Defect Classification using Pressure Change of Sleeve Soldering Machine

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Abstract: The solder joint significantly affects the quality of the electronic equipment. Recent researches focus on the automatic inspection of solder joints to detect the fault with high accuracy. The sleeve soldering system is one of the soldering equipment. The system puts a heated ceramic sleeve over the through-hole of the print circuit board and melts the solder piece dropped into the sleeve. The system also feeds a certain amount of nitrogen gas into the sleeve continuously, and the gas goes out through the lower end of the sleeve. Pressure in the sleeve is changed by narrowing down or blocking the exit hole in each soldering process, such as the sleeve approaches to the print circuit board, drop off the solder piece, and solder melting. Here, the pressure at each process may differ between correct and incorrect soldering. In this paper, the authors classify the correct and incorrect soldering from the pressure change's features. The results of the experiment show that both correct and incorrect are classified with 98.3% accuracy.

CCS CONCEPTS • Computing methodologies →Supervised learning by classification;• Hardware → Bug detection, localization and diagnosis.

Additional Keywords and Phrases: soldering, sleeve soldering, fault classification, machine learning

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1 INTRODUCTION

The solder joint between the print circuit board (PCB) and the device significantly affects the quality of the electronic equipment [8]. Hence inspection is an essential process to detect soldering defects of each soldering [1]. A typical inspection method is to visually see the result to confirm the solder fills a through-hole of PCB and the solder made a back fillet. Such manual inspection depends on the engineers' experience [7], especially when the target device is a high density of small components; the reliability is low [6]. Recent researches focus on the automatic inspection of solder joints to detect the fault with high accuracy [5].

Figure 1 shows one of the implementations of the sleeve soldering system. The system puts a heated ceramic sleeve over the through-hole of the PCB and melts the solder strip dropped into the sleeve. The melted solder slips down the pins and enters the through-hole by its weight. After a specific time, the sleeve rises and

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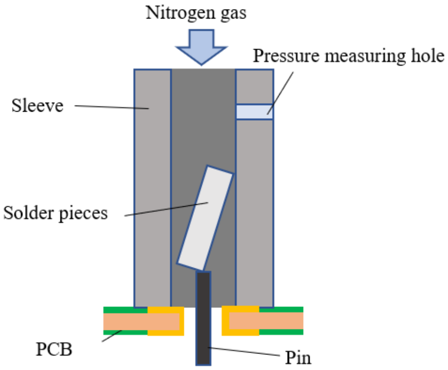

Figure 1: Sleeve Soldering System

moves to the next soldering object. The system prevents the scattering and delivers a certain amount of solder into the through-hole because the system loads a specific length of wire solder into the sleeve, the melted solder enters the specific hole. The system also prevents solder oxidation by filling the sleeve with nitrogen gas; It reduces the chance of cold joint from bad-flow solder.

In this paper, the authors propose an inspection method for the sleeve soldering system to detect soldering defects. The system continuously feeds a certain amount of nitrogen gas into the sleeve, the gas goes out through the lower end of the sleeve, a gap between the sleeve and PCB. The sleeve pressure is changed by narrowing down or blocking the exit hole in each soldering process such as the sleeve approaches to the PCB, drop off the solder piece, and solder melting. Here, the pressure at each process may differ between succeed and failed soldering. For example, some cold joint keeps melted solder on the top of the pin. The solder blocks the gas flow toward the outer-sleeve even the sleeve has a sufficient gap between PCB. The melted solder at correct soldering slips into the through-hole and not blocks the gas flow; hence the pressure drops when the sleeve rises. The authors classify correct/incorrect solders with machine learning. As classification features, the authors evaluate pressure drop at the sleeve rises; that may have different characteristics between correct and incorrect soldering.

2 PRELIMINARIES

2.1 Sleeve Soldering

The conventional point soldering method includes the iron tip soldering and the laser soldering. For the iron tip soldering, the heated iron tip touches the pin and the PCB, the solder is melted with the iron tip and supplied to the joint between the pin and the PCB. In the laser soldering case, the laser irradiates on the pin and the PCB and generates heat. The temperature of the joint rises to the melting point, and then the solder is supplied.

The sleeve soldering is an excellent method compared with other point soldering methods. For example, the sleeve soldering compared with the iron tip soldering, the wetting properties representing the solder's spread are good, and the iron tip does not wear away. The sleeve soldering compared with the laser soldering, there is no scattering of the ball solder. The quality is stable since the joint supply a certain amount of the solder piece.

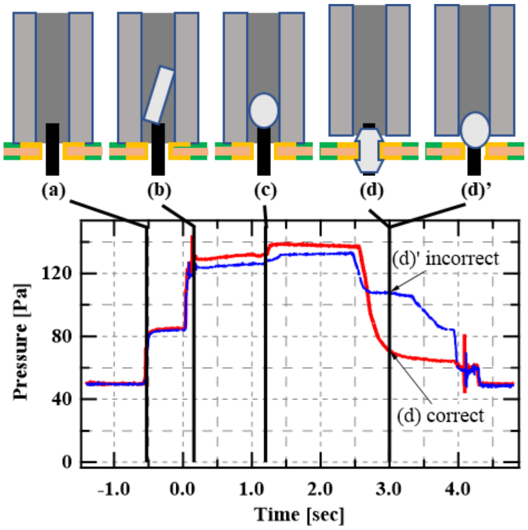

Figure 2: Sleeve’s Pressure Change during Soldering

Furthermore, the sleeve soldering differs from other soldering methods in that the nitrogen gas blocks oxygen and prevents oxidation of the solder surface.

Figure 2 shows pressure changes in the sleeve. In the figure, (a)-(d) show (a) contact between the sleeve and the PCB, (b) solder piece falling, (c) solder piece during melting, and (d) and (d)’ sleeve rising, respectively. Figure 2(d) and (d)’ indicate correct and incorrect solder, respectively. The time t = 0 s indicates when the solder piece is cut at the top of the sleeve. At t = -0.57 s, 0.03 s, and 1.2 s, the pressure rise occur. At t = 2.5 s, the pressure decline occurs. The first pressure rise at (a) t = -0.57 s is due to the contact between the sleeve and the PCB. The second pressure rise at (b) t = 0.03 s is due to the falling of the solder piece into the sleeve and narrowing the gap between the sleeve and the PCB. The third pressure rise at (c) t= 1.2 s is because the melting solder fills the gap between the pins and the PCB. The sleeve rise results enlarge the gap between the sleeve and the PCB, hence a decline in the pressure at t = 2.5 s. If the pressure does not decline sufficiently as in (d)’, the cold soldering joints narrow flow path.

2.2 Related Work

Some researches proposed methods to identify the defect solder based on features of the PCB image. Wu [10] extracts the PCB image features and identifies the defects with five machine learning methods, decision tree, k-NN, SVM, NN, and Random Forest. The result showed the random forest predicts five kinds of soldering defects with 100% accuracy. Wenting et al. [4] used semi-supervised learning to reduce the annotation cost and classified correct/incorrect solder. The result showed the annotation error rate was less than 1.5% in all data sets. Compared with these studies, our method that observes pressure changes in the sleeve soldering system has several advantages. Feature extraction from the PCB image is a post-process evaluation; that requires the soldering of each PCB finished before the camera takes a picture. On the other hand, the proposed method using the pressure changes allows in-process evaluation of each through-hole on the board while soldering the subsequent through-holes on the same PCB; the method allows early and efficient defect

Table 1: Settings for Soldering Experiment

Temperature[◦C]	Solder length[mm]	# Soldering
360	3.5	30
	3.0	70
	2.5	178
350	3.0	22
345	4.0	347
344	3.0	60

detection. The pressure change contains information about several processes from the start to the end of the soldering (see Figure 2.) Many studies use extracted features from waveform data to classification [3,9]. The authors extract features from the pressure changes to predict the defect soldering.

3 EXPERIMENT

3.1 Data

To observe a sufficient number of defect soldering, the authors measure the pressure changes during the soldering process under various sleeve temperature and the solder amount. Table 1 shows the experimental settings. The soldering system becomes more failure to solder when the sleeve temperature is lower than 350◦C, or the solder length is less than 3.0 mm or more than 4.0 mm. The setting and their number of soldering were determined to record a sufficient number of the defect soldering. A solder piece of 0.8 mm in diameter is used in all settings. The effect of temperature change due to the previous soldering is minimized by preheating and leaving sufficient time between each soldering. The system's operation speed is slowed down to clear the relationship between the soldering process and the pressure changes.

The authors selected “Smart Shot” by AND Co., Ltd. as a soldering system. As shown in Figure 2, the authors insert a pressure sensor into the sleeve and measure the pressure at 500 Hz during soldering. The universal board with 320 through-holes (20*16) is used as a soldering object. Through-holes are soldered one line at a time, starting from the top left corner. A developer of the sleeve soldering system assigns correct/incorrect labels to all soldering visually. Figure 3 shows examples of solder joints on each label. The authors also observe a pressure change during defect soldering at an industrial setting to evaluate the variability of the learned model. The pressure changes from several defects soldering at the most-qualified settings are collected. The system developer determines the setting.

3.2 Feature Extraction

The authors focus on the two processes, 1) melting of a solder piece and 2) sleeve rise after melting, which may contain the features to identify defect solders, especially for cold solder joints. The cold solder joints occur when the temperature to melt the solder strip is low. When the temperature is low, 1) the melting of the solder piece becomes slow, and 2) the timing that the melted solder blocks the sleeve also becomes slow. Since the timing of the sleeve rise is the same in every soldering, the time length of the maximum pressure at the cold solder joints is shorter than that of the correct solder; hence the shape of the waveform becomes sharp. Also, at the correct solder, 2) pressure drops rapidly when the sleeve rises due to the gap between the sleeve and the PCB. On the other hand, in the case of cold solder joints, the pressure drops slowly, even after the sleeve rises since the solder remains on the top of the pin blocks the sleeve.

The authors select two features to extract the difference between correct and incorrect solder in these two processes, 1) kurtosis and 2) pressure drop time. The kurtosis is the value that expresses the sharpness of the distribution; the sharper waveform is the higher value. The measurement is useful to detect slowly melted solders, that is, cold solder joints. Pressure drop time is defined as the time required for the pressure to drop from the maximum to a certain level. Figure 4 shows an example of pressure change. Minimum pressure is a


(a) Correct


(b) Incorrect

Figure 3: Example of Solder Joints on each Label

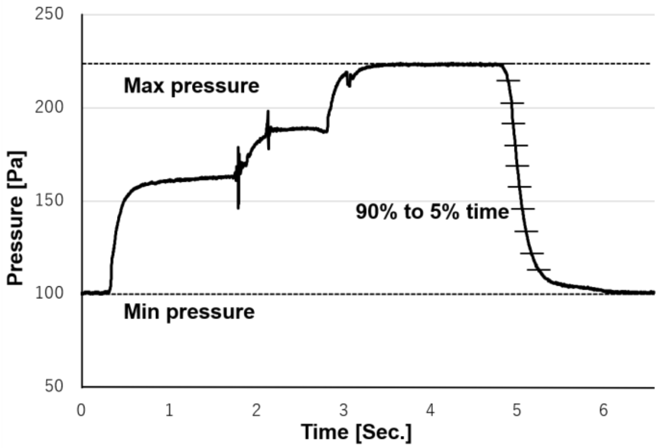

Figure 4: Definition of $T_{90\%}$-$T_{5\%}$

value without any effect from the solder piece, PCB, and others. That is defined as the average value for 0.02 to 0.04 seconds after the start of pressure measurement. Maximum pressure is a value when the sleeve touches to PCB, and molted solder seals a through-hole, or partially seals at defect soldering. That is defined as the average value from the 20th to 40th highest pressure value during observation to removes the outliers. The sleeve rises to apart from PCB in the last soldering process, hence the pressure drop down from maximum to the minimum. Here, the pressure drop curve is gentle in defected soldering because of melted solder blocks the sleeve's air flow. In this paper, times at every ten levels of pressure drop from the maximum to a specific percentage ($T_{90\%}$, $T_{80\%}$, ..., $T_{10\%}$, $T_{5\%}$) are used as features.

3.3 Classification

The features in section 3.2 are extracted from each of the measured pressure data and classified by Random Forest [2]. Random Forest predicts correctly even the model includes unnecessary features because the algorithm selects a part of the features in each decision tree. Also, the authors use the algorithm to calculate the importance of the features from the Gini coefficient.

The hyperparameters are optimized by modifying and verifying tree and mtry. To calculate the accuracy after optimization considering the generalizing capability, trees that are not used for training are collected for each training set and classified as test data. The authors also calculate the importance of each feature by the Gini coefficient.

4 RESULT AND DISCUSSION

The authors collected 707 pressure data, 296 correct, and 411 incorrect. Five incorrect solderings from 4,435 pressure data at the most-qualified settings were also collected. Table 2 shows the accuracy of the model trained with 707 data. The result showed that both correct and incorrect have a high accuracy of 98.3%, which suggests the features have a clear difference between correct and incorrect.

Figure 5 showed the importance of each feature. The vertical axis shows each feature, and the higher value on the horizontal axis is essential to accurate classification. The figure showed that the time pressure drop to a lower percentage ($T_{20\%}$, $T_{10\%}$, $T_{5\%}$) is important compared with other features. Table 3 showed the average and SD of each feature. Every incorrect feature is slower than correct, and the lower pressure has a larger difference; 0.52 seconds for $T_{90\%}$ and 1.00 seconds for $T_{5\%}$. At correct soldering, the pressure drops rapidly when the sleeve rises since all the melted solder flows to a through-hole, which does not block the sleeve's air flow. On the other hand, at incorrect soldering, the melted solder partially blocks the sleeve's air flow even the sleeve rises. Therefore, a later time such as $T_{20\%}$ to $T_{5\%}$ has a significant difference because the delay is accumulated.

Table 2: Classification Result

	Success	Failure
Correct solder	291(98.3%)	5(1.7%)
Incorrect solder	404(98.3%)	7(1.7%)
All	695(98.3%)	12(1.7%)

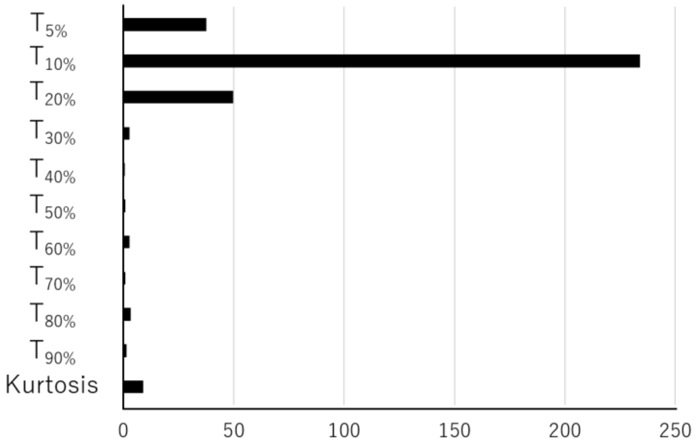

Figure 5: Importance of each Feature

Table 3: Average and Standard Deviation of each Feature

	Correct		Incorrect	
	Average	SD	Average	SD
$T_{90\%}$	0.55	0.06	1.07	1.10
$T_{80\%}$	0.59	0.05	1.12	1.06
$T_{70\%}$	0.62	0.04	1.26	0.92
$T_{60\%}$	0.65	0.04	1.34	0.86
$T_{50\%}$	0.68	0.04	1.43	0.83
$T_{40\%}$	0.71	0.04	1.57	0.76
$T_{30\%}$	0.75	0.04	1.77	0.64
$T_{20\%}$	0.80	0.04	1.99	0.46
$T_{10\%}$	0.93	0.03	2.20	0.36
$T_{5\%}$	1.37	0.07	2.37	0.30

The features $T_{5\%}$ - $T_{20\%}$ are also useful to classification because the incorrect soldering's SDs are smaller than the other features. The result suggests that pressure drops in early time shall be affected by a small difference between each incorrect soldering blocking the sleeve's air flow. However, the pressure drops in later time are hardly affected by such difference. Thus, the SD values of higher percentages are larger than the lower percentages.

The authors predicted five incorrect solderings from the most-qualified setting using the trained model. The result was four out of five incorrect solderings are correctly classified. The case failed to classify is checked visually, and the authors found that the melted solder stuck around the pin, near PCB's land, that is, no connection between the pin and the land. This appearance means the cold land with a warm pin caused the defect; the melted solder does not flow to the cold land. In this case, the sleeve's air flow is almost the same as correct soldering because the melted solder moved near to land. A classification that added land and pin temperature is one of the interesting future work.

5 CONCLUSION

This paper proposed a method to predict the incorrect soldering at the sleeve soldering system. The method extracts features from the sleeve pressure changes and classifies the incorrect soldering by machine learning. The experiment result showed 98.3% accuracy of the classification by the data set measured in the experimental environment. The model trained with the experimental data set also identified four out of five incorrect solderings in the industrial setting.

Our future work includes the classification of the soldering to multiple levels. In this paper, the soldering system's developer labeled the correct and incorrect of the solder joint. The criterion that decides the correct/incorrect solder is different by companies and soldering target, and other conditions. Therefore, classify the incorrect soldering to different levels such as solder filling in a through-hole and absence of back fillet improve the method's usefulness. Evaluation of other features to improve classification accuracy is also one of the important future work. Measurement of the pin and land temperature by thermal imaging camera or other sensors is an effective solution.

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