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Techno-commercial feasibility of soil moisture scanner for efficient irrigation scheduling

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Abstract: This study proposes a new device to aid irrigation scheduling system using sensing and automation for precision irrigation. Despite agriculture being a predominant factor in the economic growth of a country, it has been facing several challenges like low productivity levels, volatility in return, difficulties in the supply of inputs and poor market regulation. In addition, water availability for timely watering of crops is critical that affects agricultural yield. Criticality of water as a resource is expected to increase with growing population and regional imbalances. In this context, there is a need to focus on optimal use of water through efficient irrigation techniques. This study has designed, developed and tested a unique device which outperforms the currently available devices on the market regarding functionality and cost effectiveness.

Keywords: GNSS reflectometry, Precision Irrigation, Irrigation scheduling, Crop Insurance and Crop marketing.

1. INTRODUCTION

Agriculture plays a pivotal role in the development of emerging economies, specifically with respect to growth and sustainability. Though agriculture is one of the core sectors in most emerging economies in Asia, there are several challenges such as reduced productivity, volatility in returns, constraints in the supply of inputs and poor market regulations. There have been sustained efforts by many entities such as government, research fraternity, and non-profit organizations to address the challenges in agriculture from varied angles. Government subsidizes the expenses, fixes the base price for agro products and provides inputs by training farmers on scientific methods of farming for better cultivation and output. A non-profit organization (NGO) on the other hand educates the farmers on the best farming practices and provides grants for innovative agriculture projects. In addition some NGOs also provide information to the farmers on weather conditions etc. through call centres. In contrast, academic researchers have addressed this issue by pooling resources for farming and recommending adoption of practices such as cooperative farming, contract farming and corporate farming (Barth etal, 2006, Pranaya et al, 2012). The group farming method provides a gateway for farmers to adopt innovative technologies such as wireless sensors network, robotics, remote sensing and use of drones for production monitoring. Despite technological advancement for better farming, the applicability is limited due issues in commercial feasibility (Neelam Srivastava, 2010, Valente J., et al., 2011). This study is an attempt to address the commercial feasibility issue to enhance the applicability of one such technology that can be used for irrigation scheduling, namely GNSS (Global Navigation Satellite System) reflectometry. Adopting the reflectometry technology will efficiently schedule irrigation leading to enhanced productivity. The uniqueness of the developed reflectometry technology will be appreciated if the current problems in irrigation scheduling are clearly understood. In the subsequent section the current problems with existing irrigation scheduling systems are discussed.

2. ISSUES IN IRRIGATION SCHEDULING

According to Sarah (2010), irrigation scheduling means "to determine the appropriate time and quantity of water to be supplied to a crop". The study also summarized the requirement of an efficient irrigation scheduling (described in Fig. 1.) for better returns. According to Sarah (2010) there are four inputs (soil texture, field capacity, soil moisture and quantity of water needed at each stages of a crop.) to be monitored for effective irrigation and better yields. Among the four it is observed that three are time invariant, and only soil moisture content is a time varying or a temporal input, which needs regular and accurate monitoring. If all the four inputs are managed to a value close to optimum value, the resultant yield will be near optimum crop yield, decrease water loss and optimize the pumping cost. Another important attribute to be considered along with the temporal variation of soil moisture is spatial variation. Studies have indicated that selective space sampling of soil moisture does not represent the whole area and may not be useful for irrigation planning. Brocca et al., (2007), states that "the plain site presents a random soil moisture spatial pattern, following the

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standard probability distribution, without a significant correlation length". This essentially indicates that there has to be appropriate number of samples at frequent intervals to achieve a desired level of confidence. An effective system can be designed if and only if large data is collected at regular intervals, random collection of data could lead to biased estimates.

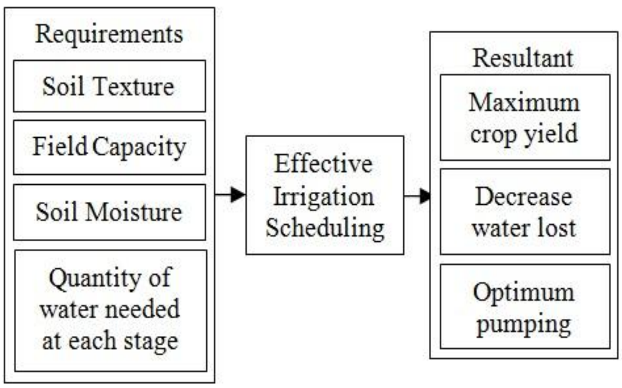

Fig. 1. Effective irrigation scheduling system.

Brocca et al. (2007) also suggested that if values are collected at a depth of 0.8 cm from the surface can be used to map up to a depth of 23 cm from the surface. Given these attributes it is almost impossible in a large farm setting to manage these parameters manually for an effective irrigation system. Though the current practices of automation in irrigation scheduling has lesser human presence (Jones, 2004) the accuracy level driven by automation is unanswered. Any level of irrigation automation has to address the following issues: (a) level of precision that can be achieved given the smaller number of sample points to test soil moisture, (b) the trade-off between cost, accuracy and maintenance of the device, (c) interruption in regular farming activity due to the contact with soil of the monitoring device. (d) cost involved in operation of control room and operation of individual valve in cases of far field monitoring such as using drones, remote sense, or in near field plant based monitoring mechanism, and (e) maintaining appropriate supply of water based on the need. In the subsequent section the ability of existing technology in addressing the concerns raised will be discussed followed by a description on the product developed to addresses the factors.

3. TECHNICAL FEASIBILITY REVIEW

The driving force for irrigation scheduling according to Jones (1990a) are namely (a) soil water measurement, (b) soil water balance calculations and (c) plant-based. Jones (2004) reported that both far field and near field plant-based methods though might communicate the need for irrigation will not be able to indicate the quantum to be supplied. Soil water balance calculation is the process of calculating the moisture content over a period by estimating the difference between supplied water to the water lost by runoff, drainage, and evapo-transpiration. Allen et al. (1999) reported that soil water balance calculation is found to be sufficient but subjected to serious issues of cumulative errors over time. Given the lack of effectiveness of these systems researchers have attempted adopted the use of camera based imaging sensing system with little effectiveness to analyze plant parameters. Due to the shortcoming of the soil water balance calculation and plant based method Allen et al. (1999) indicated that the best suited method would be soil based measurement for effective irrigation. Soil water measurement is the process of measuring moisture in the ground directly to plan for irrigation. The soil based measurement system can be used with the help of sensing technologies like wireless sensor networking (WSN), radar, radiometer, reflectometry technology, etc. Jones (2004) states that soil contact based systems as well as Unmanned Aerial Vehicle (UAV) based has drawback for irrigation scheduling, due to technology and functional limitations of the system. An alternative method to measure soil moisture is remote sensing. However, integrating the remote sensing device with ground-based real-time irrigation scheduling process is not viable due to time lag as well as cost. Further from Soil Moisture Active Passive (SMAP) satellite study, it can be observed that a far end use of radar and radiometer may not be highly effective in irrigation scheduling. Therefore, a solution for the near field moisture estimation with a non-soil contact sensing device reflectometry would be the ideal and effective method. Section 3.1, discusses the reflectometry based near field soil moisture measurement system.

3.1 *Reflectometry-Based Measurement*

The process of estimating the soil parameter including moisture based on the energy reflected from the earth surface is called reflectometry (Larson et al., 2010). It can be concluded from literature that there is no dedicated hardware device for that is used for measuring soil moisture in cropland-centric applications. This gap forms the core for developing a new device namely Soil Moisture Scanner (SMS). The expected functional capabilities of the proposed device are, (a) reduced computation platform, (b) capturing required data, (c) device clustering, (d) theft alarm, (e) inbuilt electric valve control unit and (f) at reduced cost. Section 3.2 discusses the test result of the developed SMS prototype with above functional capabilities for precision irrigation.

3.2 *SMS Prototype*

The prototype of the proposed solution, Soil Moisture Scanner (SMS), was tested in a farm located in a village called Salavathy, in rural Tamil Nadu (Fig. 2). The device is based on the principle of reflectometry, to estimate soil moisture. Based on the height of reflection the data can be segregated to identify the measurement from the soil or other elevated vegetative surface. For each quadrant covered by the device, data was recorded, continuously for 22 days. For the first eleven days, the soil moisture on the farmland was physically maintained in a pattern as illustrated in Table 1. From Fig. 3, which indicates the volumetric soil moisture values it can be observed that it is in accordance with the moisture content as indicated in the Table 1 essentially proving that the SMS device is able to assess the level of soil moisture in better way than the existing technologies. The subsequent section discusses the commercial feasibility of the instrument developed.

4. COMMERICAL VIABILITY OF SMS DEVICE

The commercial viability analysis of the proposed SMS device was conducted through field visits and interviewing the probable users of the device. Based on the responses the needs expressed by the respondents were mapped to the features of the device.

Table 1. Soil moisture pattern

Day	Section 1	Section 2	Section 3	Section 4
1	Wet*	Dry**	Wet	Wet
2	Wet	Dry	Wet	Wet
3	Wet	Dry	Wet	Wet
4	Dry	Dry	Dry	Wet
5	Dry	Dry	Dry	Wet
6	Dry	Dry	Dry	Wet
7	Rain	Rain	Rain	Rain
8	Rain	Rain	Rain	Rain
9	Rain	Rain	Rain	Rain
10	Rain	Rain	Rain	Rain
11	Harvested	No rain	Harvested	No rain

** Wet - Irrigated, Dry ** - Not Irrigated*

Fig. 2. Soil Moisture Scanner (SMS) prototype testing.

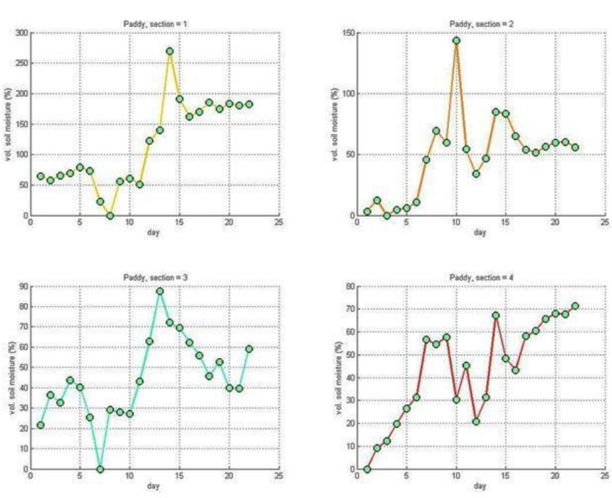

Fig. 3. Estimated volumetric soil moisture (%) variations on each day at each sections

At this it was felt that in addition to meeting their needs for an efficient irrigation system this device could be used for meeting their other farming needs in terms of farm timings, insurance etc., but analysing the other uses of this device is beyond the scope of this research output.

4.1 Exploratory market analysis

The process of exploratory field visits and interviewing farmers were randomly carried out in four states of India viz. Tamil Nadu, Kerala, Andhra Pradesh and Karnataka. The visit and interviews covered all categories of individual farmers ranging from small farmers owning about 10 acres of agricultural land to large farmers owning up to 250 acres of agricultural land. In addition interviews were also conducted for contract farmers and corporate farmers also. Largely from the interview it could be concluded that there is a very strong need for an efficient irrigation scheduling and monitoring device. The farmers expect the surveillance device to have following functional activities (a) irrigation at the appropriate location, time and quantity, (b) in the event of a constraint to optimally allocate (c) to control the valves in the right order based on the specifics of the site. In section 4.2, the features of the system that meets the demand felt by the farmers is discussed.

4.2 Proposed Solution

The proposed Soil Moisture Scanner (SMS) is designed, to meet the needs of the farming community in terms of (a) collecting and measuring based on good number samples, (b) non-soil contact assessment, (c) wide area coverage and (f) with in-built electric valve control unit. Table 2 summarizes the functional capability of the proposed device in solving the current issues of irrigation scheduling process. Table 3 compares the effectiveness of the SMS device with the existing soil contact based Soil Moisture Probe Sensor (SMPS). In the subsequent section 4.3 discuss the other possible uses of the SMS device.

Table 2. Problem – Solution Mapping

No.	Problems in irrigation	Solutions by SMS
1	Lack of accuracy due to one sample points/device.	minimum of 1000 sample points/device
2	A tradeoff between cost, accuracy, and maintenance of the device.	Highly accurate, low cost, and minimal maintenance.
3	Soil contact-based device interrupts farm activity	Non-soil contact, so no interrupts
4	Far field estimation is high value and requires several connections	Inbuilt electric valve control unit.
5	Supplying water at the time of need.	Ensures timely supply of water

4.3 Other possible applications of SMS

In addition to using the SMS device for irrigation scheduling, it has a variety of applications. The farming activities like (a) tilling, (b) sowing, and (c) weeding can also be timed based on the output from this device. It can be used to estimate the amount of water utilized by a plant at different stages, to enable planning the future water requirement for that crop. It can also maintain the required amount of water-level height in a basin type irrigation method for the crop like paddy. Crop insurance companies can also use this device to obtain live data, to assess the extent of damage caused due to flood/rain/lack-of-water/wind/humidity/solar radiation, etc. In addition it can also be used to connect the prospective buyers with farmers, based on the data pertaining to (i) farm location, (ii) type of crop, and (iii) area cultivated. The economic or financial impact, of the device is discussed in section 4.4.

Table 3. SMS in comparison to the existing device

No	Attributes	SMPS	SMS
1	No. of device/acre	30	1
2	Sample points/acre	30	1000
3	Frequency	Hourly	Hourly
4	Water wastage	High	Low
5	Approx.cost (USD)	200/device*	171**/device
6	Possible reliability	High	High
7	Possible durability	5 year	5 years
8	Contact with soil	Yes	No
9	Labor intensive	Yes	No
10	Irrigation scheduling accuracy	Very low	Close to optimum

Note: *Table 3 compares the price estimates of the SMS device and Soil Moisture Probe Sensor (SMPS). These two products are comparable in terms of reliability, durability, and frequency of measurement. The market price of SMPS which is comparable with performance of SMS is USD 420. However, with the increase in production the market price reduces to USD 200 owing to economies of scale benefits. **The estimation of total cost of ownership for SMS is obtained from Table 4.

4.4 Financial Impact

The current system of irritation based on remote sensing or visual judgement is either prohibitively expensive or inaccurate. In this section the financials of the SMS device is discussed. These financials could vary depending on the topography, geographical conditions and farming techniques adopted The Total Cost of Ownership (TCO) of the SMS device is critical in evaluating the economic benefit of using the device in the farmland. The cost of owning (on mass production basis) the device is elaborated in Table 4. The cost of using the device was estimated in during the field survey on an eight acre farm land used for cultivation of palm tree (used for extracting palm oil). The initial infrastructure required for cultivating the crop (without use of SMS device)is presented in Table 5.The initial infrastructure cost is expected to be sufficient for a period of 30 years. The operational cash flow from year 1 to year 30 was calculated, for year 1 and year 5 is presented in Table 6. It can be observed from the table that the cost and revenue are not aligned as there is very high labor cost due to manual irrigation which is eventually added to the cost of output. The proposed SMS device can address the irrigation requirement and reduce the cost substantially for the farmer. By eliminating the labor cost indicated in Table 7 and one fourth of farm inspection overhead cost in Table 8 with the use of SMS device the operational cash flows considerably which is presented in Table 9. The savings on irrigation labour cost to the farmer can be to the tune of USD 1129 (-3062 reduced to -1933, refer table 6 and 9 net profit) for an 8 acre farm land in five year cultivation of palm trees. In addition this could also improve the yield of the crop with appropriate irrigation as quoted by Zhang et al., (2011). It can be concluded that the device is also financially viable. The subsequent section the practical working aspects of the SMS device is discussed.

Table 4.Total Cost of Ownership (TCO) per device

No.	Components	Estimated cost(USD)
1	RF front end	23
2	Device stand	4
3	Signal processing unit	11
4	Theft alarm	4
5	WLAN (100 meters)	8
6	Battery (24v)	18
7	Solar plate (24v)	29
8	Relay Units	6
9	Other cost	28
10	Profit margin 30%	40
	TCO of a SMS	171

Note: Table 4 provides the estimated cost which is based on the actual cost of each component in arriving at the total cost of ownership per SMS device considering the economies of scale benefits.

Table 5. Initial infrastructure cost for farmland

No.	8- acre plot infrastructure	Total (USD)
1	Site development	594
2	Planting	2408
3	Drip irrigation/acre	1758
4	Drip installationcost	903
5	Electrical pump set	903
6	Mini tractor	7901
7	Power wheeler	1084
8	Total	15551
9	Working capital	16855
	Total cost	32406

Note: Table 5 provides the initial infrastructure cost based on the field survey among palm tree cultivators in Salavathy village, Villupuram district, Tamil Nadu India. The sample cultivators used traditional method for planting, irrigation and harvesting.

Table 6. Operation cash flow without SMS device

No.	Particulars	2008-09(1)	2012-13(5)
		(Ton)	(Ton)
1	Sales	0	34
		(USD)	(USD)
2	Price per ton	0	98
3	Revenue	0	3332
4	Cost of prod.†	3027	4994
5	Interest &taxes	0	0
6	Overheads††	1011	1400
7	Taxation	0	0
8	Total cost.	4038	6394
9	Operating profit	-4038	-3062

Note: Table 6 provides normalised operational cash flows obtained based on the field survey among palm tree cultivators using traditional method. The palm tree cultivation does not generate revenue for the initial four years and *thereafter generates revenue for next 26 years. Therefore the cost indicated for 2008-2009 is the same for the subsequent three years and varies after 2012-2013.*

Table 7. Cost of production†

No.	1st Year	Actual (USD)
1	Fertilizer	1996
2	Weeds destroy	53
3	Loosening soil	75
4	Labor for irrigation	903
	Total	3027
	4th to 30th Year	Actual (USD)
1	Fertilizer	4091
2	Labor for irrigation	903
	Total	4994

Table 8. Overhead cost††

No.	1st year	Actual (USD)
1	Farm inspection	903
2	Fertilizer sowing	78
3	Drip maintenance	30
	Total	1011
	5th year	Actual (USD)
1	Farm inspection	903
2	Fertilizer sowing	79
3	Drip maintenance	30
4	Harvest cost	388
	Total	1400

Note: Table 7 and 8 provides the estimated cost incurred by the palm tree cultivators using traditional method for 30 years.

Table 9. Operation cash flow with SMS device

No.	Particulars	2008-09(1)	2012-13(5)
		(Ton)	(Ton)
1	Sales	0	34
		(USD)	(USD)
2	Price per ton	0	98
3	Revenue	0	3332
4	The cost of prod.	2124	4091
5	Interest &taxes	0	0
6	Overheads	786	1174
7	Taxation	0	0
8	Total cost.	2910	5265
9	Operating profit	-2910	-1933

Note: Table 9 provides the operational cash flows using SMS method by assuming the same revenue and cost figures as indicated by the earlier tables. In contrast to the traditional method, the labour cost of irrigation is removed and farm inspection cost is reduced by 25% (Reduced farm inspection = 903 - 903/4= 677, which reduced the overall overhead cost to 786).

4.5 SMS field trial

The field architecture diagram of using the SMS device for irrigation scheduling, on an 8-acre farm land plot, is presented in Fig. 4. The SMS device is place at the center of each acre requiring placing of 8 devices in the farm land (each acre is assumed to be a square piece of land). Each acre will have the irrigation systems connected to the electrical control value as shown in Fig. 4. Therefore, all eight-acre valves (V1, V2, V3, V4, V5, V6, V7, and V8) will be connected to its corresponding SMS device to operate the electrical valve independently based on the irrigation needs. Monitoring each acre individually and irrigating it based on the needs will be efficient, but this would be viable only if there is continued power supply. The SMS device works based on inbuilt solar power cell and local area network for communicating to the main pumping station. Table 10, 11 and 12 presents the financials of the proposed SMS device, manual labour and SMPS device respectively, which are used for irrigation scheduling on the sample farm field discussed. It can be noted that by using the SMS device there is a substantial savings over a period of five years. It can therefore be concluded that, using the SMS device for irrigation scheduling, will reduce the cost of three times compared to the cost of using manual irrigation and 25 times compared to the cost of using SMPS device, indicating a financial viability of the proposed SMS device.

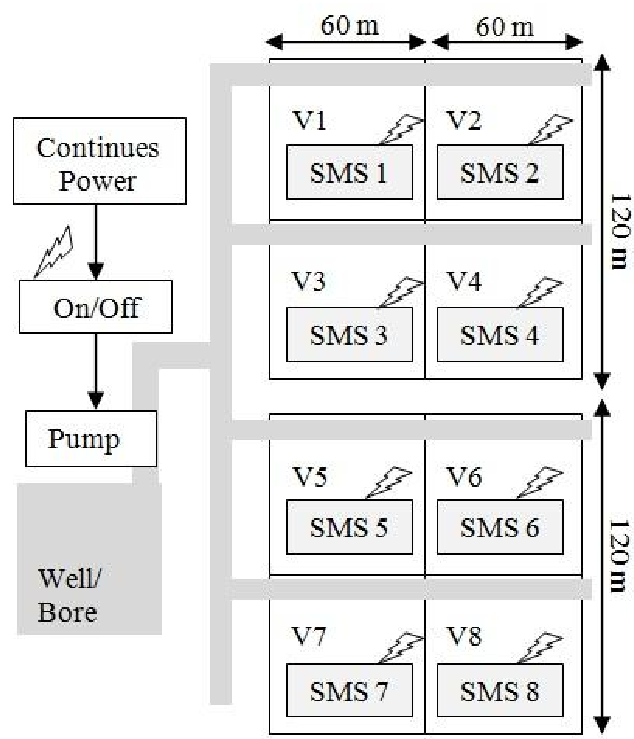

Fig. 4. The system architecture of the SMS device integrated with 8-acre farmland.

Table 10. Cost of irrigation with SMS device

No	Particulars	Value
1	Durability of a SMS	5 years
2	Cultivation area	8 acres
3	Cost of a SMS	USD 171*/acre
4	Maintenance cost of a SMS	USD 20/year
Cost of irrigation with SMS device for 5 years		
No	Details	Total (USD)
1	Cost of SMS for 8-acre	1368
2	Maintenance cost for 8-acre	800
3	Total cost for 8-acres	2168

*Note: Table 10 provides the details of the actual cost to be incurred by the farmer to completely automate the irrigation scheduling system using SMS device on a 8 acre plot for five years. Maintenance cost (800) = 8 devices x 20 USD (per year maintenance cost) x 5 years. *Refer table 4 for the break up cost.*

Table 11. Cost of irrigation with manual labor

No	Particulars		Value
1	Days of irrigation in a year		200 days
2	Four hour labor cost		USD 5/ day
3	Cultivation area		8 acres
Cost of irrigation with manual labor			
No	Details	One Year (USD)	Five year (USD)
1	labour cost	1000	5000
2	Irrigation inspection	226	1130
	Total cost for 8-acres in 5years		6130

Note: Table 11 provides the details of the actual cost incurred by the farmer for irrigation using manual labor in the 8 acre plot of palm tree for five years. One year labour cost of irrigation (1000) = 200 days x 5 USD (per day four hour labor cost). Irrigation inspection (226) = 903 (refer table 8, farm inspection cost)/4 (One fourth of farm inspection cost is irrigation inspection cost)

Table 12. Cost of irrigation with SMPS

No	Particulars	Value
1	Durability of a device	5 years
2	Cost of a device	USD 200*
3	Minimum no. of device/acre	30 no.
4	Maintenance cost of a SMPS	USD 6/year
5	Cultivation area	8 acres
Cost of irrigation with SMPS for 8 acres in 5 years		
No	Details	Total (USD)
1	Cost of 240 SMPS	48000
2	Maintenance cost of 240 SMPS	7200
	Total cost for 8-acres in 5-years	55200

*Note: Table 12 provides the details of the actual cost that would be incurred by the farmer to completely automate the irrigation scheduling system using the Soil Moisture Probe Sensor (SMPS) in the 8 acre plot of palm tree for five years. Maintenance cost (7200) = 30 devices/acre x 8 acres x 6 USD (per device maintenance cost per year) x 5 years. *Refer table 3 for the cost details.*

5. CONCLUSIONS

The need to aid farmers in irrigation is critical to achieving optimal yield. The existing monitoring devices are expensive with lower levels of accuracy. Therefore there is a need for a device that accurately measures and distributes water on the farm land based on the soil moisture requirement for the crop by controlling large number of valves in the right order on a site specific basis. The proposed device (SMS) aids in agriculture irrigation scheduling system not merely from a functionality perspective but also from a cost perspective. Therefore, the proposed SMS device is commercially feasible and functional capable to solve issues in irrigation scheduling.

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