAN) messages[8]. These data will be transferred to the server through

Received date: 2015-09-26 **Accepted date:** 2016-01-15
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cellular network for production management and remote diagnosis[9]. Since it is quite complex to combine the production factors, data from "black box" cannot reflect all production factors needed. Production factors like tractor, implement and laborer may differ for each field and different seasons. In addition, several tractors may work together in one large field. In fact, each tractor is equipped with only one "black box", which can only be used to identify the tractor's information. As a result, the complicated operation will cause the following management problems: The first one is that the employer in the office cannot know who are driving the tractors and which operation they are doing; correspondingly, the second problem is that the employer cannot precisely count operation hours and areas of each driver, which determine their salary or bonus; the third problem is that how the employer knows who should be responsible for the low operation quality. There is no suitable information system to help solve the above problems due to the limited data input. As mentioned above, "black box" is used for monitoring operation and is suitable for family farms while not suitable for social service cooperatives whose combination of production factors varies. The reason for the above problems is due to the limited ability of "black box", which doesn't have a user interface and cannot record alternation of implement and laborer.

Besides identifying production factors, the GNSS terminal should also realize the calculation function of operation mileage and operation area[10,11]. There are several methods to measure the operation area of farm machinery. By using the GNSS Real-Time Kinematic (RTK) receiver or Differential Global Positioning System (DGPS)[12], we can survey the field boundary to obtain the accurate digital field map and thus generate geometric area. It is a precise method but the workload is quite large for the laborer. In addition, by using the image of high resolution satellite like Qiuckbird[13], we can also draw the field boundary, which is suitable for middle and large fields. The above two methods can obtain the field maps, but the problem is that the geometric field area is not equal to the operation area sometimes[14]. For some advanced machines[15], they can measure the operation mileage and operation area by using the CAN messages, such as status of header, fan, velocity, etc., but most of the tractors made in China do not support CAN bus communication. Therefore, GNSS terminal is a good choice to monitor farm machinery and calculate operation area[16]. Tractor with dual-frequency RTK receiver can easily get the operation area, but the RTK system with high accuracy is not affordable for many social service cooperatives, and it is almost impossible to receive dual-frequency correction signal due to the limited fundamental infrastructure. If the tractor is equipped with single-frequency GNSS terminal that cannot process data, the area measurement error is somewhat large, especially for small fields. Handhold terminal had been used for operation area measurement in China[17], but the user should walk around the field to survey the boundary, which is very inconvenient and labor consuming.

In conclusion, new method is needed for social service cooperatives to replace the simple GNSS terminal in order to realize precise management during farm operation. We proposed a new type of GNSS terminal to record the production inputs and their changes, and trace tractors' operations. Nowadays, smartphones become more powerful and widely used[18-21], most of them are configured with built-in GNSS chip, high resolution digital camera and wireless communication module, and can provide powerful mobile computing capacity. Based on smartphone, we developed an APP to record the whole farm machinery operation, and conducted experiments to evaluate if it can be an alternative solution to replace the GNSS "black box".

2 Materials and methods

2.1 System design

2.1.1 Smartphone based system

The smartphone based system consists of both hardware and software. The hardware includes QR codes, smartphone, server and personal computer (PC)/Pad. QR code is used for identifying the production factors, each of which assigned an unique QR code[22]; the smartphone is used for data collecting and transmission; the server is used for data management and communication and the PC/Pad is used for client monitoring, historical tracks replaying and spatial data analyzing. The software consists of APP (named as PMS), server software and monitoring software. The system structure of precise monitoring software is shown in Figure 1.

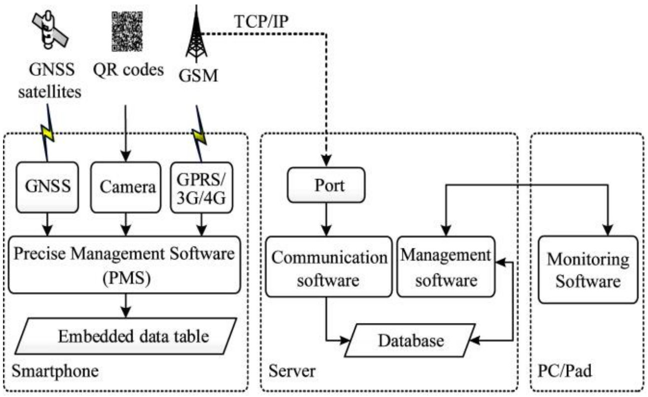


Figure 1 System structure of precise monitoring software

QR code is a type of matrix barcode (or two-dimensional code) that can be recognized much faster than traditional Universal Product Code (UPC) barcodes[14] and is widely used for information retrieval, webpage-redirecting and advertising pushing, etc.[23] In this research, QR codes were used for identifying tractor, implement and laborer. It was printed and encapsulated by plastic for dustproof and waterproof and was pasted or tied on tractor and implement or carried by driver.

Smartphone is very accessible nowadays. It can be used to scan QR codes of production factors at the beginning of farm operation, and then obtain and report GNSS positions to the server. In this research, Samsung Note 3, Galaxy 3 and HUAWEI B199 smartphone were used. The configurations of Huawei B199 includes: built-in GPS and BeiDou Navigation Satellite System (BDS) chip, 8 megapixel (MP) rear camera and 1.3 MP front-facing camera, Qualcomm MSM8628 quad core, 2 GB RAM, 16 GB ROM, dual-SIM (GSM and CDMA), 5.5-inch screen and the operation system (OS) is android 4.1. Smartphone can establish Transmission Control Protocol (TCP) connection with the server via GPRS/3G/4G mobile communication technologies. We rent a web server with 200 GB hard disk and 5 Mbps unshared internet access from AliCloud (Alibaba Group's Cloud Computing Unit, China)

2.1.2 PMS development

PMS was developed based on Java language to obtain the QR codes, GNSS positions and operation status, and then send them to the server via GPRS/3G/4G and TCP/IP protocol. Figure 2 is the interface of precise monitoring software. Figure 3 is the workflow of PMS.

Figure 2 Interface of precise monitoring software

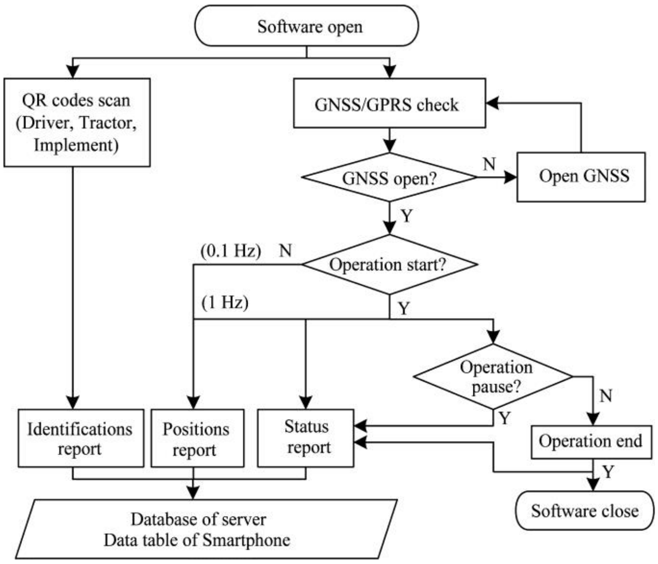


Figure 3 Flow chart of precise monitoring software

PMS records the positions of GNSS at a configured interval (1 Hz when working) and calculates the operation mileage in real-time. The workflow of APP is as follows: (1) Scan the QR codes of tractor, implement and driver to obtain their ID, plate number and other basic information before farm operation. (2) Check status of GNSS and GPRS/3G/4G[15]. If GNSS is closed, APP will pop up the GNSS configuration interface for the driver to enable the GNSS. (3) Only if GNSS works in spite of the GPRS status, which means APP can work online or offline. When the APP is offline, PMS will backup the data in the smartphone and upload it till GPRS/3G/4G available. This function ensures all GNSS positions can be uploaded. (4) When "start/pause" button is clicked, the APP starts to upload the "start" or "pause" message to indicate the operation status, which are the key factors for calculating operation mileage, and similar for button "continue/stop". (5) According to the above GNSS positions and messages, farmers can calculate operation mileage and operation area with the swath of the implement. (6) To improve the positioning accuracy, PMS is designed to receive GNSS RTK terminal's output data through Bluetooth (2.2.3)[16].

Table 1 is the illustration of the meaning with different working status.

Table 1 Working status determined by GPRS and GNSS

3G/4G status	GNSS status	Working status	Illustrations
normal	normal	normal	Data transferred to server in real-time
abnormal	normal	normal	Data transferred to server when GPRS/3G/4G connected
normal	abnormal	abnormal	Not working
abnormal	abnormal	abnormal	Not working

2.2 Experiment methods

2.2.1 Production factors identifying

Field, laborer, tractor, implement and crops are the main production factors during farm operation. Except for the unchanging factors like field and crops, all the other factors can be identified with QR code (Figure 4).

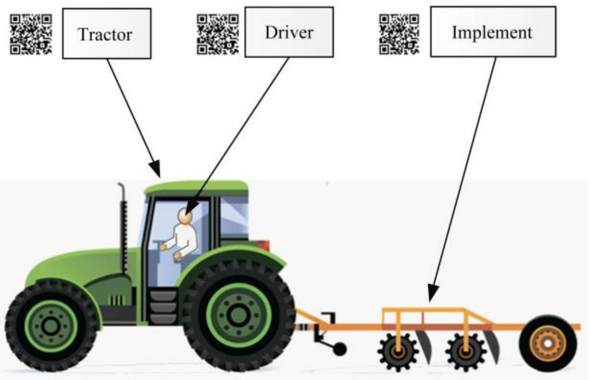


Figure 4 Main production factors of farm machinery operation

The driver is an active factor and is the key object of operation statistic. The driver's QR code mainly consists of ID and name. In some cases, several drivers have to work on one farm machine, especially big machines such as cotton picker. The tractor's QR code consists of plate number, name, type, etc. The plate number is the key ID. The implement's QR code mainly consists of ID, type and swath. The rear camera of smartphone is used to scan QR codes.

When farm operation is started, the driver should firstly scan the QR codes of the laborer, tractor and implement respectively. If laborer or implement changes during farm operation, the QR codes should be rescanned. Of course, the laborer can also input name, plate number and implement ID manually instead of scanning.

2.2.2 Wireless data transmission

As is shown in Figure 5, smartphones and GT02A (a widely used single-frequency GPS terminal in China) transfer the data to the server via GPRS/3G/4G. GT02A records and updates GPS position to the server with about 6 m error by 0.1 Hz frequency. We tested and optimized the terminal with the commercial company and canceled the zero-speed drift restrain, which limits position report when speed is less than a specific small value.

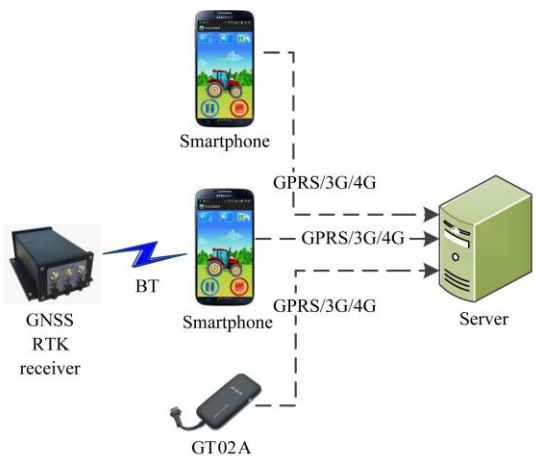


Figure 5 Wireless data transmission

Three data protocols for PMS were designed to update GNSS positioning data, identification of production factors and working status[24]: (1) The first protocol of GNSS data was developed for reporting GNSS positioning data to the server continually. This protocol mainly contains the GGA (Global Positioning System Fix Data)[25] and IMEI (International Mobile Equipment Identity) of smartphone, which are encoded in HEX format to save transferring bytes. (2) The second protocol for identification of production factors was designed to transfer the key values of the driver, tractor and implement. These key values with time-stamp will be reported to the server in string format. (3) The third protocol for working status mainly includes “start”, “pause”, “continue” and “end”. These messages will also be reported to the server in string format.

2.2.3 External GNSS RTK receiver connecting

The GNSS chip of smartphone is usually single frequency. Its positioning accuracy is about 6 m, which cannot satisfy the requirements of some high precise operation. In this case, PMS is also designed to receive the data of external GNSS RTK receiver through Bluetooth with accuracy better than 2.54 cm. Smartphone connected the GNSS RTK receiver wirelessly through a RS-232 serial port to Bluetooth adapter to obtain NMEA-0183[26] data (Figure 5). When PMS receives the high accuracy data, it uses the data to replace its internal GNSS data automatically.

2.2.4 U-turn filtering

U-turn is a necessary step when tractors moving to the border of the field, but it will cause errors to the statistics of operation mileage and area. The mileage of U-turn is mainly determined by accuracy and frequency of positioning and turning radius of the tractor and the error of U-turn is also related to the pass length of the field. If farm machine makes U-turn frequently, it will increase the pass length, so the error cannot be ignored.

GNSS based matching template with at least five consecutive points is defined to judge the operation status of farm machinery[26]. Each point is judged by other four or more points closely followed by using speed and direction of GNSS data. If the change of direction between two near epochs exceeds the threshold set, we know that the tractor begins to make U-turn or finishes U-turn. Other parameters, such as the depth of tillage, can also be used for U-turn judgment.

2.2.5 Data processing

PMS has its own SQL Server data table which mainly included time, longitude, latitude, height, speed, orientation and number of visible satellites. Map files are created by MapInfo Professional software. The PMS software collects IDs, positions, and time for the production to form a simple but useful dataset. Based on the dataset, we can know farm operation including who, when, where and what more precisely.

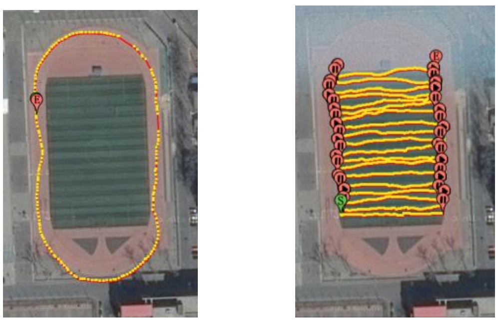
3 Results and discussion

3.1 Tracing quality and mileage accuracy

3.1.1 On the playground

Two experiments were designed to verify the functions of PMS on the playground of China Agricultural University in Beijing, China and College Station, Texas, USA. Samsung Note 3, Galaxy 3, and HUAWEI B199 smartphones were used. We walked along the circular runway and in the soccer field of playground and made U-turns at the border of the playground to simulate tractor working in the field.

As shown in Figure 6, PMS can record clear and resolvable walking tracks. Since the speed of tractor is higher than the speed of human walking, the experiment only proves that PMS can be used for field operation monitor in a certain degree. The operation mileage of the tractor is the basis for calculating operation area for the laborer and the implement. As a result, to verify whether the software is suitable for monitoring farm machinery, it is important to compare the mileage obtained by smartphone with the mileage from standard measurement. Experiments on the playground runway showed that the average mileage error of PMS was 1.6% compared to the real length of the runway. So for most of the usage, the accuracy is quite good. It can be a guarantee for operation area calculation.



a. On the oval runway b. In the soccer field

Figure 6 Walking tracks of PMS on the playground

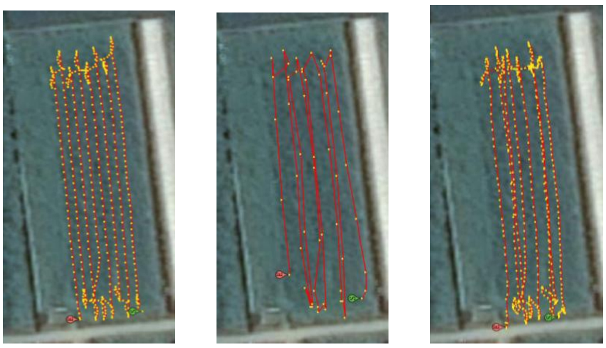
As shown in Figure 6b, if we do not use U-turn filtering, the total length of line segmented is 1428 m, this included the U-turn errors. With U-turn filter, the track could be resolved into 19 line segments, and the total length accumulated by 19 line segments was 1345 m, which was much closer to the geometric distance of 1343 m measured by Google Earth. So the U-turn filter improved the accuracy by 6.2% in this city experiment.

3.1.2 In the farmland

Experiment in the farmland was also conducted, and Figure 7 shows the experimental scene. Two experiments were designed to verify the mileage accuracy in a suburb of Beijing on May 13-14, 2014. GNSS RTK system, GT02A and smartphone were placed on the same tractor to get operation mileage. All the GNSS devices transferred the data to the server via GPRS/3G/4G (Figure 5). This experiment continued about 8 h and the operation area was 23 hm^2. Another experiment was conducted on June 23, 2014.

Figure 7 GNSS RTK receiver and smartphone equipped on the tractor

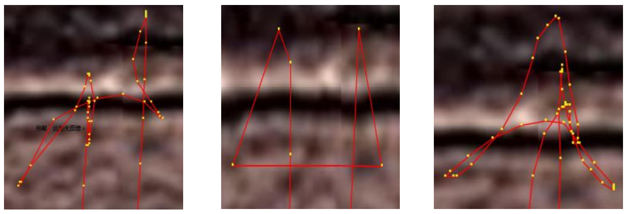
Figure 8 shows the results of farmland experiment. Since accuracy of GNSS RTK is at centimeter level, it can be the reference for other devices. The three pictures show that GNSS RTK can precisely record the operation tracks with quite good parallel spacing. Compared to GT02A, smartphone got a better result, whose parallel spacing was more uniform. Although there are two lines overlapped with each other, we can still clearly count the amount of working line segments.



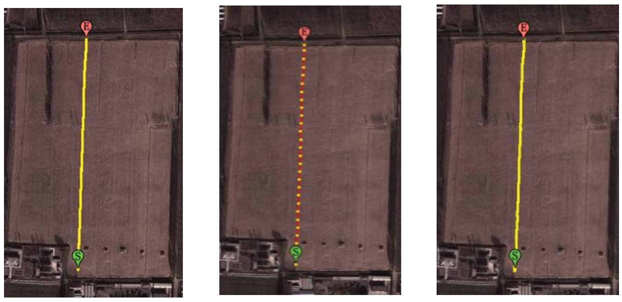
a. GNSS RTK tracks b. GT02A tracks c. Smartphone tracks

Figure 8 Farm operation tracks obtained by GNSS terminals

Furthermore, we analyzed the effectiveness of U-turn filter with the real operation data. As Figure 9 shows, tractor should make U-turns at the borders of the field, and the whole track contains two parts: U-turn track and operation track. When the tractor makes U-turn, lots of useless data will be recorded and that affects the mileage calculation, which will directly cause the error of operation area.



a. U-turn with RTK b. U-turn with GT02A c. U-turn with smartphone



d. Operation tracks with RTK e. Operation tracks with GT02A f. Operation tracks with smartphone

Figure 9 U-turn and working line (single line)

In order to discover the U-turn errors clearly, we resolved the working track of Figure 9 into five groups. The first group only had one operation line segment without U-turn. The second group had two line segments with one U-turn and the third group had three line segments and two U-turns, etc. The mileage of Google Earth (M_{google}) was the reference for comparisons. Likewise, the mileages of RTK, GT02A and smartphone were expressed as M_{RTK}, M_{GT02} and $M_{SP\ (smartphone)}$, the deviation of RTK, GT02A and smartphone were expressed as D_{RTK}, D_{GT02} and D_{SP}. The mileages and deviations of the devices were calculated with U-turn and without U-turn together as shown in Table 2.

From Table 2, we can find that U-turn brought large errors to the mileage calculation. GNSS RTK had higher accuracy but also caused 15.0% of average deviation compared with the distance measured by Google Earth image (Qiuckbird). The average mileage deviation of smartphone with U-turn was higher, while the average mileage deviation of GT02A was smaller

(8.7%). It might be caused by lower position report frequency (0.1 Hz), which ignored some details of U-turn. When U-turn tracks were filtered out, the errors dropped down quickly. The average mileage deviations of RTK, GT02A and smartphone were 1.3%, 1.6% and 1.8%, respectively. The stand deviation of smartphone was only 1.5%. So U-turn should be filtered out to improve the accuracy of operation mileage calculation.

Table 2 Working mileage comparison with Google Earth

Operation line segment	M_{google} /m	Mileage with U-turn						Mileage without U-turn					
		M_{RTK}/m	D_{RTK}/%	M_{GT02}/m	D_{GT02}/%	M_{SP}/m	D_{SP}/%	M_{RTK}/m	D_{RTK}/%	M_{GT02}/m	D_{GT02}/%	M_{SP}/m	D_{SP}/%
one	93	-	-	-	-	-	-	92	-0.90	91	-2.00	92	-0.90
	100	-	-	-	-	-	-	100	-0.30	106	5.70	100	-0.30
	669	-	-	-	-	-	-	669	0.00	671	0.30	679	1.50
two	198	213	7.60	209	5.60	223	12.60	199	0.50	201	1.50	202	2.00
	288	312	8.30	313	8.70	310	7.60	292	1.40	299	3.80	292	1.40
	140	171	22.10	146	4.30	175	25.00	143	2.10	141	0.70	145	3.60
three	342	416	21.60	352	2.90	411	20.20	344	0.60	346	1.20	358	4.70
	435	461	6.00	460	5.70	462	6.20	436	0.20	443	1.80	440	1.10
	2008	2318	15.40	2175	8.30	2415	20.30	2058	2.50	2031	1.10	2089	4.00
four	401	444	10.70	437	9.00	468	16.70	402	0.20	410	2.20	407	1.50
	265	324	22.30	314	18.50	280	5.70	279	5.30	274	3.40	268	1.10
	436	482	10.60	502	15.10	478	9.60	448	2.80	438	0.50	445	2.10
five	513	620	20.90	591	15.20	632	23.20	528	2.90	529	3.10	522	1.80
	354	436	23.20	372	5.10	447	26.30	359	1.40	356	0.60	364	2.80
	3325	3689	10.90	3532	6.20	3812	14.60	3328	0.10	3331	0.20	3348	0.70
max			23.20		18.50		26.30		5.30		5.70		4.70
min			6.00		2.90		5.70		-0.90		-2.00		-0.90
average			15.00		8.70		15.70		1.30		1.60		1.80
StDev			6.60		5.00		7.40		1.60		1.90		1.50

3.2 Field application experiment

A field of 12.5 hm^2 in the north of Beijing (N40.239765°, E116.567901°) was adopted to record the whole autumn operations. It is a standard grid filed surrounded by windbreaks. So the experiment was a classic and representative experiment.

3.2.1 Remote monitoring

As shown in Figure 10, with the IDs of the production factors, it is possible for the manager to monitor the working status for specific field, laborer, tractor and implement in the office. This improves the traditional vehicle monitor method.

Figure 10 Real-time monitoring in the office

3.2.2 Production factors identifying

As shown in Figure 11, there were mainly five processes for the autumn operations including fertilizer spreading, disc harrowing, plowing, rotary hoeing and seeding. There were 6 tractors for rotary hoeing numbered as I, II, III, IV, V and VI (Each tractor had its own license plate number). The operation type of tractors were numbered as I, II, III, etc. for each workflow, the implements were numbered as I, II, III, etc. Each driver was allocated one smartphone to record his operation when they entered into the field. Totally ten smartphones were used for this field experiment, smartphones were numbered as M001 to M010. Each laborer was required to scan the QR codes of tractor, implement and driver himself, and touched the status switch button when they began or finished the operation.

All the tractors numbered as T001 to T011 were equipped with one GT02A to obtain the positions, except the tractor for rotary hoeing II. In addition, the laborer for rotary hoeing V was not allocated smartphone since the devices were not enough at that time. But during each operation, the tractors were guaranteed to equipped at least one GT02A or smartphone. The rotary hoeing record on September 28 missed because of the bad coordination. M004 lost 20 minutes data on 27/9.

Table 3 shows the GNSS mileage comparison with Google Earth that the PMS could perfectly identify the inputs of production factors and calculated operation area, which was the basis of performance statistics.

a. Fertilizer spreading

b. Disc harrowing

c. Plowing

d. Rotary hoeing

e. Seeding

f. Driver scaned QR codes before working

Figure 11 Autumn operations

Table 3 GNSS mileage comparison with Google Earth

Date (dd/MM)	Operation type	GT02A (No.)	Smartphone (No.)	Laborer	Tractor (No.)	Implement (No.)	Area/hm^2
26/9	Fertilizer spreading	T005	M001	Wang D Y	62988	FS001	12.5
	Disking harrow Ⅰ	T011	M002	Wang X D	62976	DH003	6.1
	Disking harrow Ⅱ	T006	M008	Lee S M	62938	DH001	5.4
27/9	Plowing Ⅰ	T010	M003	Liang X L	62901	P005	3.7
	Plowing Ⅱ	T007	M008	Gao H S	61190	P003	2.5
	Plowing Ⅲ	T008	M001	Liu D Y	61173	P002	3.1
	Rotary hoeing Ⅰ	T011	M005	Fu Y J	61540	RT008	2.5
	Rotary hoeing Ⅱ	/	M004	Wang Q Y	23612	RT006	2.3
	Rotary hoeing Ⅲ	T004	M002	Lee B S	61564	RT007	3.0
	Rotary hoeing Ⅳ	T001	M009	Gao C W	61539	RT003	0.8
	Rotary hoeing Ⅴ	T005	/	Wei J G	61542	RT002	1.4
	Rotary hoeing Ⅵ	T006	M007	Wei W S	23613	RT005	2.6
28/9	Plowing Ⅰ	T011	M002	Liang X L	62901	P005	1.2
	Plowing Ⅱ	T007	M008	Liu D L	61173	P002	1.1
	Plowing Ⅲ	T008	M006	Gao H S	61190	P003	1.3
	Rotary hoeing Ⅰ	T010	M007	Fu Y J	61540	RT008	0.4
	Rotary hoeing Ⅱ	/	M004	Wang Q Y	23612	RT006	2.8
	Rotary hoeing Ⅲ	T004	M003	Lee B S	61564	RT007	0.4
	Rotary hoeing Ⅳ	T007	/	Gao C W	61539	RT003	0.5
	Rotary hoeing Ⅴ	T005	M001	Wei J G	61542	RT002	2.9
	Rotary hoeing Ⅵ	T008	/	Wei W S	23613	RT005	1.3
	Seeding Ⅰ	T006	M005	Wang X D	63767	S001	1.4
	Seeding Ⅱ	T010	M009	Wang K X	63766	S003	2.9
	Seeding Ⅲ	T001	M006	Peng J K	63765	S007	2.5
	Seeding Ⅳ	T009	M008	Gao N	63754	S005	3.5
	Seeding Ⅴ	T011	M002	Jiang L G	63755	S006	2.5

3.2.3 Working quality tracking

Five laborers operated five winter wheat seeders to finish the planting work in the same field on September 28. PMS software recorded the track of each seeder (shown in Figure 12). From the seeding map (MapInfo TAB), we can help the field owner or the manager of cooperative to retrospect the responsible area if they suffer planting quality problem. Furthermore, it will provide the evidence to evaluate the laborer's capability and skill. Even when the laborer worked cross in the field, it is still easy to find out the laborer who should be responsible for a specific area.

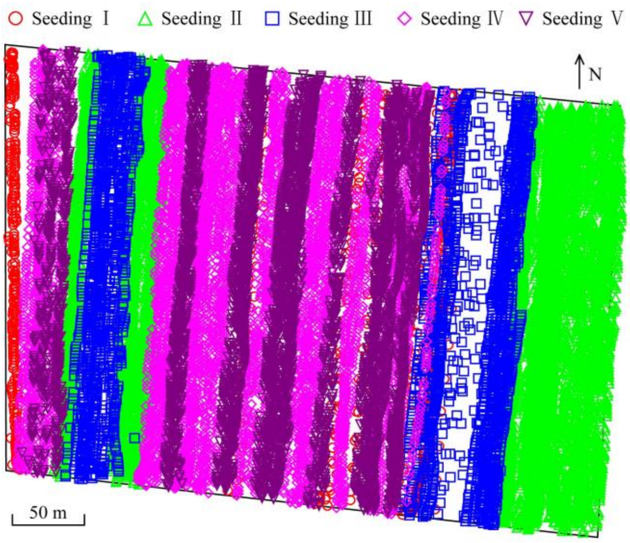


Figure 12 Seeding map

To locate the narrow seeding stripe is not easy since the seeders worked crosswise and the swath of the seeder was small (only 1.8 m). For example, the tracks of seeding I (red color in Figure 12) dispersed among the tracks of other seeders in the middle of the field.

3.2.4 Operation area calculation

With the GNSS positioning dataset, it is easy to compute the operation area for each cultivating type. There are missing data for the disk harrow due to the fact that we unloaded the device during a temporary rain. Additionally, some data of hoeing operation were lost because we failed to allocate device to the tractor in a very early morning. Plowing and seeding were integrated during the whole operation. With these data, the operation area of each device was calculated and is shown in the rightmost column of Table 3, and the summery is shown in Table 4.

Table 4 Operation area compared with the filed area

Operation type	Area/hm^2	Notes
Fertilizer spreading	12.5	The operation full covered the field
Disking harrow	11.6	Monitoring interrupted partly by bad weather
Plowing	12.8	2.3% larger than the field area
Rotary hoeing	20.8	Worked twice. One tractor lost some data.
Seeding	12.8	2.4% larger than the field area

We calculated the operation area for each smartphone. The operation area was 1.4 hm^2, 2.9 hm^2, 2.5 hm^2, 3.5 hm^2 and 2.5 hm^2, respectively by calculating its seeding operation mileage for Seeding I to V. The accumulation area of seeding operation was 12.8 hm^2, 2.4% larger than the field area. Furthermore, the operation area and working time period of each production factor could also be calculated according to the relationships in Table 3.

4 Conclusions

Smartphone based precise monitoring system was designed for vehicle fleet management of scale farm machinery cooperatives. An APP named precise monitoring system (PMS) was developed to record the production factors and their changes during farm operation including tractor, implement and laborer by scanning their QR codes. The APP could also report GNSS positions, identification of production factors and operation status to the server through GPRS/3G/4G. Two kinds of experiments were designed to verify the function and performance of the APP. Results showed that PMS could satisfy requirements of precise and real-time monitoring, operation quality tracing, operation mileage and operation area calculating, and U-turn filtering. It is effective for fleet management, especially for the social service of farm machinery cooperatives, and can replace GNSS "black box" to some extent.

However, the positioning accuracy of smartphone is about 6 m, so it is difficult to identify the specific row. For example, the swath of the seeder for experiment is 1.8 m which is much smaller than the positioning accuracy. So smartphone with sub-meter GNSS device is a better choice to perform all the functions and makes best use of PMS. The status switch button can be used for many purposes, but not suitable for filtering the U-turn, because the laborer cannot be expected to press the buttons frequently for U-turns. Near field communication (NFC)[27] is a set of ideas and technology that enables smartphone and other devices to establish radio communication with each other by touching the devices together or bringing them to a distance of typically 10 cm (3.9 inch) or less. The QR code can be replaced by NFC, which may improve the usability and operability.

Acknowledgements

Thanks for the support of National High Technology Research and Development Program of China (No. 2012AA101902), Chinese Universities Scientific Fund (No. 2014RC015), Science & Technology Pillar Program of Tianjin (14ZCZDNC00004), and Science and Technology for Xinjiang (No. 2011AB024). And also thanks ComNav Technology Ltd. who provided GNSS RTK system for experiments.

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