Chapter 7
Density Prediction Model and Characterization Method of Density Variation Rate in Finished Tobacco Box Based on Microwave Signal Value

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Abstract The detection and control of the density uniformity of finished tobacco packing can be applied in the threshing and redrying process, and in order to better popularize it, we do the following researches and practices. Through the research on the repeatability of detecting the tobacco density in the box by the microwave signal value, and the correlation between the microwave signal and the tobacco density in the box detected by the nine-point static picking-out method and the ionizing radiation method, the density prediction model based on the microwave signal value is established. According to the results, we know that the tobacco density in the box detected by microwave signal value shows good repeatability. The tobacco density detection model based on microwave signal value has a higher determination coefficient and fewer errors, and has better prediction effect. The prediction model is adopted to convert the microwave signal value in the box into the density value. And based on the results and feedback, we can guide the production and quality evaluation as well as the risk prevention and control, then the characterization methods of tobacco density variation rate in zoning and grid boxes are proposed. respectively. The results can not only be used as the adjustment basis of the homogenizing device in the tobacco packaging process, but also provide data support for the risk prevention and control of the aging process in tobacco storage.

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7.1 Introduction

The packing density uniformity of the tobacco box in the threshing and redrying process will directly affect the aging quality in the tobacco raw material storage link and the processing quality in the primary processing. For example, the large density variation in the tobacco box in the aging process will easily lead to the appearance of oil and caking, while the loosening and conditioning in the primary processing is liable to make the leaves difficult to loosen [1–5]. Therefore, the control of packing density uniformity of tobacco has always been a hot research topic in the quality control of threshing and redrying. The nine-point static picking out method (hereinafter referred to as the nine-point method) is defined in the tobacco industry standards such as Leaf tobacco-Threshing and redrying-Technical specification (YC/T146-2001) [6] and the Threshed tobacco-Quality inspection (YC/T147-2001) [7]. Based on the definition of density [8], this method uses a drill core with a diameter of 40 mm to drill samples at 9 specified positions on the finished tobacco box, and weigh and calculate its density variation rate (DVR); However, this method has some defects in the actual operation process, mainly manifested in such aspects as the damage of tobacco, high labor intensity, long detection time, and failure to meet the needs of on-line detection [9–11];Tobacco and tobacco products-non-destructive determination of strips density deviation ratio in case-ionizing radiation method (GB/T31786-2015) [12] (hereinafter referred to as X-ray method); although this method has solved the problems of the nine-point method, it faces great limitation in its popularization and application in the tobacco industry due to the problems such as large equipment investment, cumbersome radioactive source management, and psychological obstacles of users.

In recent years, with the in-depth promotion of major special projects for the upgrading of threshing and redrying technology, the characteristic process technology of Chinese-type cigarettes has been moving forward, and the quality detection and control of the threshing and redrying process has attracted more and more attention [1–3]. As an important reference index affecting the aging and primary processing, the density uniformity in the tobacco box is particularly important for the detection and control. Studies have shown that the microwave micro winding method uses the corresponding relationship between the density of the material placed in the resonance cavity and the perturbation of the resonance cavity to detect the density [13, 14]. This method is an online, non-destructive, and safe density detection method [15, 16], and has been successfully applied in tobacco rod density detection [17–20]. In order to further strengthen the application of the detection and control of the density uniformity of tobacco packing in the threshing and redrying, after combining with the current situation that microwave moisture detector is generally set up in the preloading and packaging link in threshing and redrying enterprises, we study the relationship between the microwave signal and the density value of tobacco in the box detected by nine-point method and X-ray method, establish a prediction model of the tobacco density value based on the microwave signal value, and propose a characterization method of the density variation rate. By doing so, we hope these efforts could provide data support for the regulation basis of the homogenizing device in the leaves packaging process and the risk prevention and control of the aging process of tobacco storage.

7.2 Materials and Methods

7.2.1 Instruments, Equipment, and Materials

Materials: Middle tobacco leaves are selected in Yulong in Lijiang, Yunnan, Ninghua in Sanming, Fujian and Fei County in Linyi, Shandong, in 2020.

Instruments: MMA-4020 microwave moisture meter (MALCAM); Detector for density variation rate of tobacco in Fe3 box (Beijing Bangruida Mechanical and Electrical Equipment Co., Ltd.); Sample plate for detecting the variation rate of tobacco density in the box by nine-hole method, and the sampling drill core with diameter of 40 mm and length of 725 mm (self-made).

Equipment: Double KY161B pre-pressing packers and KY242 re-pressing packers (Baoying Yanlord Industrial Co. Ltd.), triple KY16A pre-pressing packers and KY25A re-pressing packers (Kunming Fengdong New Technology Group Development Co., Ltd), and triple KY17A pre-pressing packers and KY25A re-pressing packers (Kunming Fengdong New Technology Group Development Co., Ltd).

7.2.2 Sample Preparation and Methods

Sample preparation: In order to increase the representativeness of the data and the generalization ability of the model, nine weight gradients of 160 kg, 170 kg, 180 kg, 190 kg, 200 kg, 205 kg, 210 kg, 215 kg, and 220 kg are prepared, respectively, with 3 boxes of each weight gradient (1 box of Shandong Linyi sample with 180 kg weight gradient is missed). The net weight of packed tobacco in each gradient box is shown in Table 7.1.

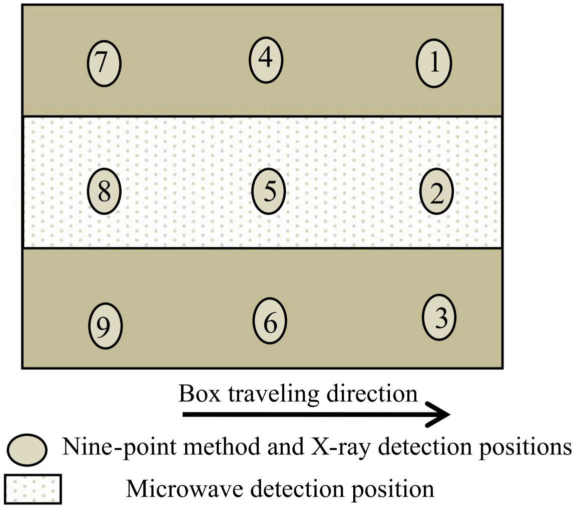
Experimental methods: We use the microwave method and X-ray method to detect for 10 times, and then select the "2" sample box to implement the nine-point detection method; Among them, the detection methods of Lijiang samples are used by microwave method, nine-point method and X-ray, Sanming samples are used by microwave method and nine-point method, and Linyi samples are used by microwave method and X-ray. MMA-4020 microwave moisture meter is used for microwave method; The X-ray uses the tobacco density variation rate detector in box FE3; The nine-point method uses the sampling drill core to drill samples at the specified 9 positions on the finished tobacco box, weigh and detect its density. Among the nine points detected by the nine-point method and X-ray, the average density values of the

Table 7.1 Net weight of packed tobacco in each gradient sample box (unit: kg)

No	Gradient box number	Samples of Lijiang, Yunnan	Samples of Sanming, Fujian	Samples of Linyi, Shandong
1	160–1	160.4	160.8	157.5
2	160–2	159.8	160.3	160.2
3	160–3	160.5	160.3	162.2
4	170–1	171.8	168.8	170.1
5	170–2	168.0	170.0	170.5
6	170–3	169.9	170.2	171.6
7	180–1	179.8	179.5	180.3
8	180–2	179.5	179.7	180.9
9	180–3	179.3	180.3	/
10	190–1	189.9	191.4	187.5
11	190–2	189.2	190.5	189.7
12	190–3	188.8	191.1	190.7
13	200–1	198.3	199.6	200.7
14	200–2	200.8	200.1	200.9
15	200–3	200.4	199.7	200.9
16	205–1	205.7	203.3	203.6
17	205–2	205.3	203.8	206.2
18	205–3	205.7	203.3	206.3
19	210–1	211.5	212.0	209.8
20	210–2	208.7	211.6	210.0
21	210–3	210.1	211.7	210.8
22	215–1	213.7	213.2	214.0
23	215–2	214.1	213.7	214.8
24	215–3	215.5	214.2	216.3
25	220–1	220.9	220.5	220.4
26	220–2	221.2	221.2	220.8
27	220–3	218.2	221.5	222.0

second, fifth, and eighth points corresponding to them are selected to represent the nine-point method and X-ray detection values for analysis; The detection positions of microwave detection, X-ray, and nine-point method are shown in Fig. 7.1.

Fig. 7.1 Identification of detection area



Data statistical analysis method: The model is established by univariate linear regression method, and the prediction model of univariate linear regression analysis method is

$$Y_i = ax_i + b \tag{7.1}$$

Where, xi represents the value of phase i independent variable; Yi the value of phase i dependent variable; a and b the parameters of univariate linear regression equation;

Parameter b is obtained by the following formula:

$$b = \frac{\sum Y_i}{n} - a\frac{\sum x_i}{n} \tag{7.2}$$

Parameter a is obtained by the following formula:

$$a = \frac{n\sum x_i Y_i - \sum x_i \sum Y_i}{n\sum x_i^2 - \left(\sum x_i\right)^2} \tag{7.3}$$

7.3 Results and Analysis

7.3.1 Repeatability of Microwave Signal Value in Tobacco Density Detection

It can be seen from Fig. 7.2 that the variation coefficient of microwave signal value for ten-time repeated detection of the boxes of each gradient sample is less than 1.0%, except that the Linyi sample 210–2 is 9.26%. This result indicates that good repeatability of microwave signal value in detecting tobacco density can meet the stability requirements of tobacco density detection in the box.

7.3.2 Correlation Between the Microwave Signal Value and the Density Value Detected by the Nine-point Method and X-ray Density Value

Samples of Lijiang

From Figures 7.3 and 7.4, we can see that with the increase of the density value detected by the nine-point method and X-ray method, the microwave signal value tends to increase, and its correlation coefficients reach 0.940 and 0.897, respectively, demonstrating that there is a strong correlation between the microwave signal value and the density value detected by the X-ray method and the nine-point method.

It can be seen from Fig. 7.5 that with the increase of the density value detected by the nine-point method, the X-ray detection density value tends to increase, and its correlation coefficient reaches 0.921. It shows that there is a strong correlation between X-ray and nine-point method.

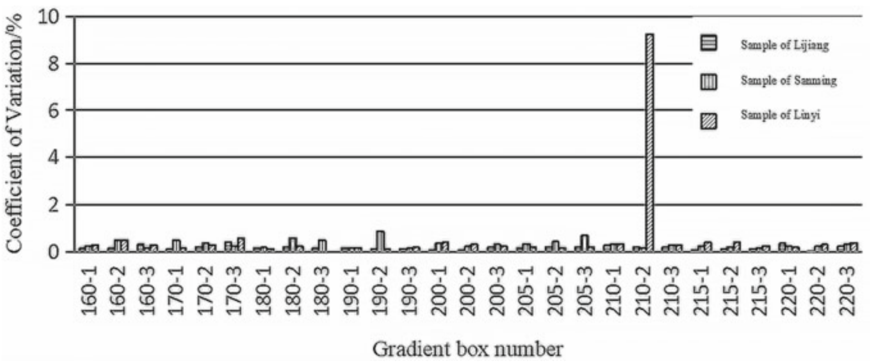


Fig. 7.2 Statistical graph of coefficient of deviation for repeated detection of microwave signal value

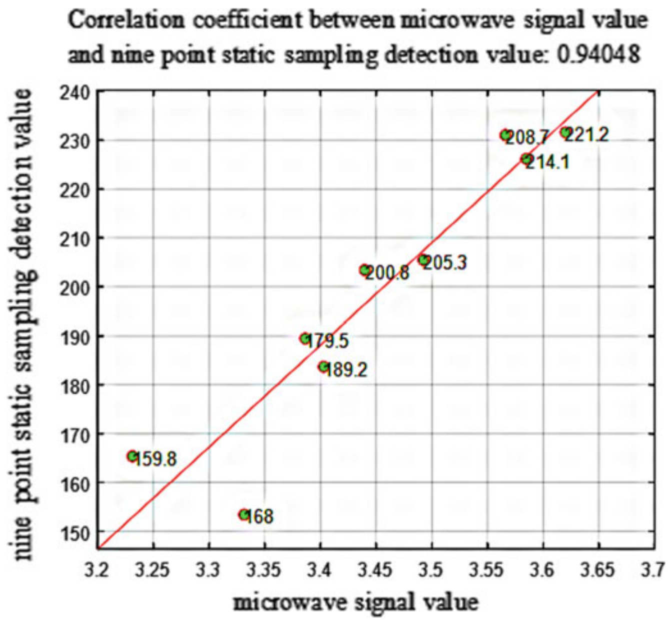


Fig. 7.3 Scatter plot of nine-point method and microwave signal value

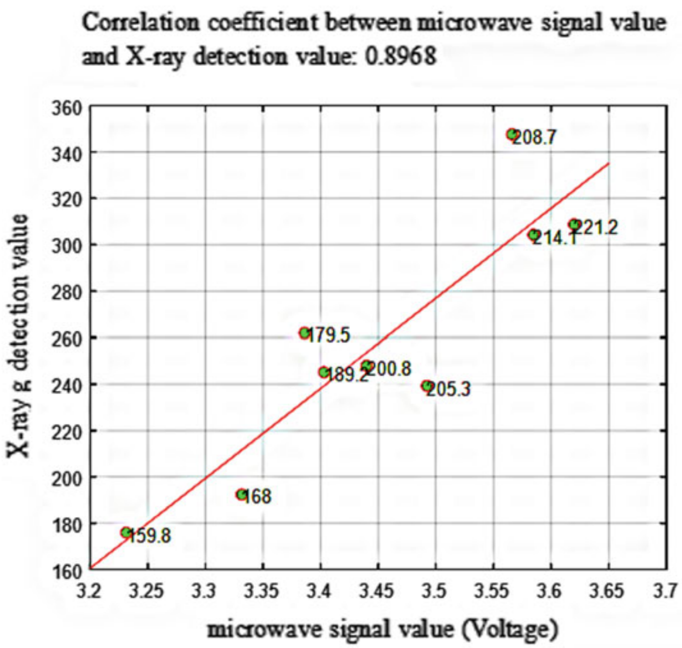


Fig. 7.4 Scatter plot of X-ray and microwave signal values

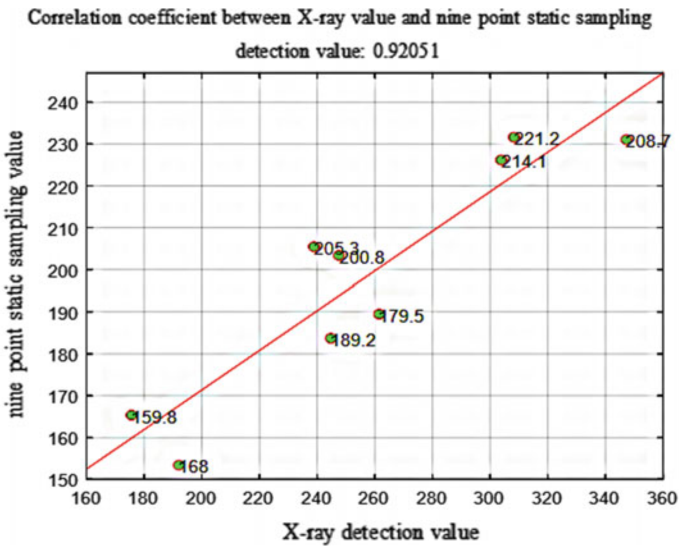


Fig. 7.5 Scatter plot of X-ray and nine-point method

Samples of Sanming

According to Fig. 7.6, we know that with the increase of the density value detected by the nine-point method, the microwave signal value tends to increase, and its

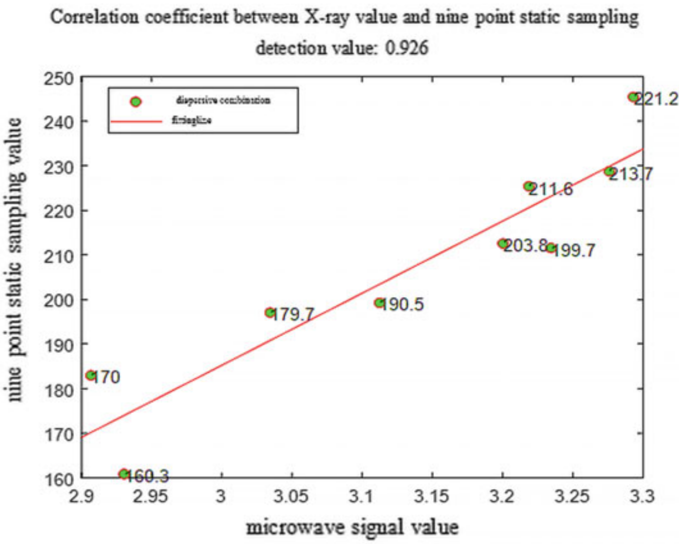


Fig. 7.6 Scatter plot of nine-point method and microwave signal value

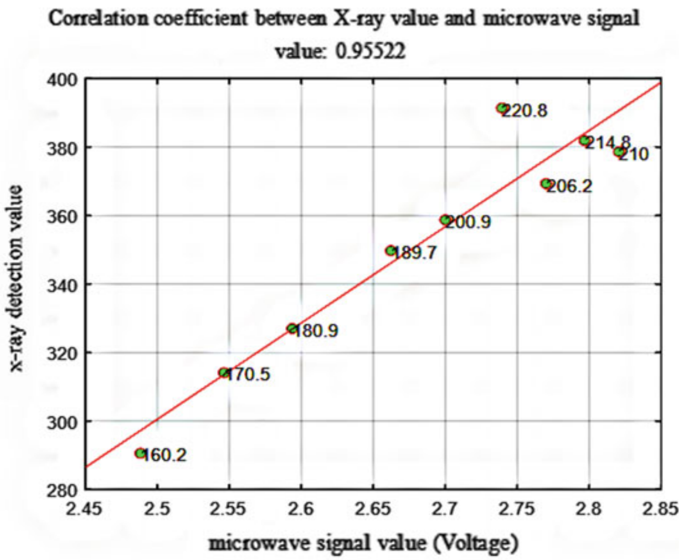


Fig. 7.7 Scatter plot of X-ray and microwave signal values

correlation coefficients reach 0.926, respectively, indicating that there is a strong correlation between the microwave signal value and the density value detected by the nine-point method.

Samples of Linyi

It can be seen from Fig. 7.7 that with the increase of X-ray detection density value, the microwave signal value tends to increase, and its correlation coefficient reaches 0.955, indicating that there is a strong correlation between microwave signal value and X-ray detection density value.

7.3.3 Establishment of Box Density Prediction Model Based on Microwave Signal Value

There is a strong correlation between the nine-point method and the X-ray detection density value. Therefore, when establishing the box density value prediction model based on the microwave signal value, we adopt the classical nine-point method detection data.

Correction of Test Data

Nine-point density detection value

In order to eliminate the errors of the equipment and personnel in the detection process of nine-point method, the detection data of Lijiang samples is corrected based on the nine-point density detection value of Sanming samples. The correction model is as follows:

$$f(x) = 1.028 * x - 14.03 \tag{7.4}$$

Where $R^2 = 0.8556$.

It can be seen from Figs. 7.8 and 7.9 that the systematic error between the nine-point density test value of the Sanming samples has reduced after correcting the test data of Lijiang samples.

Microwave signal value

In order to eliminate the error between different microwave density detector equipment, the detection data of Lijiang samples is corrected based on the microwave signal value of Sanming samples. The correction model is as follows:

$$f(x) = 0.8116 * x + 0.7468 \tag{7.5}$$

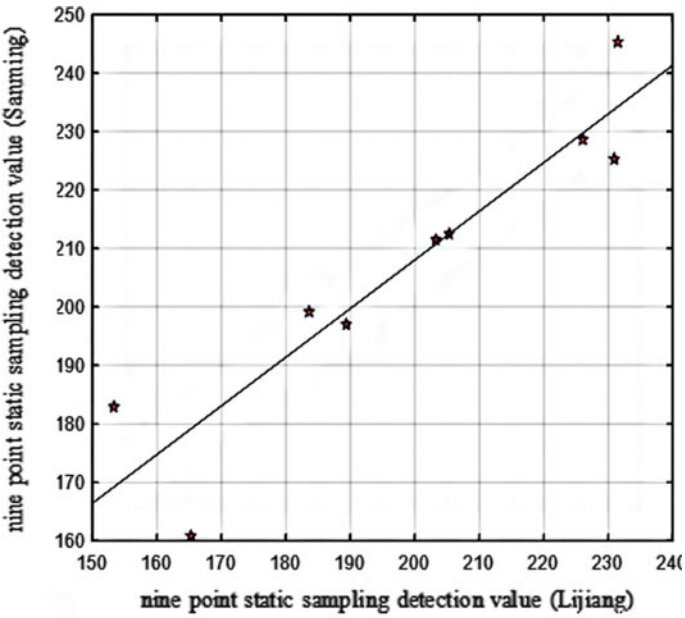


Fig. 7.8 Comparison chart of density value detected by the nine-point method

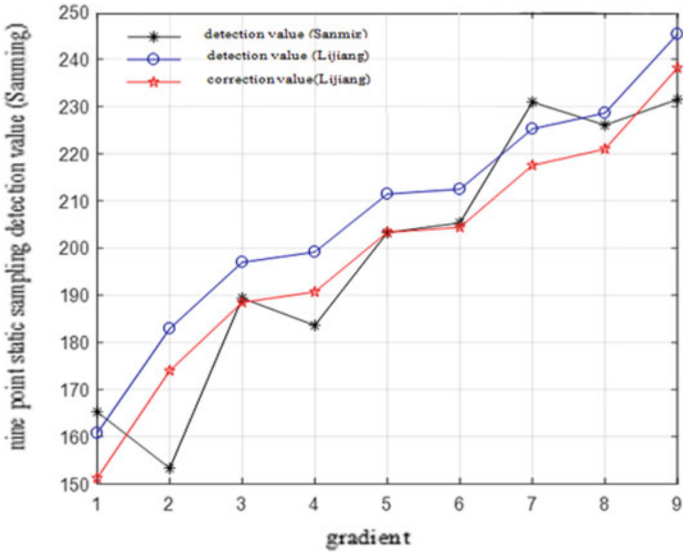


Fig. 7.9 Comparison chart of density value before and after correction by the nine-point method

Where $R^2 = 0.8341$.

From Figs. 7.10 and 7.11, we can see that after using the microwave signal value of Sanming samples to correct this value of Lijiang samples, the systematic error between the microwave signal values has effectively reduced.

The Establishment of Prediction Model

The corrected nine-point method detection density value and microwave signal value data are randomly divided into correction set (modeling set) and verification set. 80% of the samples are selected to establish the model, and 20% of the samples are used to predict the established model. The prediction model of microwave signal value and nine-point method detection density value is established as follows:

$$y = 204.9 * x - 202.4 \tag{7.6}$$

Wherein, the determination coefficient of the model is $R^2 = 0.8626$; The root mean square error of the model validation set RMSEP = 5.282, the average absolute deviation MAD = 5.0525, and the average relative deviation MRD = 2.45%.

The model has high determination coefficient and small error; Fig. 7.12 shows its good prediction effect.

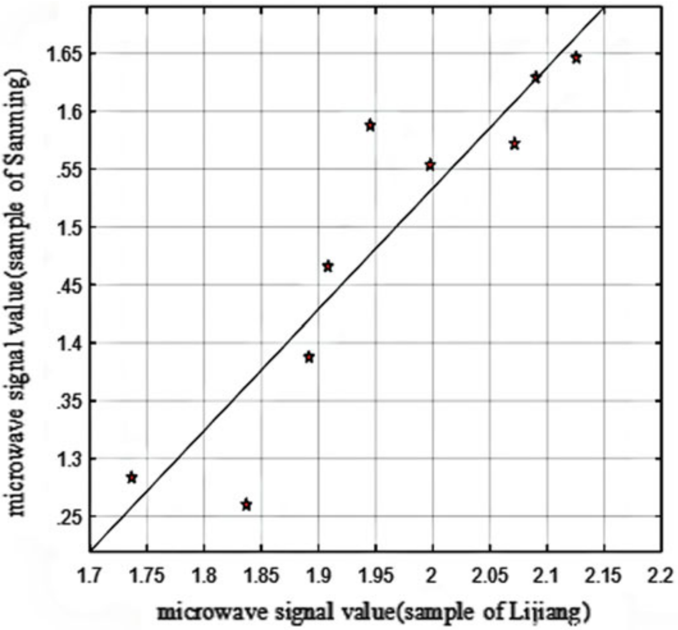


Fig. 7.10 Comparison of microwave signal value

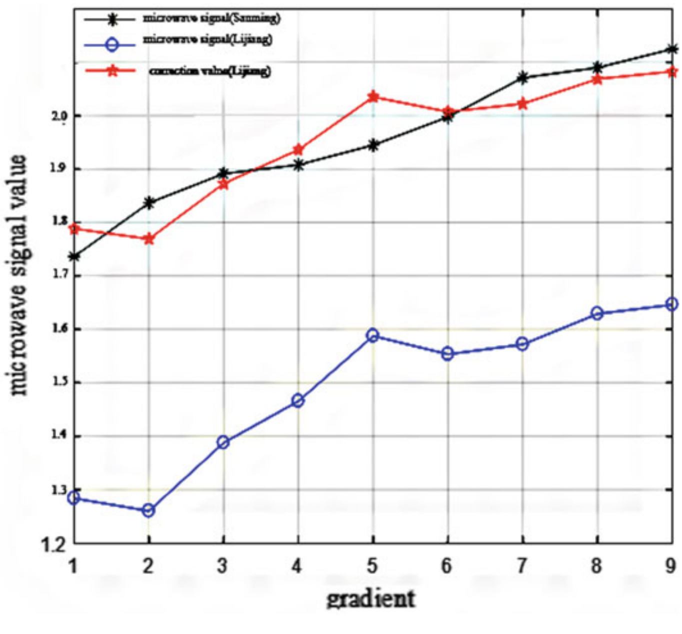


Fig. 7.11 Comparison of microwave signal values before and after correction

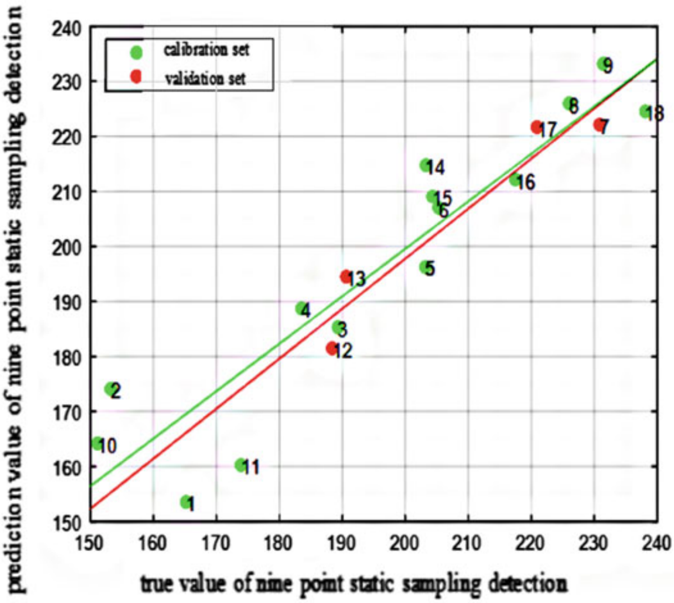


Fig. 7.12 Comparison between the real value and the predicted value of the nine-point density detection value model for microwave signal value

7.3.4 Characterization Method of Tobacco Density Variation Rate in Box Based on Microwave Signal Value

Variation Rate of Tobacco Density in Gridded Box Based on Quality Evaluation and Risk Prevention and Control

Based on the two main box models currently used in the tobacco industry, the surface area of the box is divided into grids according to the area of the nine-point sampling pipe. It can be seen from Table 7.2 that the two general-purpose boxes of model 1 and model 2 can be divided into 514.24 and 483.29 grids, respectively. In order to facilitate the application and statistics collection, the two types of boxes are uniformly divided into 500 grids.

The microwave detector is used to scan the finished box to obtain its microwave signal value. According to the prediction model of the density value in the box based on the microwave signal value, the value in each grid is transformed into the density value, and its mean value is calculated, respectively. The density variation rate DVR of the tobacco in the box is calculated by the density mean value in each grid. After that, the proportion of the number of grids with deviation of 10%, 20%, 30%, 40%, 50%, and > 50% from the absolute value of tobacco density in the box in the total grid shall be counted (see Table 7.3 for an example).

Table 7.2 Grid division of different types of tobacco box

Types of tobacco box	Type 1	Type 2
Length, width, and height/mm	1136 × 720 × 725	1115 × 690 × 725
Volume/mm3	592992000	557778750
Packing weight/Kg	200	
Theoretical density value/(kg/m3)	337.27	358.57
Surface area/mm2	817920	769350
Strap width/mm	12.5	12.5
Area of strips on the upper surface of tobacco box(four)/mm2	36000	34500
Inside and outside diameter of nine-point sampling tube/mm	40/44	
Nine-point sampling tube area/mm2	1520.53	
Number of grid division/piece	514.24	483.29

From Table 7.3, we can see that when the number of grids in which the absolute value deviation of the tobacco density value in the box is less than 10% accounts for a large proportion, the DVR value in the box is small and the density is relatively uniform; While a small proportion of this number shows large DVR value and poor uniformity. The results can finely describe the uniformity of the density of tobacco in the box, and provide data support for the prevention and control of quality risks such as mildew and carbonization in the later aging process of tobacco storage.

Density Variation Rate of Tobacco in Partitioned Box, Where the Tobacco Production is Guided by the Feedback

According to Table 7.2, the surface of two types of tobacco boxes can be divided into 9 areas on average, the average tobacco density of each area can be calculated, respectively, and then the DVR of tobacco density in the box can be calculated (see Table 7.4 for an example), which can be used to guide and optimize the homogenization device of tobacco leaves packaging process online. Therefore, the uniformity of packed tobacco density can be further improved.

Table 7.3 Density deviation rate of tobacco in gridded box (unit: %)

Samples in tobacco box	Deviation from the absolute value of the theoretical density of tobacco in the box and the proportion of the number of grids						DVR
	≤10	***10–20***	***20–30***	***30–40***	***40–50***	***>50***	
box 1	73.96	17.02	9.02	0	0	0	9.71
box 2	74.23	25.77	0	0	0	0	6.20
box 3	97.08	2.92	0	0	0	0	5.50

Table 7.4 Deviation rate of tobacco density in partitioned box

Samples in tobacco box	Tobacco density value in the area (kg/m3)									DVR
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
box 1	265.16	331.52	317.86	314.64	322.86	324.95	320.73	314.04	268.80	7.90
box 2	350.38	375.93	368.80	357.88	341.15	336.54	329.36	324.14	317.53	5.84
box 3	360.38	346.71	343.68	339.54	327.00	320.34	314.43	314.98	311.18	5.23

7.4 Conclusion

According to the variation coefficient of microwave signal value detected repeatedly for 10 times in each gradient sample tobacco box, we can conclude that the microwave signal value in detecting the tobacco density in the box shows good repeatability; The correlation between microwave signal value with nine-point method and X-ray detection density value can reach 0.90 or so, which has a strong correlation; And these results show that the microwave method is a feasible way to detect the density deviation rate of tobacco in the box and meets the repeatability requirements. Based on the univariate linear regression equation, the prediction model of microwave signal value and nine-point density value is established by fitting the linear relationship between microwave signal and nine-point density value; The determination coefficient of the model $R^2 = 0.8626$; Root mean square error of model validation set RMSEP = 5.282, mean absolute deviation MAD = 5.0525, mean relative deviation MRD = 2.45%; These results indicate that the model has high determination coefficient and small error, and the prediction effect is good. Based on the results and feedback, we can guide production and quality evaluation, and propose the characterization methods of density deviation rate of tobacco in partitioned and gridded boxes, respectively. Compared with the previous methods, these two characterization methods represent the overall density distribution of the box through the density values of nine points, which can comprehensively and accurately reflect the uniformity of tobacco density in the box. It can not only provide a relatively reliable basis for the on-line feedback control of the homogenizing device in the tobacco leaves packaging process, but provide data support for the prevention and control of quality risks such as mildew and carbonization in the aging process of tobacco storage.

Using the microwave method to detect the density variation rate in the finished tobacco box can not only overcome the shortcomings of nine-point method and X-ray method in practical application, but also fully combine the current situation that the threshing and redrying processing enterprises generally set up microwave moisture detectors in the preloading and packaging links, effectively reducing the investment of density variation rate detection equipment in the finished tobacco box. It provides technical support for better popularization and application of the detection and control of tobacco packing density uniformity in threshing and redrying processing. However, due to the difficulty in preparing samples with different packing weights and the heavy detection workload through the nine-point method, the paper only tested three middle tobacco leaves. In the later stage, experimental research will be carried out on the upper and lower tobacco leaves to improve the density variation rate method in the finished tobacco box. By doing so, the methods can be suitable for the research of different parts of tobacco.

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