Building A Fuzzy Expert System For Solder Joint X-Ray Inspection From On-Line Data

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ABSTRACT: Visual inspection automation is a very important part of automation technology. In electronics manufacturing, automatic X-ray inspection of solder joints is used to detect soldering defects on printed circuit board assemblies. In the current practice, too many false alarms are reported by X-ray inspection. This causes increasing unnecessary rework time and production costs. To improve the X-ray inspection algorithm, a real-time fuzzy expert system based on fuzzy reasoning is developed. This fuzzy expert system can successfully learn the knowledge from human inspectors by analysing on-line data and then use the knowledge to support decision making. The expert system has been tested in mass production environment. Experimental results show that 44% of false alarms could be reduced.

KEYWORDS: Fuzzy reasoning, expert system, X-ray inspection, electronics manufacturing.

INTRODUCTION

This research project is carried out at Nokia Telecommunications Co. (Finland) Fixed Access System Operation, Haukipudas factory. The factory assembles components on Printed Circuit Boards (PCBs) for telecommunication devices. The percentage of fine pitch components is very high. In the factory, the PCBs are inspected by X-ray inspection machine after soldering and inspection results are sent to the factory database. In paperless rework station, rework personnel retrieves data of defective joints from database and sends re-inspection results to database after checking the joints carefully.

In X-ray inspection machine, as the X-ray passes through the board, more dense areas, such as solder, attenuate more of the beam while less dense areas, such as the substrate, absorb less of the beam. After passing through the board, the beam is projected onto a detector, converting the X-ray into a visible light image that is viewed by a high-definition video camera. The camera transmits the signal to a computer where the X-ray image is digitised. Algorithm compares the measurement value and its threshold. When the measurement value is larger (smaller) than its threshold, it is defective (O'Shea, 1995).

In Haudipudas factory, Parts Per Million (PPM) for false alarms and escape defects are calculated every month in order to measure the performance of the X-ray inspection. False alarm is an indication of a defect even when the solder joint actually is acceptable. Escape defect is a defect that has not been noticed by the X-ray inspection. The escape defect PPM is acceptable, while false alarm PPM is not satisfying, about 5000. If the number of false alarms would be reduced, the rework time would be shortened and the production costs would be significantly reduced.

REDUCING FALSE ALARMS BY FUZZY REASONING

In the visual inspection of solder joints, there is no clear boundary between acceptable and defective joints. Fuzzy reasoning could set up the fuzzy boundary as human inspectors do. Fuzzy logic could be used to derive knowledge from training data and then use the knowledge to support decision making (Klawonn and Kruse, 1997). This kind of knowledge is difficult to describe by mathematical functions. In this case, the knowledge is the correlation between human-confirmed results and measurement values.

A REAL TIME FUZZY EXPERT SYSTEM

A real-time Fuzzy Expert System for X-ray Inspection (FESXI) is developed to solve above problems. In the fuzzy expert system environment (Figure 1), the X-ray inspection machine reports the defective joints after a PCB is inspected. This report, called the defect candidate list, contains many false alarms. The defect candidate list is the input to the fuzzy reasoning module. The fuzzy reasoning module processes defect candidates together with their measurement values, and makes the decision. The output of fuzzy reasoning module is the defect report that has fewer false alarms. The rework station now receives the improved defect report. After been verified by human inspectors, the results are sent to the knowledge base as historical data. The knowledge in the knowledge base is the correlation between human confirmation results and measurement values.

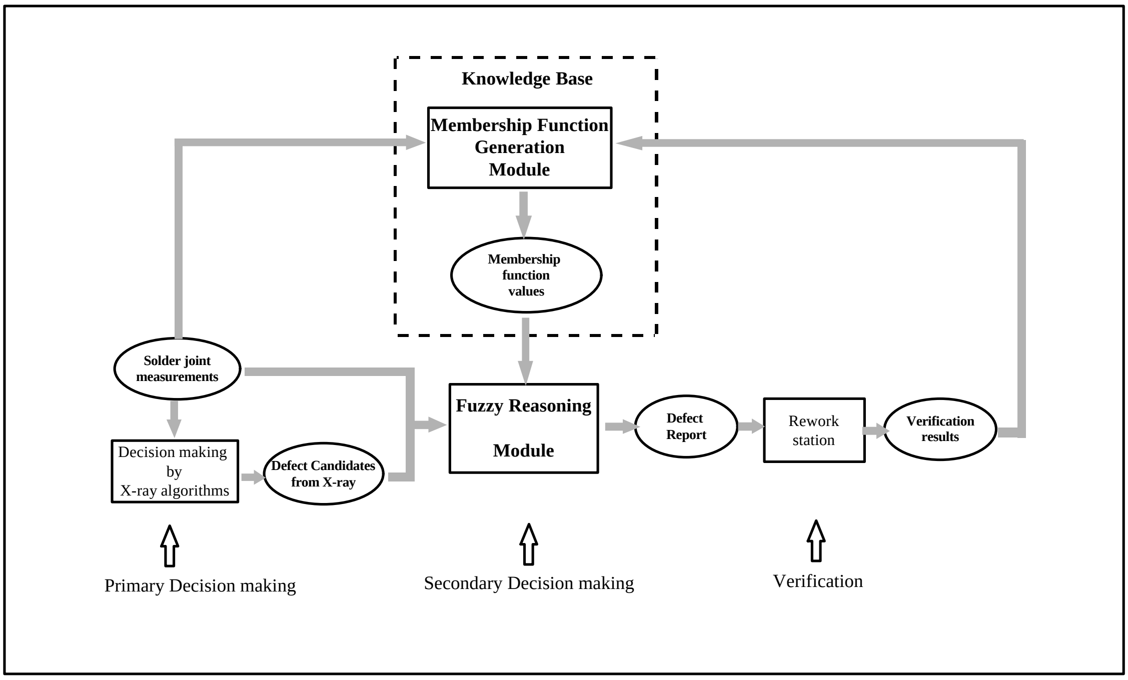

Figure 1. Fuzzy expert system environment

THE ARCHITECTURE OF THE FUZZY EXPERT SYSTEM

The Fuzzy Expert System for X-ray Inspection (FESXI) consists of six subsystems according to Figure 2: inspection data acquisition subsystem, X-ray operator interface subsystem, board status monitoring subsystem, decision making subsystem, historical data collecting subsystem and membership function generation subsystem. The expert system is coded in C++ in Borland C++ 5.0 environment and object Pascal in Borland Delphi 3.0 environment and runs in the Microsoft NT Windows.

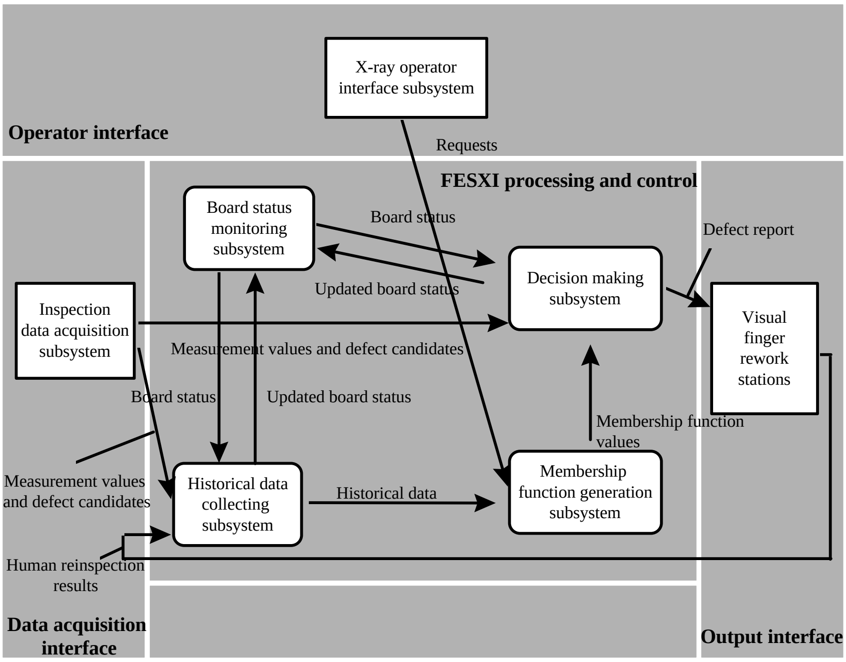

Figure 2. The architecture of X-Ray Fuzzy Expert System

X-ray operator interface subsystem- the user interfaces of FESXI

One option of decision making subsystem is processing defect candidates one by one under operator's manual control. The user interface of decision making subsystem displays the results graphically. The user interface of the membership function generation subsystem allows X-ray operator to select package type, joint type and defect type and choose the range of training data. It displays training data and membership function values graphically.

Inspection data acquisition subsystem

After inspecting one board, the X-ray system generates the measurement file and the defect candidate file. When the inspection data acquisition subsystem detects files are available, it performs the following tasks: converts file format, transfers data from a PC to the UNIX system and loads data into the measurement value table and the defect candidate table in the UNIX Oracle database.

Board status monitoring subsystem

The board status monitoring subsystem maintains a board status table. It inquires the measurement value table and the defect candidate table. If data is available, it records the board status.

Decision making subsystem

The decision making subsystem sends inquiry to the board status monitoring subsystem. It starts operating when the board status indicates that data is available. Then the item ID, package type, measurement value and membership function values for the board in question, are queried from the database. The core of the decision making subsystem is a fuzzy reasoning module. It will be discussed in more detail later. After decision making, the defect report is generated and sent to rework station. Then board status is updated.

Historical data collecting subsystem

The historical data collecting subsystem copies defect candidates’ information and their measurement values into the historical data table. After it detects that a board is repaired, it queries human reinspection results and copies them to the historical data table.

Membership function generation subsystem

Different package type, joint type and defect type have different membership function values. The membership function generation module calculates the membership function values from on-line data. The training data consists of solder joint measurements and human inspectors verifying results. The membership function values are automatically calculated as in Frantti (1996) and Juuso (1992, 1997). The graphical user interface allows user to select the package type and the defect type, and it shows the calculation results graphically.

FUZZY REASONING MODULE

The fuzzy reasoning module consists of three parts for fuzzification, inference, and defuzzification (Figure 3). In the fuzzy expert system, the measurement values of solder joints, such as solder thickness, joint location position, are used as the input variables. The output is the possibility of defect occurring.

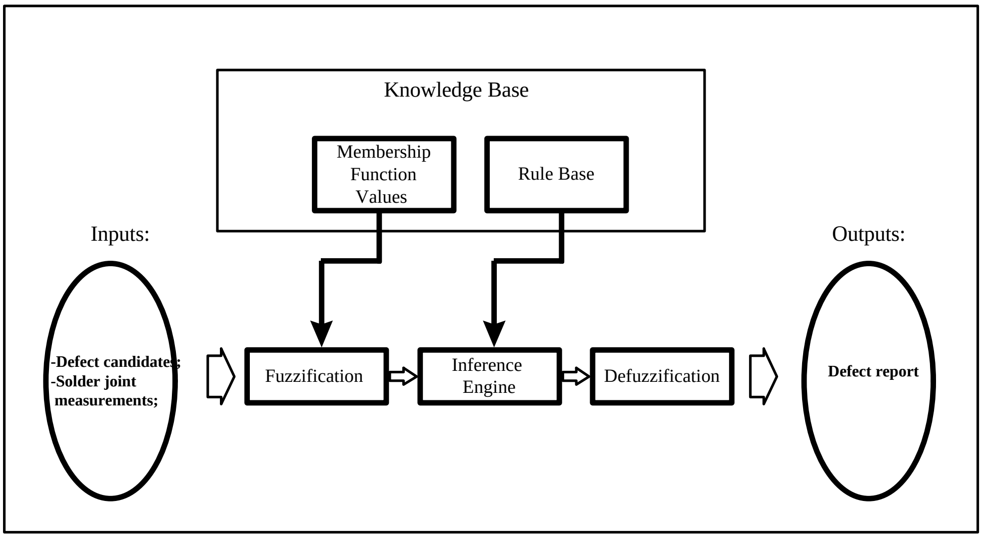

Figure 3. Fuzzy Reasoning Module

MEMBERSHIP FUNCTION GENERATION MODULE AND TUNING

Current tuning method.

In the current X-ray inspection system, tuning is done by manually adjusting thresholds. As each package type of component joint has many thresholds and one board usually contains many package types, thousands of thresholds has to be adjusted. Manually tuning the system becomes a time-consuming and low efficiency task.

Taking insufficient (joint) as an example, the threshold tuning process suggested by the manufacturer is following (Figure 4):

Step 1. Run 2-3 boards, set the threshold 10 % below the lowest thickness percentage measured. There are only three possible results as shown in Figure 4.
(I) Threshold is set in a good joint area as (I). Thus causes false alarms.
(II) Threshold is set in a defective joint area as (II). Thus causes escape defects.
(III) If very lucky, threshold is just on the border between defective joints and good joints.
Step 2. Testing boards.
Step 3. If it is (I), decrease threshold, then go to 2.
Step 4. If it is (II), increase the threshold, then go to 2.
Step 5. If it is (III), then stop.

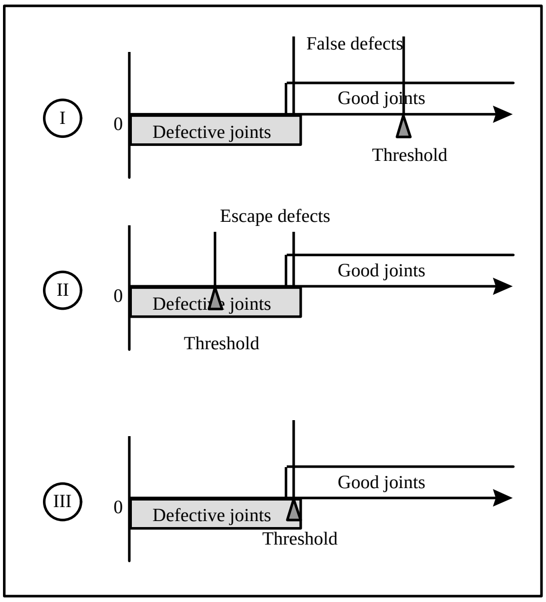

Figure 4. Threshold manually tuning process

To reach better modelling results, which mean less escapes and less false alarms, the current system requires manually iterating the above tuning process many times until (III) is reached (Figure 4). Theoretically manual tuning of the system by adjusting thresholds is possible. In reality, especially in production of small lot and variety products, e.g. in this case, about 86400 thresholds need to be adjusted every time. So tuning the X-ray system manually is very hard work and becomes impossible.

Retrieve human knowledge from on-line data to tune the system

Human knowledge used by fuzzy expert system comes from three sources: interviewing human experts, observations and on-line data. The rule base in this case is built from the first two sources.

In the factory database, human re-inspection results are recorded for the purpose of quality control. The values of X-ray inspection measurements are automatically collected and stored in the database. These two kind of on-line data contain the human knowledge about what are good or bad solder joints. We tune the system by calculating membership function values from on-line measurement values and re-inspection results.

Calculating membership functions from on-line data

In the fuzzy expert system, membership function values are automatically calculated from on-line data (Figure 5). First, training data is clustered. Those measurement values that appear few times are considered as noise data. Noise data is removed from training data to improve its quality. The fuzzy distribution of training data, NB, ZE, PB, NS, PS, is determined respectively from the histograms.

EXPERIMENTAL RESULTS

This fuzzy expert system has been tested on mass production line in Haukipudas factory. From 23 981 530 solder joints inspected by X-ray, 103 538 defective joints were reported. The fuzzy expert system processed 103 538 defective joints data, and reported that 39 682 joints are acceptable. After human checking 13 435 real defects were found. The false alarms were reduced from 90 103 to 50 421 meaning that about 44% of false alarms were reduced by the fuzzy expert system. The escape defect PPM is 0.42.

CONCLUSIONS AND FURTHER STUDIES

This fuzzy expert system can successfully learn the knowledge from human inspectors by analysing on-line data and then use the knowledge to support decision making. Implementation of fuzzy expert system in mass production is going on.

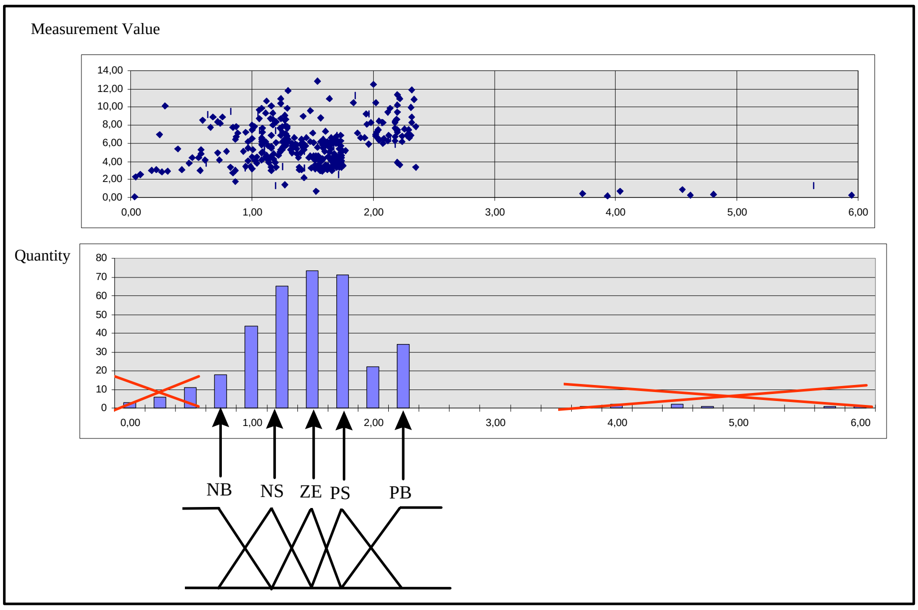

Figure 5. Calculating membership functions from on-line data

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