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<https://doi.org/10.5109/4068619>

出版情報 : Evergreen. 7 (3), pp.396-403, 2020-09. 九州大学グリーンテクノロジー研究教育センターバージョン :

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Read Range Optimization of Low Frequency RFID System in Hostile Environmental Conditions by Using RSM Approach

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(Received May 5, 2019; Revised August 24, 2020; accepted September 23, 2020).

Abstract: RFID system plays a major role in asset tracking but its performance may get challenged when it has to work in extreme atmospheric conditions. RFID system can play an important role in military or defense purpose to track the land mines, military containers etc. Keeping these things in mind, this research work was carried out for the military areas which are situated in arid and semiarid regions. In this research work, experimental investigation, statistical analysis and optimization of the low frequency RFID system read range has been carried out with respect to four major input parameters i.e. varying sandy soil grain sizes (0.45 mm, 0.78 mm, 1.18 mm, 1.6 mm and 2 mm) which is present in between RFID reader and tag, temperature (15 °C to 50 °C), humidity (35 %RH to 70 %RH) and sandy soil layer thickness (0 mm to 90 mm). Here the optimization is being done by using response surface methodology (RSM). From the investigations and optimization it was found that maximum value of read range which the LF RFID system can attain is 118.14 mm for the optimum combination of input variables i.e. temperature, soil layer thickness, relative humidity and soil grain size were found to be 25.606 °C, 0 mm, 35 % and 2 mm respectively.

Keywords: RFID; RSM; Detectability; Read Range; Tag; Reader.

1. Introduction

RFID system is similar to the bar code system which is one of the methods used in automatic identification and data capturing. It uses electromagnetic waves for the transmission of information between the tag and the reader. This system consists of three major parts tag antenna or transponder, reader and microchip, the microchip is used in storing the data and transferring them to the reader to read. RFID system basically collects the data about an object or substance automatically without any manual readings involved in it¹. Due the storage capability and without manual reading requirement this system is being used more frequently as compared to other identification and data capturing

method and it can hold more amount of information than bar code system². There are various advantages of RFID tags because of which it is being utilized in various areas of defense, aeronautics, agriculture and even in soil corrosion and location tracking as well as pre-prediction of environmental changes as it is a real-time monitoring system^{3,4}. Advantage of RFID tag is that it is “low budget” and to keep it a low budget system, there is a need for reduction in its manufacturing cost. Due to this reason RFID tag has thin conducting layers with high radiation efficiency. Though from past experiences about this method had shown that the decrement of conducting layer can result into the increment of losses and decrement of efficiency, resulting into weak backscatter power from tag.

Another beneficial factor of RFID tag is that each RFID sensor has its unique identity and hence the faulty sensor can be located easily. Though it can be used in adverse condition but there are various obstacles that come while the transferring data between the tag and the reader and it could be because of the atmospheric variation which may affect the RFID system parameters and sometime it may result into undetected tag even though it is in readable range of reader. Noise is another essential reason behind the changes in the parameter as it is a wireless communication. This could lead to the errors in the detectability of the tag by the reader.

So keeping these challenging situations in mind, this work mainly considered the effect four parameters i.e. relative humidity, temperature and the presence of different soil layer thickness and its different grain sizes in between the tag and the reader may affect the RFID system performance or the RFID system read range. Investigations were carried out experimentally as well as statistically and the optimization was done by using response surface methodology to find the best value of read range for optimum values of input parameters.

2. Related Work

There have been many attempts to study the various factors that can affect the detectability of RFID System. That includes four major parameters i.e. varying temperature, humidity as well as the presences of soil and its different grain sizes that can be encountered in the path between the channel of RFID System tag and reader may affect the system performance. C. Bauer-Reich et al. in their work shows that if the presences of the humidity content get increased by 15% in the atmosphere it can lead to high attenuation in the channel or even complete loss of the signal and as the amount of water content increases as a result the read range decreases⁴⁾. To reduce the monitoring cost Fangming Deng et al. bring up another idea in which they use RFID sensor and LoRa technology for reading soil environment by real time monitoring in which the RFID sensor consisted of three sections first is communication; second is power management section and third is the digital section and then they found an error percentage of 1.0% due to the humidity effect when the sensor was in the depth of 60 cm and the soil moisture content was less than 30%⁵⁾. Kirsi Saarinen et al. studied the effect of varying humidity on performance of UHF RFID tag with anisotropic conductive adhesive (ACA) joint. Tag was tested for 85 %RH to 10 %RH and 85°C to 10°C atmospheric conditions. During the experiment different form of failures was observed. They also gave the reason that the variation in the impedance matching of the antenna of tag can be because of the cracks on the antenna due to the chemical or mechanical changes in the ACA joint while testing the RFID system⁶⁾. Sari Linnea Merilampi et al. in their research while testing found that the presence of water molecules in the environment the

frequency response and the losses of tag antenna gets affected and the impedance of antenna gets increased from “ideal or matched” impedance and hence it results in the increase in the power coefficient as well as threshold power⁷⁾. Juvenal Alarcon et al. Juvenal Alarcon et al. proposed a modified tag and they found that if this flexible tag is fixed with a non-metallic object, its performance gets enhanced⁸⁾. Sabina Manzari et al. in their research brought a new technique where polymer doped RFID tags were used⁹⁾. K. Dastoori et al. in his studied the effects of charged particle in the channel between RFID system tag and reader. From the study they observed that these charged particle or dust attenuates the response with respect to the distance between the tag and the reader¹⁰⁾. Hong, Yizhi et al. in their work explained that there are millions of dollars’ worth of property damage as well injuries and many such incidents occurs due to the pipeline corrosion and to overcome these problems they used RFID tag system. Simultaneously, real time monitoring of outside the pipeline corrosion in wireless communication as these tags are made up of non-metallic substances¹¹⁾. As per the findings of S. Choudhary et al. the read range of RFID system has inverse relation with relative humidity and shows the same effect with respect to temperature if it ranges above 25°C and if temperature reduces below 25°C, read range also decreases with it¹²⁾. Mathieu Le Breton et al. worked over the effects on passive RFID tags of 868 MHZ by the meteorological effects in outdoor area. In this investigation they observed about the effect of water on the antenna, heating effects of cables and tags and moisture of tag support and other atmospheric parameters. As a result they found that there is impact of these outdoor meteorological parameters on the passive RFID tags¹³⁾. Abdulsalam Dukyil et al. worked over a model that is efficiently cost effective and targets to solve two issues regarding the RFID tag designing firstly, in allocating the number of related facilities that should be introduced and secondly, minimizing operational and implementation costing¹⁴⁾. Emran Md Amin et al. worked over low budget UHF RFID light sensor and they found that in between 0 to 1000 lux four light intensities can be detected easily¹⁵⁾. Jian Ming-Shen et al. in their worked showed that RFID system can be easily and effectively used in automatic management procedures and proposed that fulfilling a consumer’s desire is more essential than the cost to some points¹⁶⁾. Li Zhenzhong et al. in their work experimentally showed that there is linear relation between the resonant frequency of passive RFID tag and the temperature when the relative humidity is between 50%-80% whereas there is no significant variation in the resonant frequency when there is change in relative humidity while the temperature is kept constant 200 °C to 800 °C¹⁷⁾. Jussi Nummela et al. in their practical of studying the effect of low temperature of about -210 °C on RFID tag observed that it is feasible to use them even at snow or icy surfaces¹⁸⁾. Chonggang Wang et al. found a

new algorithm of optimization of RFID tags and showed that it shows better reading performance than GEN 2 adaptive Q algorithm¹⁹⁾. Steve E. Watkins et al. in their work propose that RFID system can be used in location markers significantly in outer world rather than just in laboratory²⁰⁾. There are some work performed by Andrea Luvisi et al. that also highlighted the fact about the properties of different soils referring the moisture content in it and their case study says that the clay soil having maximum moisture content had failure in reading the signal received from RFID tag²¹⁾. Sérgio Francisco Pichorim et al. observed the performance of RFID system for detecting the moisture of soil mixture containing two solutions and as a result they found that these systems can successfully detect the moisture content and hence can be useful in indicating landslides²²⁾. H.S. Pali et al.²³⁾, Abhishek Sharma²⁴⁾ and Fachransjah Aliunir et al.²⁵⁾ suggest that RSM technology can be used as the optimization tool with which optimization of system parameters can be done and that too with minimum number of experiment runs.

From the related work it is very much clear that varying atmospheric parameters does affect the performance of RFID system and much of work has already been done to study the effect of various atmospheric parameters on the performance of RFID system but no one have yet optimized the performance parameters in the work. So keeping these challenging situations in mind, this work mainly considered the effect four input parameters i.e. relative humidity (35 %RH to 70 %RH), temperature (15 °C to 50 °C), the presence of different soil layer thickness (0 mm to 90 mm) and its different grain sizes (.45 mm to 2 mm) which may affect the RFID system performance or RRSS (read range in presence of sandy soil). Only these four parameters were considered as input parameters because this research work was basically carried out for arid or semi-arid reason and these four parameters are the major constraints in such reasons. Later the investigations were carried out experimentally as well as statistically and the optimization was done by using response surface methodology to find the best value (maximum value) of RRSS for optimum values of input parameters.

3. Materials and Methods

The conceptual model of work is shown in Fig. 1 and its experiment setup is shown in the Fig. 2. It was used to observe the variation in read range in presence of sandy soil (RRSS). Here the read range is the maximum distance between the tag and reader up to which the tag can be detected by the reader. In the experimental setup the RFID module is connected with the computer by using RS-232 interfacing cable. This computer screen will keep on displaying 12 bit ASCII code up to the time tag is in readable range of reader. In this experiment the car jack was used to give smooth vertical movement to the tag over the reader. Up to the time tag is in readable

range, computer will show the 12 bit ASCII code and the maximum distance between the tag and the reader after which the tag will become unreadable has been term as read range of RFID system. To measure the RRSS, digital Vernier caliper was used. In this setup a glass chamber was used to simulate the challenging environment conditions (varying temperature, Relative humidity, different soil layer thickness with varying grain size) which were required to carry out the experiment. Varying relative humidity, temperature, soil grain size and soil layer thickness were measured with the help of hygrometer, thermometer, sieves of 5 different sizes and digital Vernier respectively. In this research work, varying temperature, Relative humidity, different soil layer thickness with varying soil grain size were considered as input parameters whose effect has to measure on the output parameter i.e. Read Range in presence of sandy soil (RRSS).



Fig. 1: Conceptual model of work

This research work was mainly focused about the military areas situated in arid or semi-arid region of Rajasthan and the sandy soil is the only soil which covers the major portion in that reason. So the sandy soil was used in this experiment. Sandy soil has poor water retention capacity, high permeability and has poor structure.

Different levels of coding for all these input parameters are shown in Table 1. This extreme range of input variables was selected as per probable variations in climatic conditions of arid and semi-arid reasons. So practically the existence of these input parameters is not possible above and below the specified range. So, Table 2 is generated after exhaustive experimental run(s). Using these parameters experimental design developed through the statistical tool MINITAB 17. After that experimental results obtained after implementing the CCRD were stated in Table 3. Centre value of the process parameters were taken as per the climatic conditions available for most of the time throughout the year. ANOVA was applied on statistical model, R^2 value for Read Range in presence of sandy soil was found to be 98.93%.

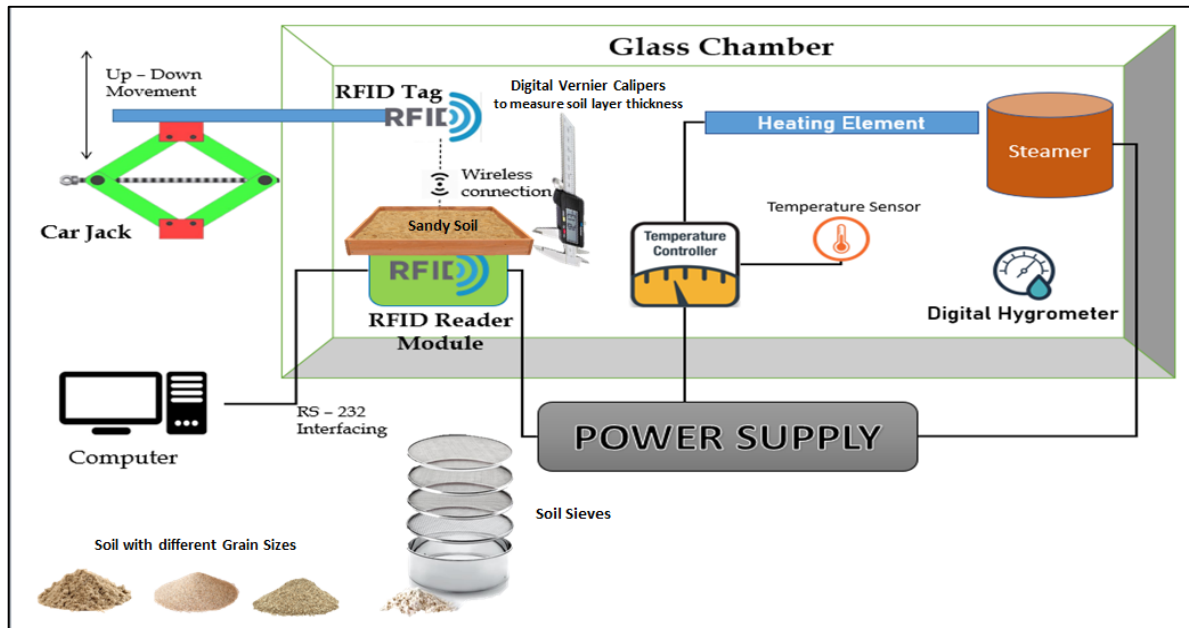


Fig. 2: Experiment setup

3.1 RSM Technology

RSM mathematical method is used to optimize the response. In practice, the RSM method capability is to access the best structure of the input variables for achieving the highest results with the least number of tests. This technique can be utilized in certain fields and does not have any constraint based on its application.

This study discussed the application of response surface methodology (RSM) and central composite rotatable design (CCRD) for modelling and optimization of the influence of some operating variables on the response. Four operating variables, namely ambient temperature (15-50) °C, Soil layer (0-90) mm, Relative humidity (35-70) % and soil grain size (0.45-2) mm were changed during the tests based on CCRD.

3.2 Experiment based on RSM

In this work, the variation in RFID system response i.e. RRSS (read range in present of sandy soil) was observed with varying input parameters i.e. SLT (soil layer thickness), SGS (soil grain size), RH (relative humidity) and TEMP (temperature).

Table 1: Experiment coding level

Factors or input parameters	Coded Levels				
	-2	-1	0	1	2
Temperature	15	20	25	40	50
Soil Layer Thickness	0	25	45	65	90
Relative Humidity	35	44	52	61	70
Soil Grain Size	0.45	0.78	1.18	1.6	2

Different levels of system input parameters are shown in Table 1. Experimental results obtained after executing CCRD are shown in Table 2.

Table 2: Post CCRD Experimental results

Exp. Run	Temp (°C)	SLT (mm)	RH (%)	SGS (mm)	RRSS (mm)
1	40	65	61	1.6	110.6
2	25	45	52	1.18	112.0
3	25	45	52	1.18	112.0
4	25	45	70	1.18	111.7
5	40	25	61	0.78	112.1
6	20	25	61	0.78	112.4
7	40	65	61	0.78	110.3
8	20	25	44	1.6	113.0
9	20	25	61	0.78	112.4
10	25	45	52	0.45	111.8
11	25	45	52	1.18	112.0
12	25	45	35	1.18	112.3
13	20	65	44	1.6	111.2
14	25	45	52	1.18	112.0
15	25	45	52	2	112.3

16	40	65	44	0.78	110.5
17	20	65	61	1.6	110.9
18	15	45	52	1.18	111.6
19	20	65	61	0.78	110.6
20	25	0	52	1.18	114.1
21	25	90	52	1.18	110.0
22	20	25	61	1.6	112.7
23	25	45	52	1.18	112.0
24	25	45	52	1.18	112.0
25	40	25	44	1.6	112.7
26	40	65	44	1.6	110.8
27	40	25	61	1.6	112.4
28	20	65	44	0.78	110.9
29	25	45	52	1.18	112.0
30	40	25	44	0.78	112.4
31	50	45	52	1.18	111.1

After the experimentation, as per the architecture matrix, ANOVA was applied, which offers quantitative results about the p-value. The p-value is explained as the alternative to the rejection levels to provide the lowest level of worth at which the null hypothesis would be rejected. The highest level of p is taken as 0.05 and the values above than 0.05 are referred as an irrelevant. R^2 and R^2 (adj) for this work are 98.93% and 97.99%

The MINITAB 17 software is used to developed empirical correlations for Read Range for Sandy Soil (RRSS) below Eq. 1.

$$\begin{aligned}
 RRSS(mm) = & 117.41 + 0.09 * Temp(^{\circ}C) - 0.052 \\
 & * SLT(mm) - 0.033 * RH(\%) + 0.19 \\
 & * SGS(mm) - 0.001 * \{Temp(^{\circ}C)\}^2 \\
 & + 0.00002 * \{SLT(mm)\}^2 + 0.0001 \\
 & * \{RH(\%)\}^2 + 0.01 * \{SGS(mm)\}^2 \\
 & + 0.00001 * Temp(^{\circ}C) * SLT(mm) \\
 & + 0.0001 * Temp(^{\circ}C) * RH(\%) \\
 & + 0.0001 * Temp(^{\circ}C) * SGS(mm) \\
 & + 0.000047 * SLT(mm) * RH(\%) \\
 & + 0.0004 * SLT(mm) * SGS(mm) \\
 & + 0.00226 * RH(\%) \\
 & * SGS(mm) \dots (1)
 \end{aligned}$$

4. Result and Discussion

MINITAB17 software was used to plot surface and contour plots. In this research work variation in RRSS (Read range in presence of Sandy Soil) were observed with four input parameters i.e. SGS (soil grain size), TEMP (temperature), RH (relative humidity) and SLT (soil layer thickness). But while plotting response curves only two control parameter were considered varying and rest two were taken at a constant value or hold value and these hold value has been sited on top right corner of each contour plot. All these hold values are the center values as mentioned in Table 1.

Fig. 3(a) to Fig. 3(f) shows the variation in LF RFID system read range in presence of sandy soil (RRSS) in between the RFID reader and tag. Variations were observed with respect to the varying input parameters i.e. Temperature - TEMP (15°C to 50°C), Relative humidity - RH (35% to 70%), Soil layer thickness - SLT (0 mm to 90 mm) and Soil grain size - SGS (.45 mm, .78 mm, 1.18 mm, 1.6 mm, and 2 mm).

Fig. 3(a) shows that how the RRSS get effect with varying SLT and RH, keeping other two parameters constant i.e. SLT at 45 mm and Temp at 25°C. This figure clearly shows that there is sharp decrement of RRSS with increase in SLT, at the same time it also shows that RRSS is decreasing with increase in RH but the fall is not so sharp.

Fig. 3(b) is the contour plot for the surface plot shown in Fig. 3(a). Fig. 3(b) clearly shows that the RRSS will have its maximum value of around 117.8 mm when the SLT is 0 mm and RH is 35 % and it will be at its minimum value of approximately 113 mm when the RH is 70 % and SLT is 90 mm.

Fig. 3(c) and Fig. 3(d) are the surface and contour plots which shows the variation in RRSS with varying TEMP and RH and rest two input parameters were keeping constant i.e. SLT is 45 mm and SGS is 1.18 mm. Fig. 3(c) gives the clear information that RRSS is decreasing with increase in RH but in case of varying TEMP, it keeps on increasing with increase in TEMP from 15°C to 25°C and after that it starts decreasing with increase in TEMP till it reaches up to 50°C. Contour plot for the parameter shown in Fig. 3(c) has been shown in Fig. 3(d). From contour plot it can be observed that RRSS achieves maximum value of 115.70mm when the TEMP is 25°C and 43%RH.

Fig. 3(e) shows the variation in RRSS with respect to varying TEMP and SGS with SLT and RH remains constant at 45 mm and 52 % respectively. Fig. 3(e) shows that RRSS keeps on increasing with increase in TEMP from 15 °C to 25 °C and later on it starts decreasing till the TEMP reaches up to 50 °C. From the same curve we can also observe that RRSS increases with the increase in SGS. Fig. 3(f) shows the contour plot for the same parameters and it shows that RRSS will attain its maximum value of 115.65 mm when the SGS is of 2 mm and the TEMP is 25 °C.

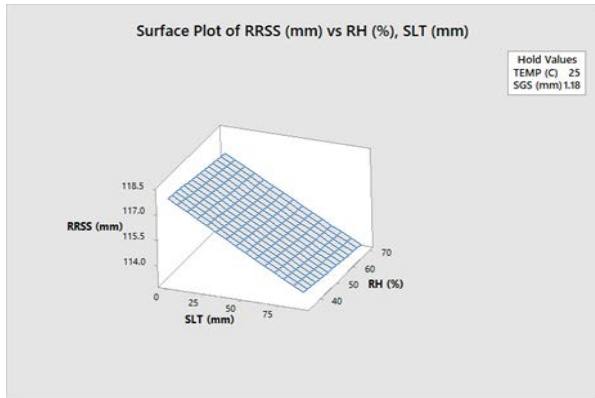


Fig. 3(a)

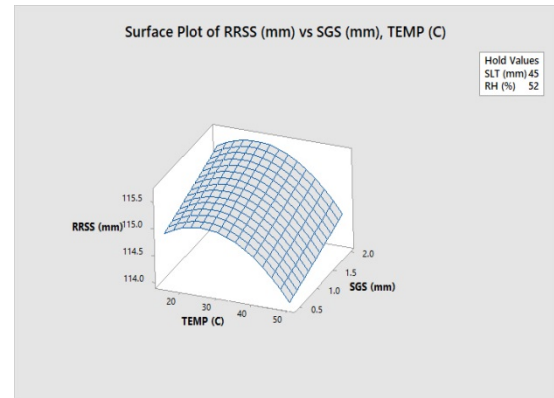


Fig. 3(e)

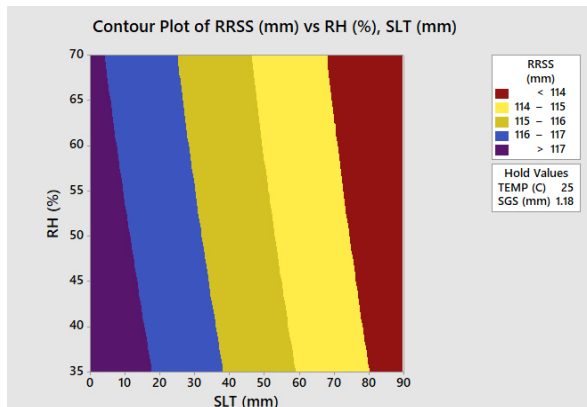


Fig. 3(b)

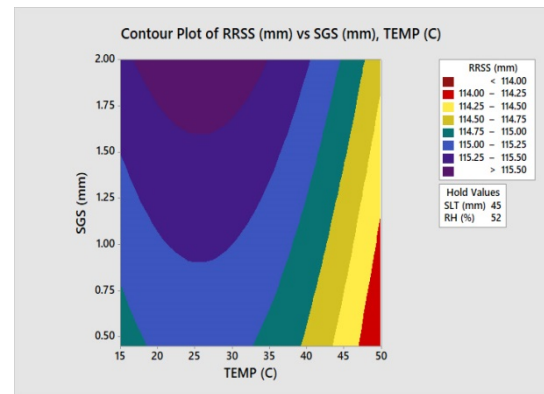


Fig. 3(f)

Fig. 3: Effect of environment parameters on read range in presence of sandy soil.

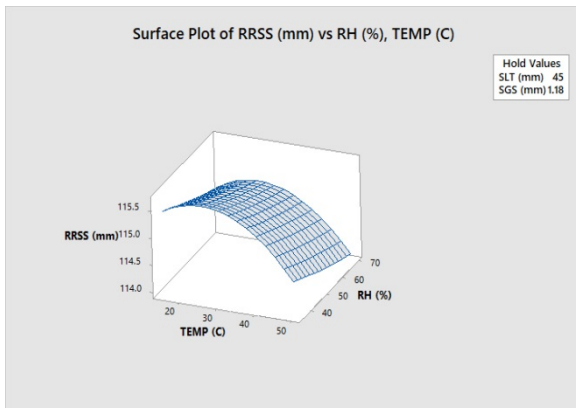


Fig. 3(c)

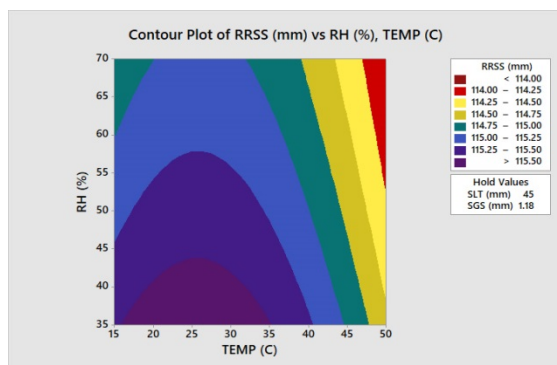


Fig. 3(d)

5. Input parameter optimization and its experimental validation

Optimized results based on RSM have been shown in the Fig. 4. From this figure it is clear that RRSS can achieve its maximum value for the combination of optimized values of input variables i.e. SLT, SGS, RH and TEMP. This research work mainly focuses on optimization of RRSS when the sandy soil is present in between the RFID tag and reader.

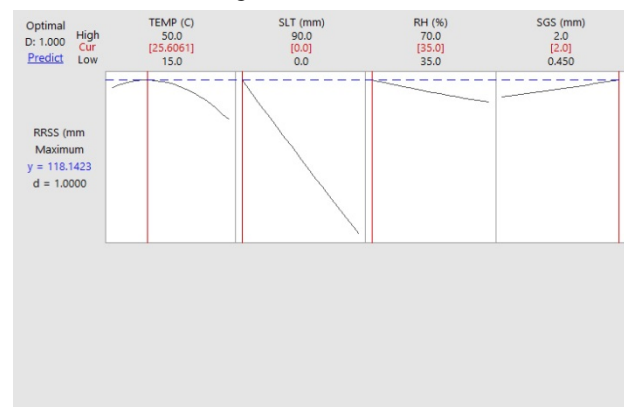


Fig. 4: Optimization plot: Impact of input parameters on responses

From the optimization plot it is observed that best possible value of RRSS of 118.1423 mm can be achieved for the optimum combination of input variables i.e. TEMP, SLT, RH and SGS were found to be 25.606 °C, 0 mm, 35 % and 2 mm respectively. In this process the received value of desirability was unity and it is the favorable condition for the optimization process of RRSS.

For validation the RSM result was verified at 25.6 °C atmospheric temperature, 0 mm soil layer thickness, 35 % relative humidity and 2 mm soil grain size (approximately). Table 3 shown lab experiment details and it also shows the output response for RRSS. Experimental responses and RSM optimizer values were compared.

Table 3. Experimental validation of RSM results

Experimental Validation			
RRSS at 25.6°C, Zero mm SLT, 35% RH, with 2 mm SGS	Predicted	Actual	% Error
	118.14	114.2	3.33

Percentage error for the RRSS response is 3.33% and it is was well within the tolerable limits²³⁾. Hence, the results predicted by RSM can be used for best utilize for the input setting.

6. Conclusions

This research work was carried out to optimize the RRSS (Read Range in presence of Sandy Soil). Statistical and experimental analyses of RRSS (Read Range in presence of Sandy Soil) were carried out with respect to four input variables i.e. SLT (Soil Layer Thickness), SGS (Soil Grain Size), TEM (Temperature) and RH (Relative Humidity). Later the RSM mathematical modeling was used to carry out the optimization process. With the help of RSM, optimization of system parameters can be done and that too with minimum number of experiment runs (L31). From the complete study it was concluded that -

- The input parameters whose affect was observed on RRSS were Temp (15°C to 50°C), RH (35% to 70%), SLT (0 mm to 90 mm) and SGS (0.45 mm to 2.0 mm).
- Best value of RRSS was attained for the optimum values of input variables i.e. Temp, RH, SLT and SGS were 25.606 °C, 35 %RH, 0 mm and 2 mm respectively.
- RRSS (read range in presence of sandy soil) attained its maximum value of 118.142 mm for the combination of optimum values of input variables.
- Validation of RSM results were carried out by

multiple confirmation trials and the errors were calculated between the predicted and actual values. The calculated error was well within the tolerable limit i.e. below 5 %.

From the above conclusion it can be said that the low frequency RFID system can attain maximum RRSS (read range in presence of sandy soil) if it works at above mentioned optimized values of input parameters and it can work well in arid or semi-arid region where hostile environmental condition prevail and effects the RFID system detectability.

Nomenclature

<i>RRSS</i>	Read Range in presence of Sandy Soil
<i>SLT</i>	Soil Layer Thickness
<i>SGS</i>	Soil Grain Size
<i>TEMP</i>	Temperature
<i>RH</i>	Relative Humidity
<i>LF</i>	Low Frequency
<i>ACA</i>	Anisotropic Conductive Adhesive
<i>RFID</i>	Radio Frequency Identification
<i>RSM</i>	Response Surface Methodology

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