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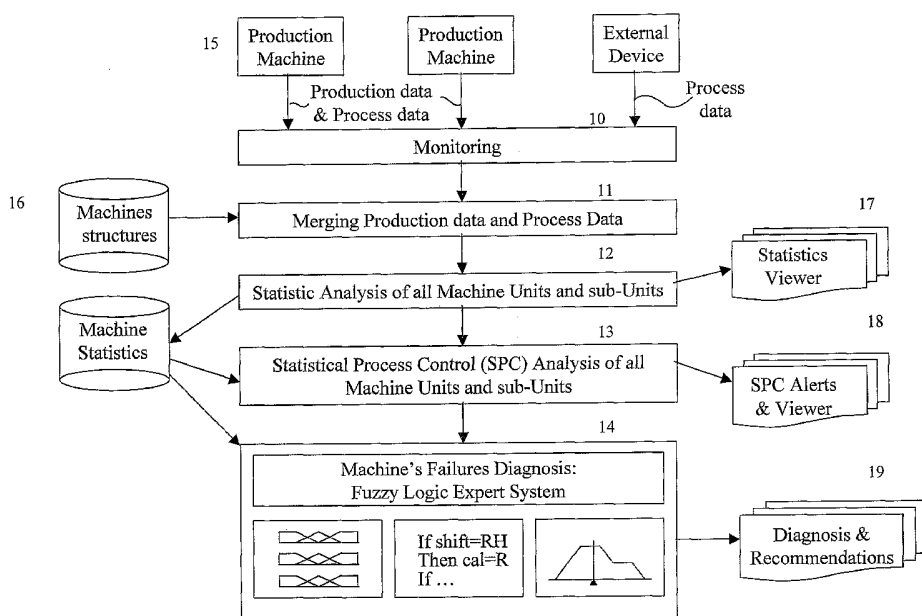
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(54) Title: METHOD AND SYSTEM FOR REAL TIME DIAGNOSIS OF MACHINE OPERATION



(57) Abstract: The proposed system according to the present invention provides a real time diagnosis of machine failures during operation, wherein said diagnosis is based on in-depth Statistical Process Control (SPC) data of all machine assembly units at all structure levels. The system defines the malfunctioning machine's units, while presenting the failure type and recommended correction actions that should be taken in order to repair the failure. Moreover, the system provides explanations of the system's logic that lead to its conclusions. These explanations are presented to a user in natural language that is easy to work with and understand by human operators.

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METHOD AND SYSTEM FOR REAL TIME DIAGNOSIS OF MACHINE OPERATION

BACKGROUND

The present invention relates to machine operation. More particularly, the invention relates to a system and method providing a real time diagnosis of machine failures during operation.

Standard monitoring devices and sensors known in the art are provided to detect and diagnose machine failures during operation. Such devices monitor various production parameters, such as temperature and pressure in a chemical reactor (well known as input parameters), and quality parameters, such as the size and weight of the product (well known as output parameters).

Existing techniques for detecting poor machine performance during the production phase include the Statistical Process Control (SPC). Control Charts are provided to analyze the different production parameters in order to identify out-of-control and non-random trends in the production process over time. Activated alarms are further provided to notify the operational and technical staff on poor process results, in order to repair the failures.

However, SPC techniques suffer from few vital limitations. Firstly, such techniques cannot diagnose failures and cannot recommend on the operative corrective actions that should be taken in order to repair them. Expert technicians are needed in order to identify the malfunctioned machine element and diagnose the failure, even when it can be easily repaired by the line operators. Secondly, existing alarms are supported with statistical qualitative measures that are not clear enough to the 'average' line operator. In other words, these measurers do not provide natural language style conclusions, which are more comprehensive to the users. Thirdly, SPC techniques provide an overall statistical analysis, wherein the analysis is not correlated with the location of a specific machine element. Moreover, when such failure is finally detected more test procedures are needed to identify the malfunctioned element in order to repair it. Furthermore, such techniques detect machine malfunctions when at least one of the analyzed process parameters is out of control, i.e. the statistical behavior point declares a

non-random poor result or a non-random process trend. SPC techniques can not examine the interactions between different process parameters, which sometimes pinpoint on machine malfunctions, even when each process parameter is under control. Other outcomes are long treatment time, long machines downtimes and productivity loss. In addition, SPC techniques pinpoint on poor but exceptional (under control) machine performance, i.e. machine performance is near the edge of its 'normal' behavior or process trend is detected while process maintain within its control limits. Lack of meaningful information on the potential machine failures causes in many situations to avoid those indications, resulting in poor quality and low yield rates.

Surface Mounting is the dominant used technology for electronics assembly. The heart of Surface Mount Technology (SMT) is the automated assembly machine that places electronic components onto the Printed Circuit Board's (P.C.B.) land areas prior to soldering. Assembly machines use vacuum pickup tools to hold the components and provide vision-assisted alignment. The components are placed on pre-defined X, Y and θ (Orientation) coordinates on the P.C.B.'s.

In general, assembly machines are very fast and very accurate. Some of them can place thousands of components per hour. Placement defects on the produced P.C.B.'s, such as offsets and off pad components, are quite rare on a steady production state. However, when a failure occurs in one of the assembly machine's element, the defects rate on the produced P.C.B.s can grow exponentially and as a result the wasted costs that are spent on defects detection and repair sharply increases. Machine failures detection and diagnosis can also be very time consuming and expensive as a result of machines downtime, technicians and engineers costs etc.

Assembly machines are very complex. Many mechanisms, such as pick-up tools, machine's cameras, lightning units, and X/Y/ θ placement servos can be malfunctioned and cause many placement defects.

In order to detect SMT assembly machines failures during production, two types of process control systems are used. The first one is the Automated Optical Inspection (AOI) machine, which is used to inspect the produced printed boards in order detect components placement defects. AOI machines photograph the printed boards after the electronic components assembly and apply image processing algorithms to measure the

placement shift of each component from the target. The machine alerts when the placement shift exceeds an exceptional limit.

Most of AOI systems provide basic reports on the detected failures, such as failures type pareto. Few vendors also added to their systems statistical process control (SPC) capabilities to analyze the components placement shifts. Using SPC module enables the AOI system to alert not only when a specific placement failure is detected on a printed board, but also when the machine placements statistical results point on poor machine performance. We can get for example poor machine statistical results when the components placement average shifts are larger then the normal or shifted from the target.

The second control system for SMT assembly machines is the assembly machine monitoring system. This system monitors machine messages that are automatically generated during production in accordance to the electronics machines messaging standard (GEM-SECS), including error messages such as component miss-pick and component vision system rejection. Statistical analysis is performed to detect high machine error rate, which generally pinpoints on machine failure.

However, current AOI and monitoring systems suffer from the mentioned SPC limitations. AOI and Monitoring systems have only a limited ability to detect assembly machine failures. Many critical machine elements such as vision system elements (camera, lightning and assembly shape files), placing elements (X, Y and θ servos) and vacuum system elements (central pump, vacuum head and nozzles) are not analyzed during production. As a result they occasionally do not detect specifically located failures in those elements. Moreover, when such failures are detected occasionally more test procedures are needed to identify the malfunctioned machine elements in order to repair them, which longer significantly the repair time. It is definitely possible that in a machine containing dozens of vacuum nozzles for example, malfunction in one of them won't be evident in an overall statistical analysis, unless the malfunction is acute. Only a precise nozzle by nozzle statistical examination will reveal such problem, and will pinpoint on the exact location of the malfunctioned nozzle. AOI and Monitoring systems also do not provide an operative explanation and recommendation on the detected machine failure and the actions that should be taken to repair it.

AOI systems, which are located after solder paste printing machines, are used for detecting solder paste printing failures on the printed boards, such as insufficient solder paste and non-accurate printing. AOI systems, which are located after reflow ovens, are used to detect reflow and assembly failures such as shorts and missing components. All of those can not provide the appropriate feedback to the line operators and technicians in order to diagnose machine failures, i.e. printing machines, assembly machines and reflow ovens.

Numerous advances have been made in recent years providing real time diagnosis of machine failures during operation. Prior art techniques include European Patent No. EP1109101, which introduces real-time failure prediction and diagnoses of electronic systems operating in a network environment by using monitoring data, feedback data, and pooling of failure data from a plurality of electronic devices. Having determined and/or predicted a system failure, a communication to one or more remote observers in the network allows the remote observers to view the diagnostic information and/or required action to repair the failure.

Another attempt is made in US Patent No, 6,115,643, disclosing a method for identifying unacceptable levels of defects in specific sections or work centers of a manufacturing process on a real time basis and initiating corrective action. The system allows a user to define defect tolerances or thresholds for manufacturing work centers, tracks defects at the work centers, compares the level of faults with the tolerances, reports out of tolerance work centers, automatically initiates contact with the appropriate personnel to affect a correction to the out of tolerance work center, and maintains records of corrective actions taken.

US Patent No. 6,532,555 discloses a method and apparatus for providing near real-time fault detection in a manufacturing process. The method involves receiving operational data, which is related to the manufacture of a processing piece, and receiving product data, which defines characteristics of the processing piece. A fault detection unit is provided to determine if a fault condition exists with the processing tool from the operational data or with the processing piece from the product data.

US Patent No. 6,697,691 provides a method and an apparatus for fault model analysis in manufacturing tools. A sequence of semiconductor devices is processed through a manufacturing process. Production data resulting from the processing of the semiconductor devices is acquired. A fault model analysis is performed using the acquired production data.

US Patent No. 6,725,402 introduces a method and apparatus for providing fault detection in an Advanced Process Control (APC) framework. A first interface receives operational state data of a processing tool related to the manufacture of a processing piece. The state data is sent from the first interface to a fault detection unit for determining if a fault condition exists within the processing tool.

However, none of the existing methodologies propose an improved system and method for providing real time diagnosis of machine units failures at all structure levels during operation, wherein the diagnosis includes an explanation and treatment recommendations.

It is thus an object of the invention for diagnosing failures in machine assembly production process, while presenting the failure type, an explanation and recommended correction actions that should be taken in order to repair the failure, wherein said diagnosis is based on in-depth Statistical Process Control (SPC) data of all machine assembly units at all structure levels

SUMMARY OF THE INVENTION

The present invention seeks to provide an improved system and method for diagnosing failures in machine assembly production process, wherein said diagnosis is based on in-depth statistical process control (SPC) data of all machine assembly units at all structure levels.

The present invention seeks to provide an improved system and method for SMT assembly machines calibration, failure detection during machine process control and

failure diagnosis. The present invention works as an intelligent layer on the process control data that is generated by the AOI system during printed boards' inspection. The present invention provides current AOI and monitoring systems, novel and improved abilities supporting assembly machines operation, maintenance and management.

The present invention enables to use the AOI system as a calibration test tool for SMT assembly machines thus gaining many benefits on the current test tools supplied by the machines providers. The present invention can test **simultaneously different machine types** (different machine structures of different machine providers) while providers test tools are fitted only to their machine types, thus saving production time.

The proposed method comprises the steps of: monitoring production data (performance) and process data of the units at all structure levels; correlating production data to appropriate machine assembly units; performing statistical analysis on each units' monitored process data during operation; performing statistical process control analysis on each units' monitored process data; and applying a machine failure diagnosis based on the unit's statistical results, wherein each assembly machine type is diagnosed according to a respective diagnostic model, said model constructed from several diagnostic blocks that represents different machine element types.

Correlating production data to appropriate machine assembly units involves examining the interaction between different process parameters and revealing machine malfunctions, even when all the process parameters are in control.

Performing statistical analysis on each unit's monitored process data during operation enables to analyze the performance of each machine element in order to detect and pinpoint at the malfunctioned ones. As a result, the present invention is more sensitive to malfunctioned machine elements, thus reducing the time spent to identify them and reducing their treatment time and down time. Early failure detection prevents poor production quality and low yield rates.

The proposed system comprises: monitoring means for monitoring production data and process data of the units at all structure levels; correlating means for relating production data to appropriate machine assembly units; statistical means, provided to perform statistical analysis on each units' monitored process data during operation; SPC means, provided to perform statistical process control analysis on each units' monitored

process data; a Failure Diagnosis Unit, provided to identify each units error type based on the unit's statistical results and obtain a failure diagnosis; and analyzing means provided to produce a diagnosis conclusion for each machine failure with respect to the machine failure diagnosis based on machine diagnosis models,

Furthermore, in accordance with the present invention, the correlating procedure further comprises the step of utilizing a tree structure definition in order to correlate between the process data of a machine unit and units implemented at upper structure levels.

Furthermore, in accordance with the present invention, the statistical analysis includes measurements from the list of: process mean, standard deviation, and process capability measurements.

Furthermore, in accordance with the present invention, the statistical analysis further comprises the step of providing a graphical representation for displaying the statistical results and their control limit (e.g. in a bar chart, box-plot, and histogram).

Furthermore, in accordance with the present invention, the statistical process control analysis further comprises the step of detecting out-of-control and nonrandom trends measured in statistical process results. The present invention is also capable to analyze calibration changes within time in order to detect deterioration in different machine elements calibration.

Furthermore, in accordance with the present invention, the method further comprises the step of triggering an alarm in case a nonrandom trend is measured in a statistical process result.

Furthermore, in accordance with the present invention, the statistical process control analysis is carried out either in automatic mode during production or in manual mode, in response to a user's request.

Furthermore, in accordance with the present invention, wherein applying a machine failure diagnosis uses fuzzy logic rules, said rules based on integrated analysis results of all machine assembly units.

Furthermore, in accordance with the present invention, applying a machine failure diagnosis is obtained using automatic diagnosis algorithms.

Furthermore, in accordance with the present invention, wherein the step of applying respective machine diagnosis model comprises the steps of: producing diagnosis conclusions with respect to the machine failure diagnosis; and presenting an explanation and pre-defined treatment recommendations with respect to produced conclusions. The explanation is presented in natural language that is friendly and comprehensive to the user.

Furthermore, in accordance with the present invention, the pre-defined treatment recommendations include an automatic calibration operation treatment in case the produced conclusion indicates a calibration problem.

Furthermore, in accordance with the present invention, the method further comprises the step of storing in database the produced diagnosis conclusions and pre-defined treatment recommendations.

Furthermore, in accordance with the present invention, the method further comprises the step of receiving AOI (Automatic Optical Inspection) results of assembled printed boards' of all machine assembly units.

BRIEF DESCRIPTION OF THE DRAWINGS

These and further features and advantages of the invention will become more clearly understood in the light of the ensuing description of a preferred embodiment thereof, given by way of example only, with reference to the accompanying drawings, wherein-

Figure 1 is a generalized block diagram of the proposed system in accordance with a preferred embodiment of the present invention.

Figure 2 is a block diagram of the proposed system, wherein the system is implemented for SMT assembly machines.

Figure 3 illustrates a typical connection key field between the assembly program and the placement shifts.

Figure 4 illustrates the connection key field between the assembly program and the machine's error message.

Figure 5 illustrates a partial tree structure of an SMT assembly machine.

Figure 6 is a generalized block diagram of the Machine Failure Diagnosis Unit that performs the diagnosis process within the system.

Figure 7a illustrates the diagnosis process within a Machine Diagnosis Model.

Figure 7b is a hierarchic illustration of the diagnosis process, in accordance with Figure 7a.

Figure 8 illustrates the process in which statistical input variables are transformed to fuzzy variables.

Figure 9 illustrates a failure diagnosis conclusion.

Figure 10 illustrates the X, Y and θ shifts of an inspected component.

Figure 11 illustrates the placement shifts of all the components on a printed board.

Figure 12a illustrates placement shift results of a first head, representing high standard deviation resulting from vacuum leak in the head.

Figure 12b illustrates placement shifts of a second head, representing normal results.

Figure 13a illustrates placement shifts a first assembly machine components camera, representing normal results.

Figure 13b illustrates placement shifts a second assembly machine component camera, representing a shifted calibration average shift in X coordinate.

Figure 14 illustrates the machine components vision rejection rate of the machine assembly shapes.

Figure 15 is a graphical representation of assembly machine placement shifts.

Figure 16 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in a table.

Figure 17 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in box-plot.

Figure 18 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in bar charts.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The proposed system according to the present invention provides a real time diagnosis of machine failures during operation by monitoring the performance of each of the machine's elements (units, sub-units etc.), identifying malfunctioned machine elements and diagnosing their failures.

The system defines the malfunctioning machine's elements, while presenting the failure type and the recommended correction actions that should be taken in order to repair the failure. Moreover, the system provides explanations of the system's logic that lead to its conclusions. These explanations are presented to a user in natural language that is easy to work with and understand by human operators.

The proposed system combines in-depth statistical analysis with Fuzzy Logic expert system in order to provide in-depth statistics analysis of the performance of the machine and its sub-elements, diagnostic conclusions, treatment recommendations and explanation on the logic that lead to the diagnostic conclusion.

A **Statistical Analysis Unit** analyzes the statistical performance of each production machine using the process data that is monitored during its operation. The innovation of the proposed system, according to the present invention, is by relating a monitored process data element to a relevant machine element and performing a Statistical Process Control (SPC) analysis to each critical machine element.

In-depth SPC analysis provides a more sensitive malfunction detection mechanism, allowing identification of changes in the machine elements' performance over time. It also helps the operational and the technical staff to focus immediately on malfunctioned machine elements, thus saving long testing procedures. The **Statistical Analysis Unit** according to the present invention is provided to generically analyze different lines and machines structures and to specifically identify the malfunctioned machine elements.

Fuzzy Logic is a type of logic that recognizes more than simple true and false values. With fuzzy logic, propositions can be represented with degrees of truthfulness and falsehood. The Fuzzy Logic rule base is constructed using expert technicians' knowledge

and automatic rule search algorithms in data mining. The system is tuned (by the membership functions) using a neural-net (neuro-fuzzy system).

The machine's statistics results are fed to an **Expert System Unit** in order to detect and diagnose machine failures. Performance parameters of each of the machine's elements are analyzed and controlled by the SPC technology. When machine failures are detected, the **Expert System Unit** displays the diagnosis conclusion, the production rules that lead to this conclusion (an explanation), and treatment recommendations.

Combining detailed machine SPC analysis with Fuzzy Logic expert system improves the ability of the proposed system to detect machine failures, for it can detect malfunctions even when a process result over time is "under control". It also provides treatment recommendations and operative repair actions (instead of simple alarms) when such failures are detected. The Expert system Unit provides a natural style interface presentation, which is friendly to a user and comprehensive to the operational and technical staff.

The proposed system can be implemented in any process industry, such as in Electronics (assembly and semiconductors), in Automotive, Aerospace, and Health care. It can further be implemented in pharmaceuticals and chemistry industries. The system can be implemented within current monitoring systems and within an e-diagnostic system for remote monitoring. Production machines are monitored in the factory during operation and then the monitored data is sent via the Internet to a remote machines provider support center. The data is analyzed online in order to detect machines malfunctions. Support technicians receive a closer insight on remote machines operation from different factory locations and can provide immediately repair instructions.

Implementation of the proposed system in the Electronics industry provides a series of actions, which are carried out during the machine's operation. Such actions include Surface Mount Technology (SMT) machines calibration, process control, failures detection and diagnosis, and testing. Analyzing specially designed test boards placement results, for example, enables to use the proposed system as a calibration testing tool.

The Automated Optical Inspection (AOI) machine is used to inspect produced printed boards in order to detect components placement defects. Connecting the proposed system to an in-line or off-line Automatic Optical Inspection (AOI) machine is essential

for alerting on the various machines failures during their occurrences. The AOI machine provides an explanation regarding the relevant failure and a recommendation on the repair actions that should be taken.

Figure 1 is a generalized block diagram of the proposed system in accordance with a first embodiment of the present invention. The different steps in which constructs and operates the proposed system are as follows:

At the first step 10, monitoring of line machines' production and process data is carried out. According to the general structure, the proposed system is linked to monitoring devices of production line machines 15. The system is implemented to collect two types of data – process data and production data.

Process data is the data flow of process variables that are monitored during production from the line machines via standard monitoring devices. The monitoring devices are directly connected to the machines themselves or to external sensors. Process data is highly correlated to the process quality. Measuring and analyzing the process data during production can detect significant changes in the process performance and can indicate in many cases on machine failures. Single process data element within the data flow can be a measurable variable with a specific value, such as temperature or pressure, or it can be a binary variable that confirms the existence or non-existence of any event such as machine error.

Production data is a data flow of machines program data, that are monitored during the production from the line machines via standard monitoring devices. Each production cycle in a machine is separated to numerous steps (up to thousands). The machine program describes each step along with the machine units and sub-units associated with it.

At the second step 11, merging of production and process data is obtained. The object of this step is to identify which process data elements are related to each machine element in the production line in order to perform in-depth statistical analysis of the machines elements. For example, to examine the production results of special equipment in the line, the process data that was produced during its operation must be identified.

The proposed system uses relevant information concerning the production data for relating the process data elements to the machine elements. Each production step is defined in the production data which includes the involved machine elements during this step.

The proposed system further uses the machine elements' tree structure definition 16 in order to correlate between the process data elements of each machine's unit and its parents' machine units. The tree structure definition is stored in the system database.

At the third step 12, statistical analysis of the line machines is obtained. The object of this step is to calculate the statistics of each machine element in the line. The proposed system performs a statistical analysis on each production machine and its elements. From a process control point of view, while the machine assembly units at all structure levels are independent variables, the associated process data elements are dependent variables, which result in accordance to the machine elements' performance. A generic statistical unit receives as an input the products of the previous step, i.e. the lists of process data elements that are associated to each machine element. The system calculates for each machine element statistical process measurements, which indicate on its performance capabilities. The statistical measures can be process mean, standard deviation, and process capability measurements, such as Cp, Cpk and Cpm. The system stores the calculation results in its database. The "generic" manner of the statistical unit according to the present invention enables an automatic calculation of the machine tree structure's statistics.

The stored process data elements and the statistical results of each machine element can be retrieved and presented in the system viewer 17. The user, whether he is an operator, a machine technician or an engineer, performs a drill-down in to the stored data of each machine element. Such procedure is carried out from the overall machine data and respective statistics into each element data and respective statistics. The proposed system provides a graphical representation, e.g. Bar chart, Box-plot and Histogram, for displaying the statistics and appropriate control limits. This gives an intuitive presentation of the machine's performances and indicates whether a specific displayed value exceeds its control limit. Bar chart and Box-plot are used to compare between different machine

elements' statistical results, while histograms are used for displaying their process distribution. Furthermore, the system provides an automatic calibration reparation recommendation for line machines whose statistical results indicate a calibration problem.

At the fourth step 13, statistical process control analysis of the line machines is carried out. The object of this step is to analyze the line machines and their elements statistical process results over time. This process uses Average and Range Control Charts (X' and R charts) or Average and Standard Deviation Control Charts (X' and S charts) to detect out-of-control process results and nonrandom trends of measurable process variables. It uses Proportion control charts (P and NP charts) to detect out-of-control process results and non-random trends of binary process variables. Standard SPC rules 18 are used to alarm on abnormal performance such as out-of-control and running tests. The control limits are specifically set according to each machine unit type at all structure levels.

The proposed system retrieves the statistical results (which were stored in the system's database in the previous step) of the line machines units at all levels. The retrieval process is carried out during a sufficient period of time so that the statistical analysis is presented in the control charts. This process can be either carried out in an automatic mode during production or in a manual mode, in response to a user's request.

Any event indicating a non-random statistical result during the SPC analysis triggers alarms to the operational or technical staff.

At the fifth step 14, a machines failure diagnosis is obtained. The object of this step is to diagnose machine failures. The proposed system performs machine failure diagnosis using machines statistics and fuzzy logic expert system. Although this invention uses expert technicians' diagnosis knowledge 19 within fuzzy logic rule base, the scope of the invention is not limited to the use of these techniques and any other automatic diagnosis algorithms such as neural networks or other artificial intelligence algorithm can be used.

The fuzzy logic implemented in the proposed system is based on inference engine rules. This logic receives the fuzzy input variables and activates the rules. The rules are defined in the following form:

If **X** is **F** (And / Or) **X** is **F** (And / Or) Then **Y** is **G**,

where X represents an input variable, F represents a membership function, Y represents an output variable and G represents a membership function. The left clause (If statement) contains conditions, while the right clause (Then statement) contains conclusions.

The following example depicts the implementation of a fuzzy rule:

If **Nozzle (X) Standard Deviation** is **Very Large**

Then **Nozzle (X) Vacuum Failure** is **High**.

The condition clause includes the machines elements' statistics, in which the rule refers to, and the conclusion clause includes the machine element's failure type. The fuzzy results of the fired rules are defuzzified to crisp values using fuzzy membership functions. A threshold value between 0 and 1 is provided to filter conclusions that are less likely to occur.

The Machine Diagnosis Model is provided to produce the diagnosis conclusions, including the malfunction machine unit and the failure type. Furthermore, this model presents the fired rules that lead to the failure conclusions. The fired rules are presented as an explanation clause to the system's diagnosis logic. These rules give the operational and technical staff information (an explanation) on how the system reached its conclusions. This information is essential during machine failure diagnosis.

The Machine Failure Diagnosis Unit, which contains the diagnosis models, stores in its database the pre defined failure diagnostics along with the pre defined treatments recommendations. When a failure is detected by the proposed system, the diagnosis unit retrieves from the database the recommended correction actions. The correction actions are presented in a recommendation clause along with the failure and explanation clauses.

The unit's manager is provided to update new diagnostic rules, can remove others and can tune the parametric data associated to each rule and membership functions. This

manager can further update new machine failures type and new treatment recommendations.

Figure 2 is a block diagram of the proposed system, wherein the system is implemented for SMT assembly machines. The different steps in which constructs and operates the proposed system are as follows:

At the first step 20, monitoring of line machines' production and process data is carried out. The proposed system is located within a Personal Computer (PC). The computer terminals of the system located near each production line and is provided to monitors the assembly machines and AOI inspection results during production. The PC is connected to the factory's Local Area Network (LAN) via Ethernet connection and is connected to the assembly machines via RS232 connections.

The AOI system 25 is located in-line after components assembly and before the reflow oven. This system inspects each assembled printed board and stores the inspection results in ASCII files. A new AOI file is produced whenever a printed board inspection is completed. Different AOI systems (from different providers) produce different file structures. However, all file structures have the following basic elements: the placement reference designator of each component on the printed boards, X coordinate shift (from the planned X coordinate according to the assembly program file), X, Y coordinate shifts and θ coordinate shift.

During operation, assembly machines generate different messages indicating various operation events. Such events may be machine running (during assembly), machine waiting (for data or printed boards), machine blocked (cannot release assembled printed board), and machine errors. The messages are generated in real-time close in time to the events' occurrences. Most assembly machines messages are implemented in accordance with the Generic Equipment Model (GEM) standard.

The occurrence of machine malfunctions during component placement involves generating error messages that include the placement reference (each component placement on the printed boards is identified by a specific reference name) along with the error type. The proposed system is applied to monitor the line machines error messages into the line PC.

Assembly machine program files include all of the information needed to assemble the printed boards. The program files contain general data on the printed boards, such as board size, fiducially marks, and specific data regarding each component placement. The placement reference is followed by its X, Y and θ coordinates on the printed boards, component information, e.g. component name, feeder and assembly shape file, collected information, e.g. pickup head and nozzle, and vision information, e.g. camera and lighting types. Printed boards assembly is carried out sequentially in the line machines, such that each machine assembles a portion of the printed boards' components. The program files are stored on the factory LAN and transmitted to the line machines during production setup. The proposed system monitors and intercepts replicates of the transmitted program files during transmission and then stores them in the line PC.

At the second step 21, merging of production and process data is obtained. The proposed system, according to the present invention, utilizes the placement references as a connection key field between the machine elements, the AOI placement shifts and the assembly machine error messages. As mentioned in the previous step, this reference placement represents a specific component placement on the printed board and is included to the AOI files, to the machine messages and to the machine program files. The proposed system is provides to utilize this key field (the placement reference) in order to identify all the process data elements that are related to each machine element. After the identification procedure, the system proceeds to store the process data in the system database for data analysis.

The system uses the defined assembly machines structures 28, which are also stored in the system database, to correlate between the process data elements of each machine's unit and its parents' machine units. This correlation is applied in accordance with the machine's hierarchical structure.

At the third step 22, statistical analysis of the line machines is obtained. The proposed system calculates the placement shifts statistics, including maximum shift, minimum shift, median shift, average shift and standard deviation measurements for all the line assembly machines elements. The system also calculates the machine errors rate (components miss-pickup and rejections) for all the line assembly machines elements.

The process capability measures, i.e. Cp, Cpk and Cpm, are calculated to the placement shifts statistics of each machine element.

At the fourth step 23, statistical process control analysis of the line machines is carried out. The proposed system performs SPC analysis of the line machine placement shifts and the line machines errors. This analysis is carried out on all the machine's units and sub-units. Average shift and standard deviation control charts are provided in order to analyze the placement shift statistical results, while proportion control charts are provided in order to analyze missed components pickups and rejections rates. In an automatic mode the system sequentially analyzes the statistical results of the inspected printed boards. The SPC analysis is performed whenever a printed board inspection is completed and whenever a new error message is collected. In case a non-random process result is identified, the system activates an alarm 26 and alerts the operational staff on such a scenario. In a manual mode the user is capable of selecting the period of time in which he wishes to analyze the statistical results received from the machine. The analysis can be performed on any machine element and for any process parameter (X, Y etc.).

At the fifth step 24, a machines failure diagnosis is obtained. The proposed system, according to the second embodiment of the present invention, provides machine diagnostic models 27 with relevance to appropriate assembly machine types. Each model comprises several diagnostic blocks for each machine unit type. These blocks include a pickup unit, a vision unit, a components unit, a placement unit, a fiducially unit and a printing board clamping unit. The diagnostic process can be automatically operated during machine operation or manually operated according to a user's request.

Figure 3 illustrates a typical connection key field between the assembly program and the placement shifts. The placement reference of each machine's unit at all levels is used as the key field. The assembly program includes the following parameters: the machine name, component part name, component feeder, component shape, component camera type, illumination type, pickup head and nozzle, and the X, Y and θ coordinates. The placement shift result, within the AOI file data, includes the X, Y and θ coordinates.

Figure 4 illustrates the connection key field between the assembly program and the machine's error message. The error message includes the placement reference and the error type of each machine assembly units at all levels.

Figure 5 illustrates a partial tree structure of an SMT assembly machine.

Figure 6 is a generalized block diagram of the Machine Failure Diagnosis Unit that performs the diagnosis process within the proposed system. The machine Failure Diagnosis Unit contains several Machine Diagnosis Models for each machine type in the production line. When the machine's statistics are produced and stored 40, the Machine Failure Diagnosis Unit identifies the machine's error type and applies the appropriate Machine Diagnosis Model 41. The Treatment Recommendation Database 42 stores the pre defined treatment recommendations. When a failure is detected by the proposed system, the diagnosis unit retrieves from the database the recommended correction actions 43. The proposed system then proceeds to process these treatment recommendations along with the diagnosis conclusion 44 and relevant explanation 45. As a result, an appropriate diagnosis result 46 is obtained.

Figure 7a illustrates the diagnosis process within a Machine Diagnosis Model. This process comprises three basic steps as follows:

The first step 50 involves applying a machine failure diagnosis based on statistical results received from the machine's units from all structure levels.

The second step 51 involves applying fuzzy logic rules, wherein said rules are based on integrated analysis results of all machine assembly units.

The third step 52 involves producing diagnosis conclusions with respect to the machine failure diagnosis

Figure 7b is a hierarchic illustration of the diagnosis process, in accordance with Figure 7a. Each set of sub-units 53 transmits the statistical results to appropriate Failure Diagnosis Unit sub-unit 54. Each of these Failure Diagnosis sub-units 54 provides a diagnosis conclusion based on received statistical results. Each diagnosis conclusion is then transmitted to a Failure Diagnosis Unit 55 of an upper structure level, and so on.

Figure 8 illustrates the process in which statistical input variables are transformed to fuzzy variables. This process is carried out by fuzzy membership functions. The diagram illustrated herein includes three Membership Functions as follows – NO, indicating normal standard deviation, LA, indicating large, and VL, indicating very large. For example, transforming input standard deviation of 0.035 millimeter to 0.75 of NO and 0.2 of LA indicate that the standard deviation is Normal with 0.75 intensity and Large with 0.2 intensity.

Figure 9 illustrates a failure diagnosis conclusion. When a machine failure is detected, the presented diagnosis conclusion includes the detected failure type, an explanation on how the system reached its conclusion (i.e. the failure type), and proposed treatment recommendations.

Figure 10 illustrates the X, Y and θ shifts of an inspected component.

Figure 11 illustrates the placements shifts of all the components on a printed board. Each placement inspection result is stored sequentially in the AOI file. The AOI file can be stored in the AOI system computer. Alternatively, it can be retrieved from external databases through factory LAN, using an Ethernet connection. Whenever a printed board inspection is completed and a new file is produced, the proposed system monitors the AOI files, which are located on the factory LAN, into the PC line.

Figure 12 illustrates the placement shifts of two different assembly machine pickup heads.

Figure 13 illustrates the placement shifts of two different assembly machine components cameras.

Figure 14 illustrates the machine components vision rejection rate of the machine assembly shapes. The X coordinate represents the assembly shape, wherein the Y coordinate represents the rejection rate.

Figure 15 is a graphical representation of assembly machine placement shifts. Pointing on one of the machine's units defines the placement shifts associated to this element.

Figure 16 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in a table. As is illustrated in this figure, the proposed system is able to present in a single table the statistical results of machine's units working in parallel.

Figure 17 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in box-plot.

Figure 18 illustrates the statistical results of a machine's different pickup heads, wherein the results are presented in bar charts.

While the above description contains many specificities, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of the preferred embodiments. Those skilled in the art will envision other possible variations that are within its scope. Accordingly, the scope of the invention should be determined not by the embodiment illustrated, but by the appended claims and their legal equivalents.

What is claimed is:

1. A method for diagnosing failures in machine assembly production process, wherein said diagnosis is based on in-depth statistical process control (SPC) data of all machine assembly units at all structure levels, the method comprises the steps of: monitoring production data (performance) and process data of the units at all structure levels;

correlating production data to appropriate machine assembly units;

performing statistical analysis on each units' monitored process data during operation;

performing statistical process control analysis on each units' monitored process data; and

applying a machine failure diagnosis based on the unit's statistical results, wherein for each unit is applied respective machine diagnosis model.

2. The method of Claim 1, wherein the correlating procedure further comprises the step of utilizing a tree structure definition in order to correlate between the process data of a machine unit and units implemented at upper structure levels.

3. The method of Claim 1 wherein the statistical analysis includes measurements from the list of: process mean, standard deviation, and process capability measurements.

4. The method of Claim 1, wherein the statistical analysis further comprises the step of providing a graphical representation for displaying the statistical results and their control limit.

5. The method of Claim 4, wherein the graphical representation is displayed in a bar chart.

6. The method of Claim 4, wherein the graphical representation is displayed in a box-plot.

7. The method of Claim 4, wherein the graphical representation is displayed in a histogram.

8. The method of Claim 1, wherein the statistical process control analysis further comprises the step of detecting out-of-control and nonrandom trends measured in statistical process results.

9. The method of Claim 8 further comprising the step of triggering an alarm in case a nonrandom trend is measured in a statistical process result.

10. The method of Claim 1, wherein the statistical process control analysis is carried out in automatic mode during production.

11. The method of Claim 1, wherein the statistical process control analysis is carried out in manual mode, in response to a user's request.

12. The method of Claim 1, wherein applying a machine failure diagnosis uses fuzzy logic rules, said rules based on integrated analysis results of all machine assembly units.

13. The method of Claim 1, wherein applying a machine failure diagnosis uses automatic diagnosis algorithms.

14. The method of Claim 1, wherein machine failure diagnosis comprises the steps of:

producing diagnosis conclusions with respect to the machine failure diagnosis; and presenting an explanation and pre-defined treatment recommendations with respect to produced conclusions.

15. The method of Claim 14, wherein the pre-defined treatment recommendations include an automatic calibration operation treatment in case the produced conclusion indicates a calibration problem.

16. The method of Claim 14, wherein the explanation is presented in natural language that is friendly and comprehensive to the user.

17. The method of Claim 14 further comprising the step of storing in database the produced diagnosis conclusions and pre-defined treatment recommendations.

19. The method of claim 1 further comprising the step of receiving AOI (Automatic Optical Inspection) results of assembled printed boards' of all machine assembly units.

20. The method of Claim 1, wherein the machine assembly production process is carried out in a process industry of the group of: electronics, automotive, aerospace, health care, pharmaceuticals, and chemistry industry.

21. A system for diagnosing failures in machine assembly production process, wherein said diagnosis is based on in-depth statistical process control (SPC) data of all machine assembly units at all structure levels, the system comprising:
monitoring means for monitoring production data and process data of the units at all structure levels;
correlating means for relating production data to appropriate machine assembly units;
statistical means, provided to perform statistical analysis on each units' monitored process data during operation;
SPC means, provided to perform statistical process control analysis on each units' monitored process data;
a Failure Diagnosis Unit, provided to identify each units error type based on the unit's statistical results and obtain a failure diagnosis; and
analyzing means provided to produce a diagnosis conclusion for each machine failure with respect to the machine failure diagnosis based on machine diagnosis models,

22. The system of Claim 21 wherein the statistical results are measurements from the list of: process mean, standard deviation, and process capability.

23. The system of Claim 21, further comprising a Treatment Recommendation Database, provided to store the diagnosis conclusion.

24. The system of Claim 23, wherein the diagnosis conclusion includes an explanation and pre-defined treatment recommendations.

25. The system of Claim 21 further comprising a system viewer for displaying the statistical results and control limits of the units at all levels.

26. The system of Claim 25, wherein the statistical results are graphically represented in a bar chart.

27. The system of Claim 25, wherein the statistical results are graphically represented in a box-plot.

28. The system of Claim 25, wherein the statistical results are graphically represented in a histogram.

29. The system of Claim 23, wherein the Failure Diagnosis Unit further detects out-of-control and nonrandom trends in a unit based on the unit's statistical process results.

30. The system of Claim 29 further comprising means for triggering an alarm in case a nonrandom trend is detected in a unit.

31. The system of Claim 21, wherein the statistical results are measured in automatic mode during production.

32. The system of Claim 21, wherein the statistical results are measured in manual mode, in response to a user's request.

33. The system of Claim 23, wherein the Failure Diagnosis Unit uses fuzzy logic rules, said rules based on integrated analysis results of all machine assembly units.

34. The system of Claim 23, wherein the Failure Diagnosis Unit uses automatic diagnosis algorithms.

35. The system of Claim 24, further comprising automatic operational treatment means, wherein part of the treatment recommendations are carried out automatically.

36. The system of Claim 24, wherein the explanation is presented in natural language that is friendly and comprehensive to the user.

37. The system of claim 21 further comprising an AOI (Automatic Optical Inspection) system, provided for detecting components placement shifts by inspecting produced printed boards.

38. The system of Claim 21 implemented in a process industry of the group of: electronics, automotive, aerospace, health care, pharmaceuticals, and chemistry industry.

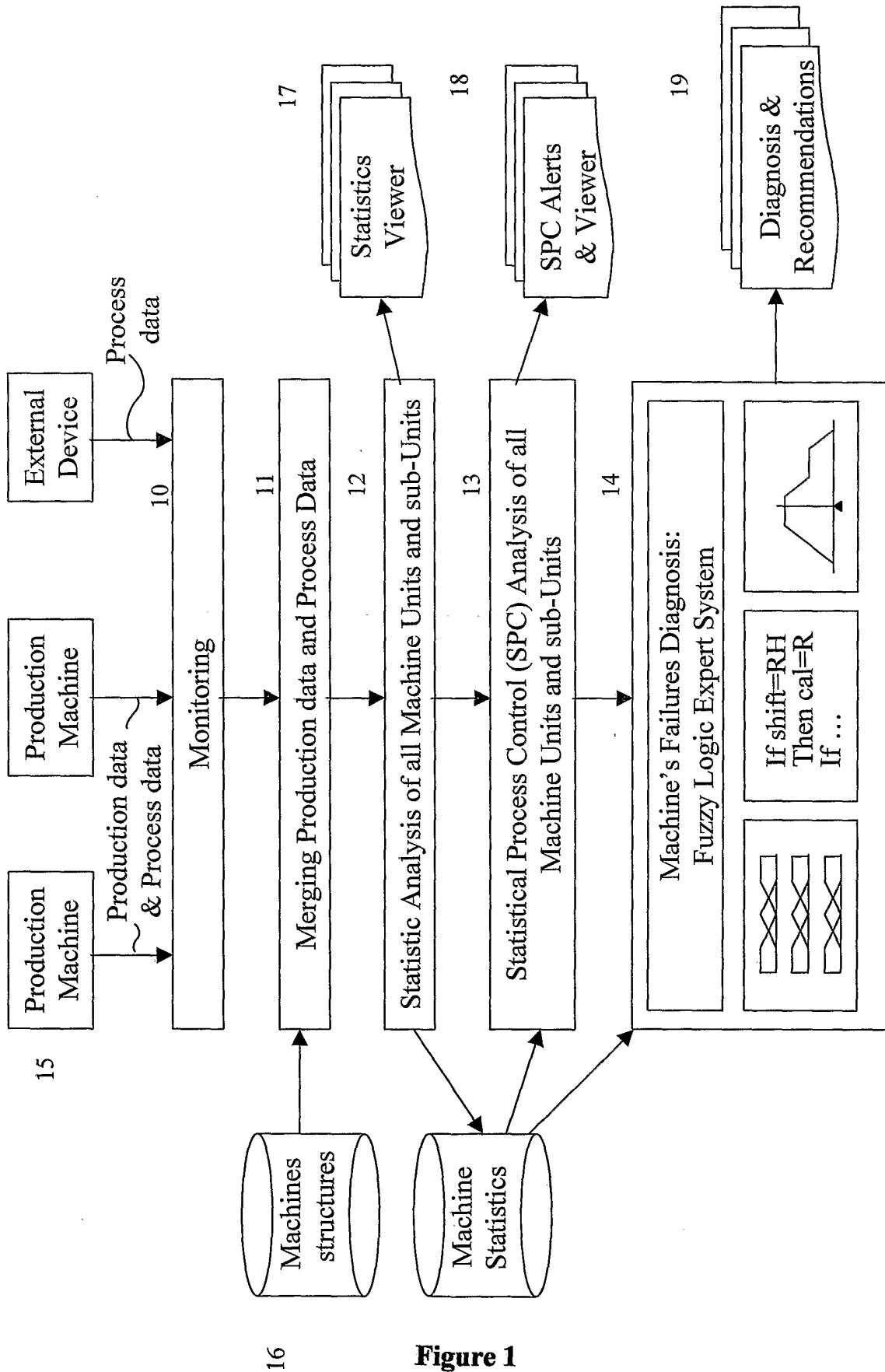


Figure 1

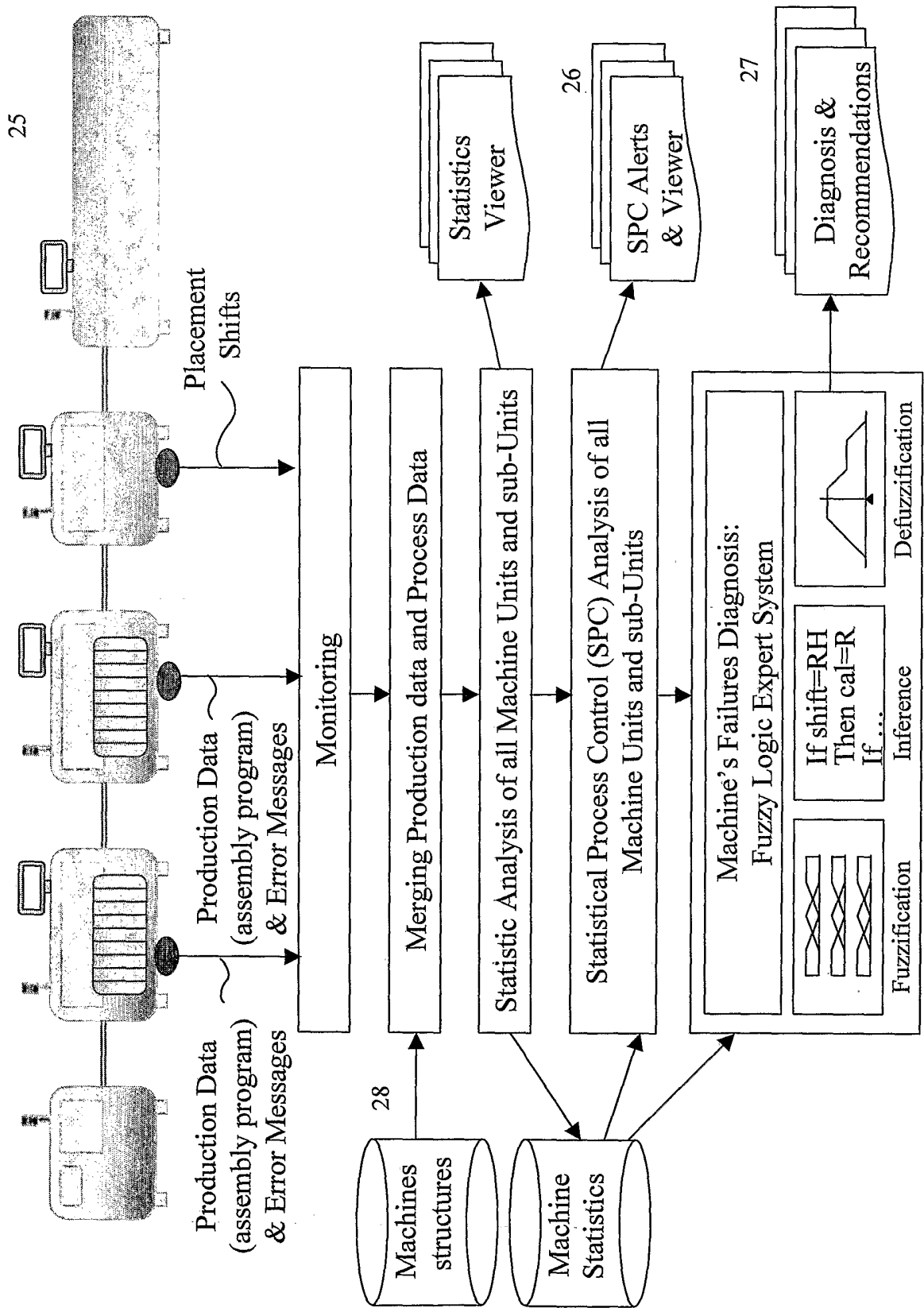


Figure 2

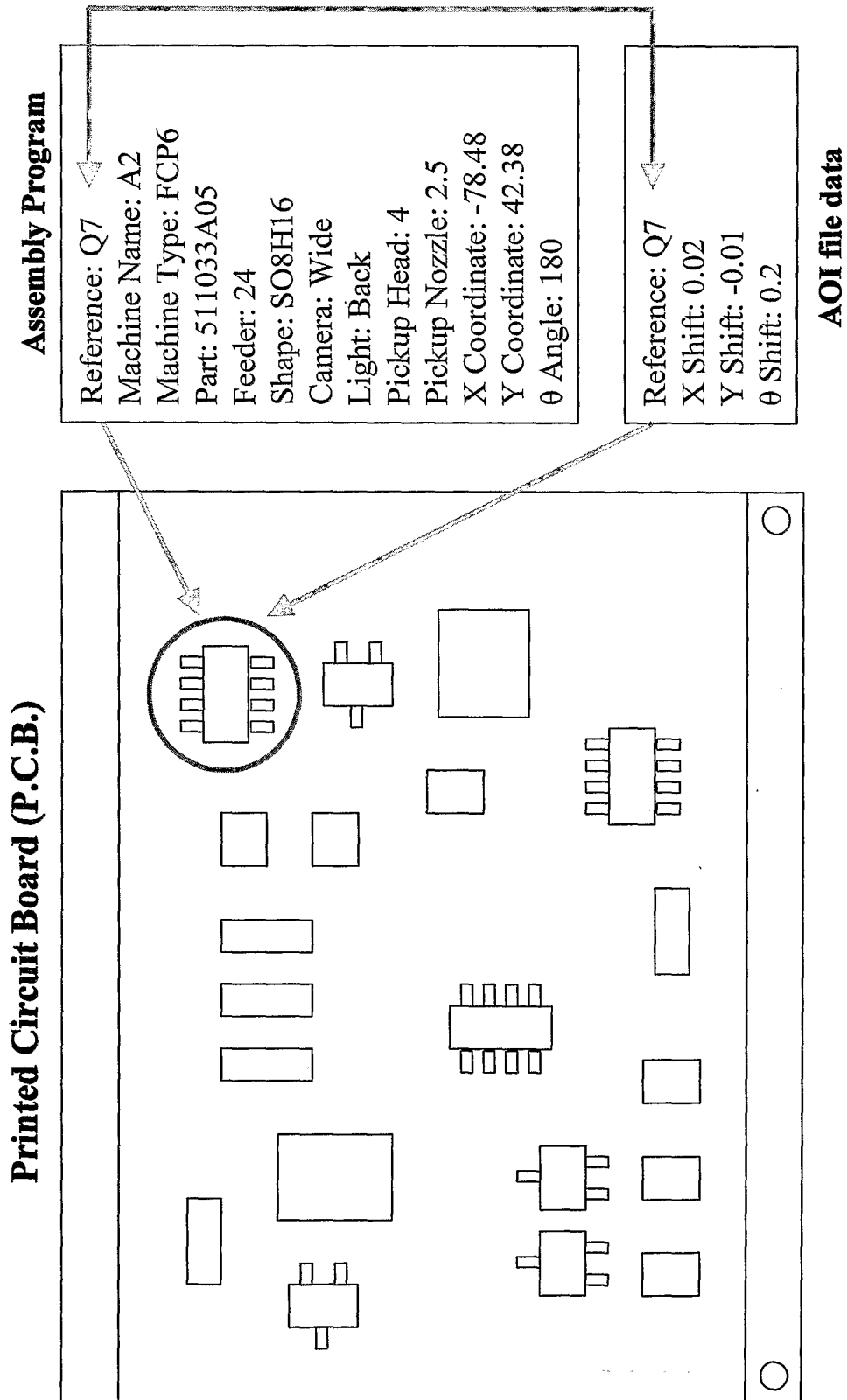


Figure 3

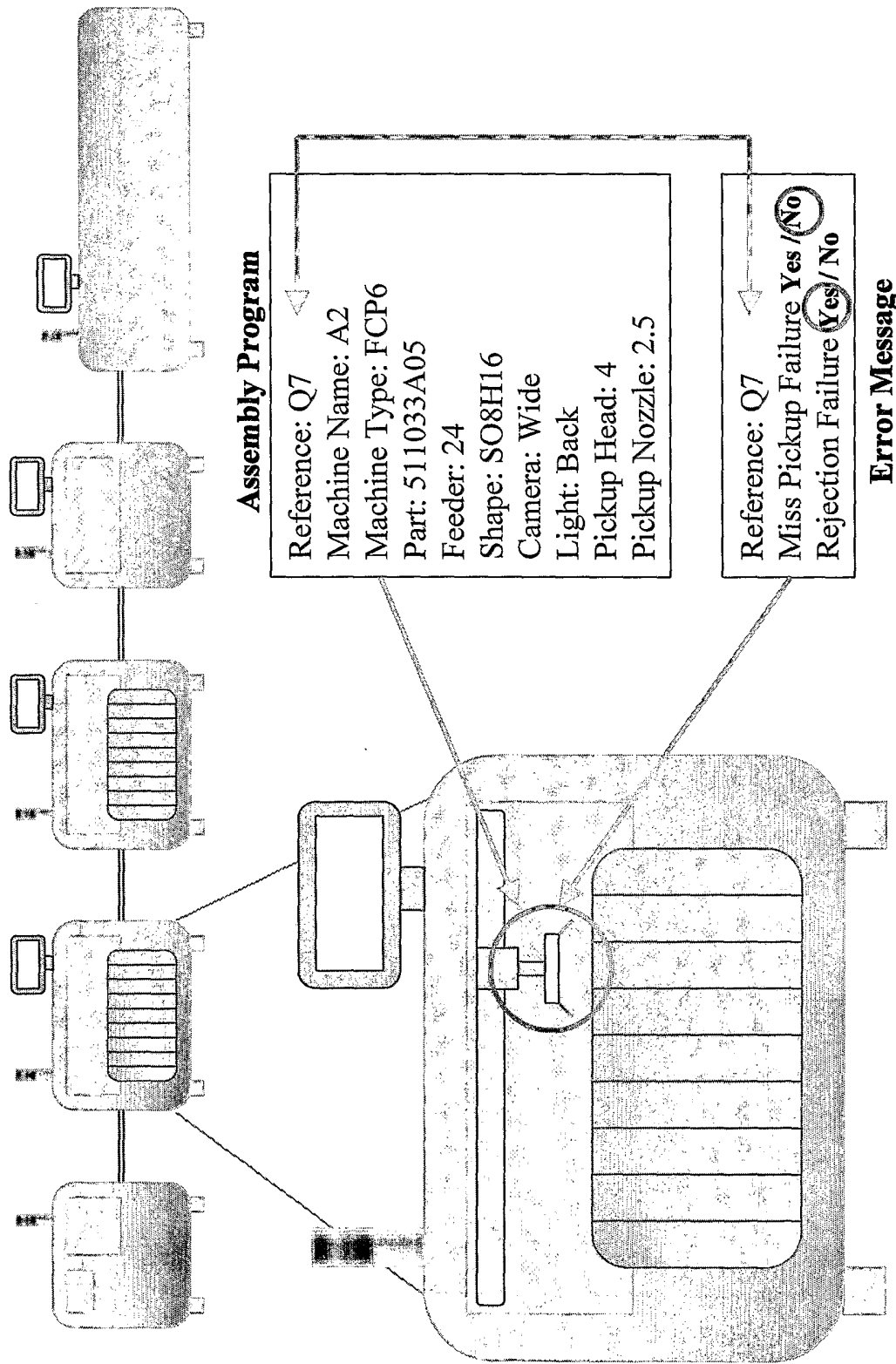


Figure 4

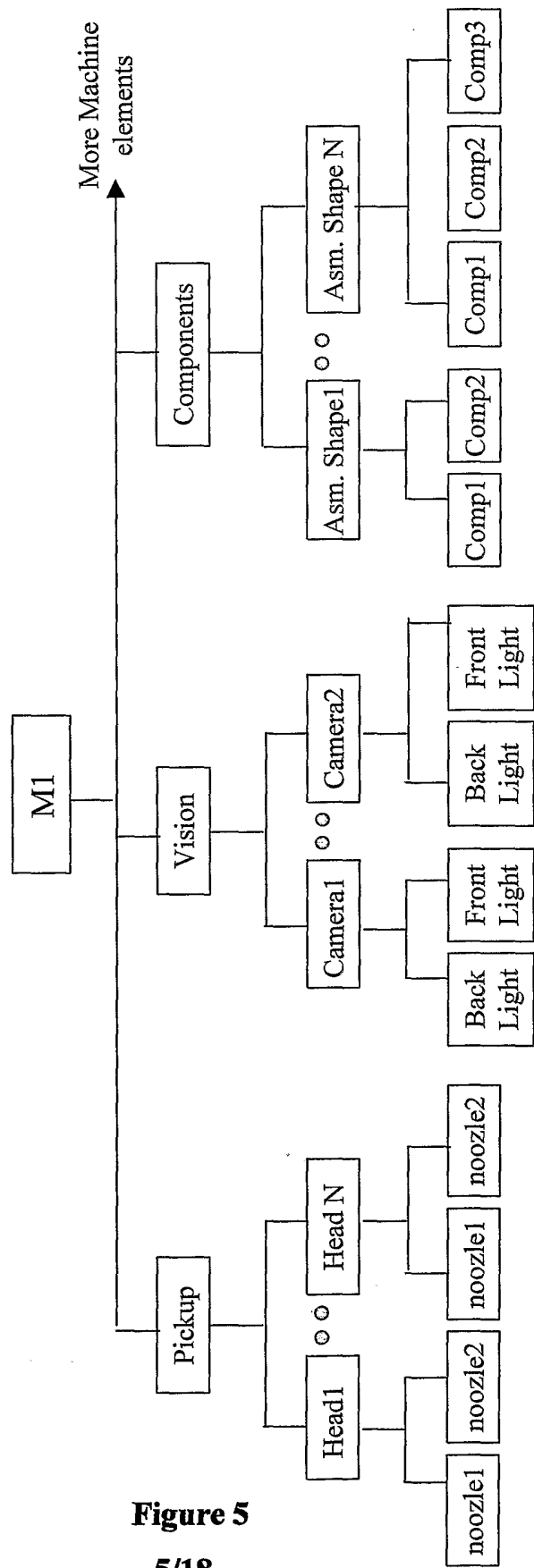


Figure 5

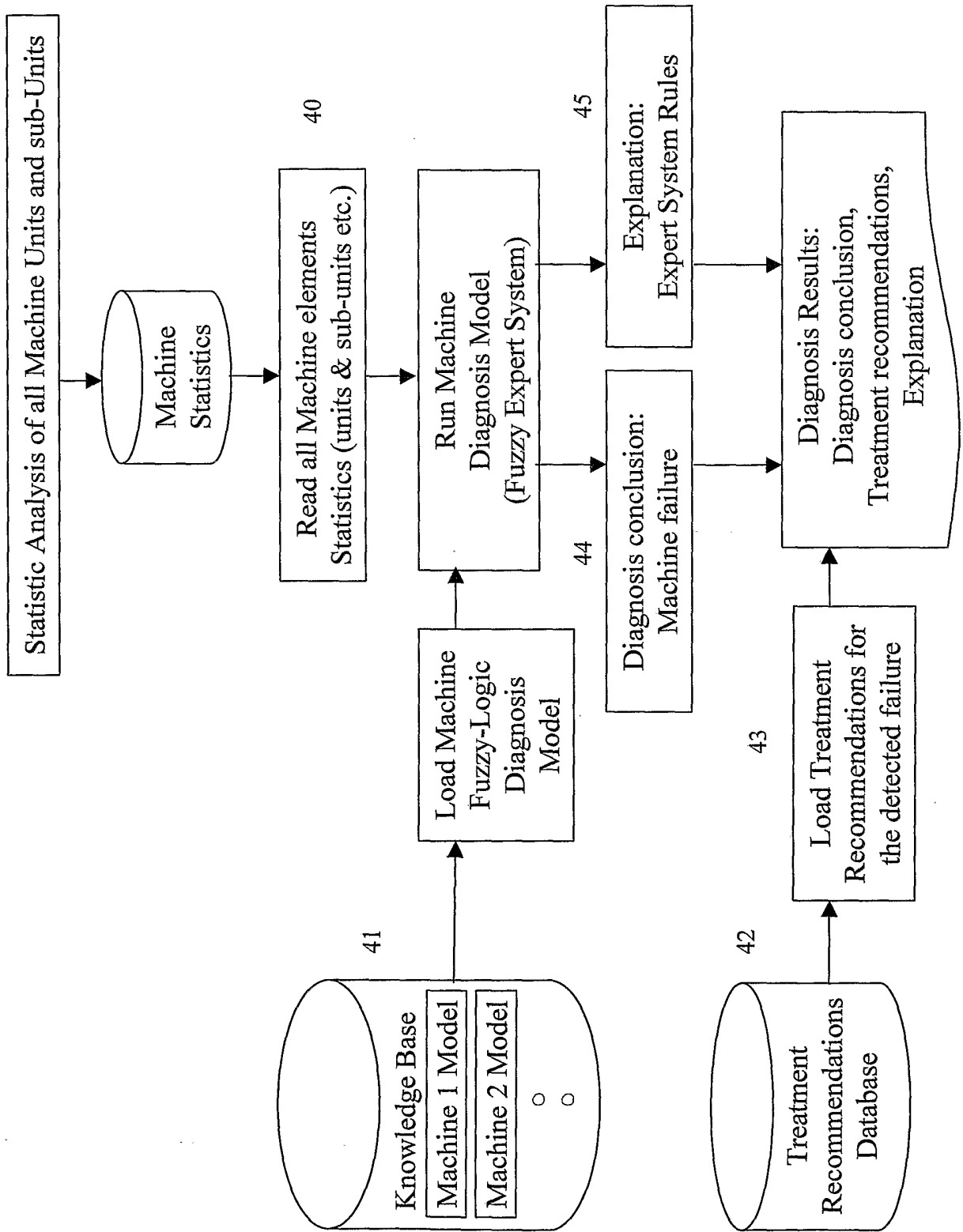


Figure 6

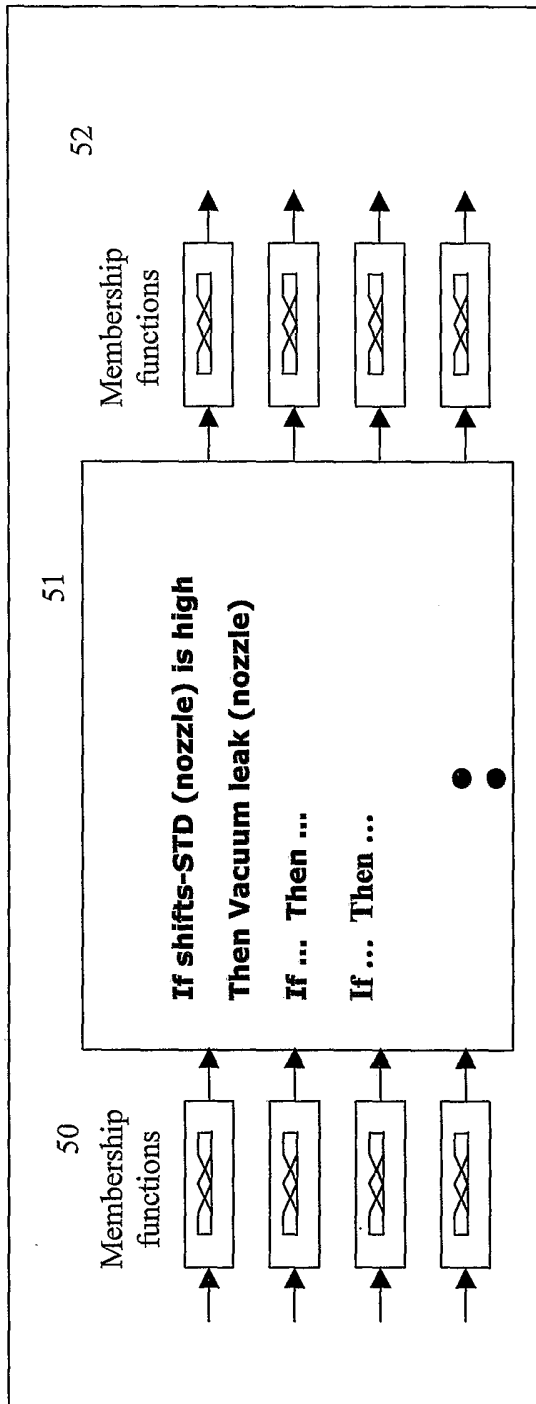


Figure 7a

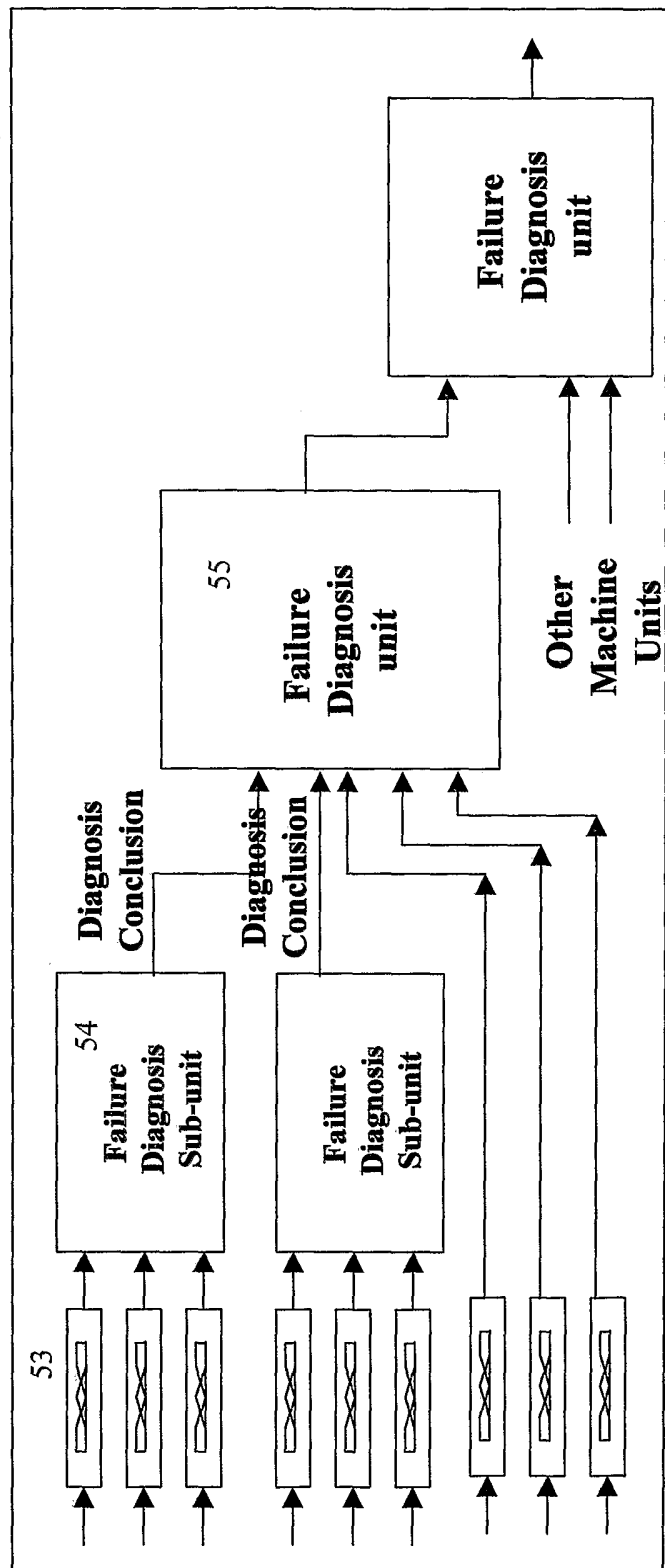


Figure 7b

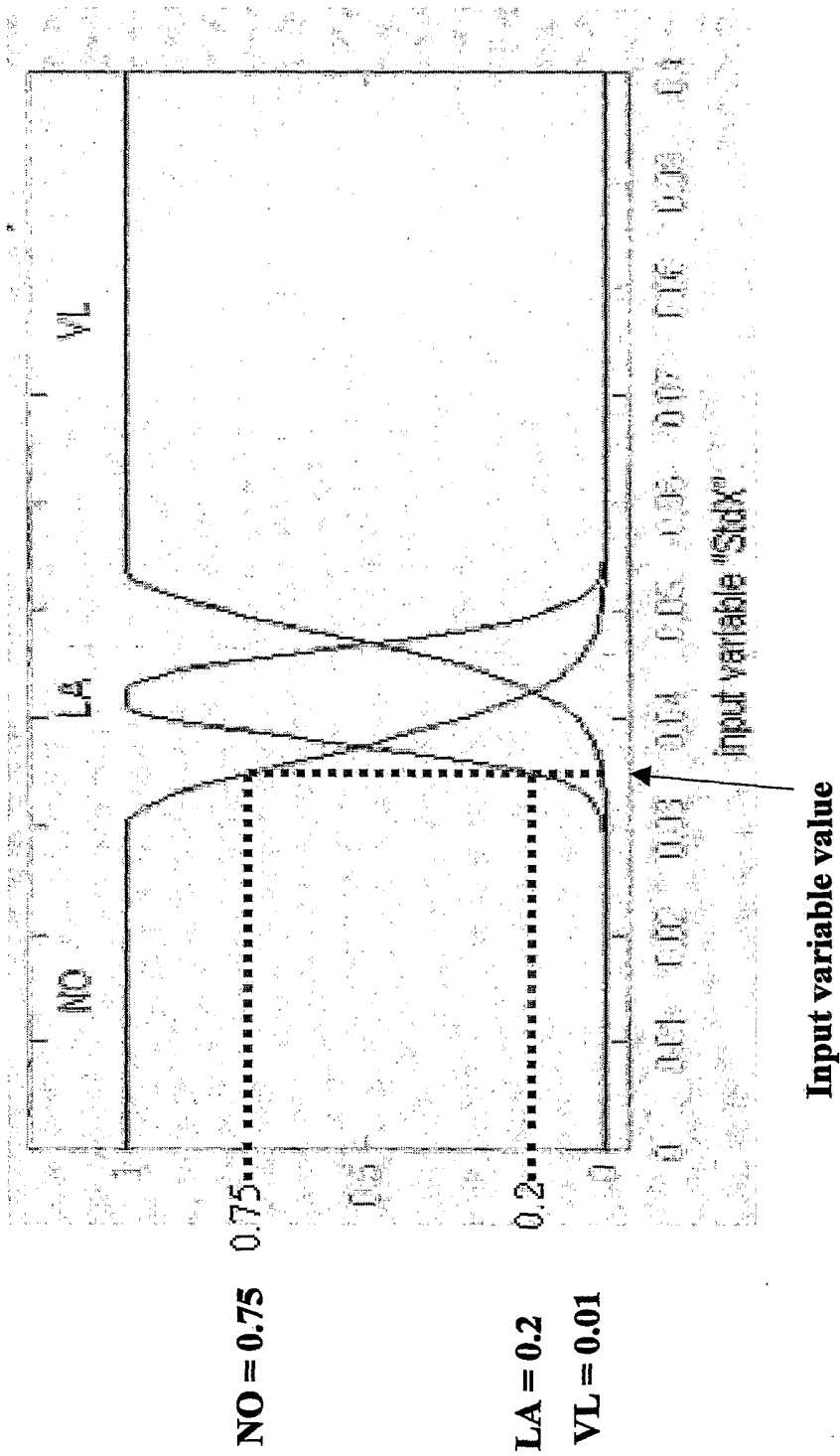


Figure 8

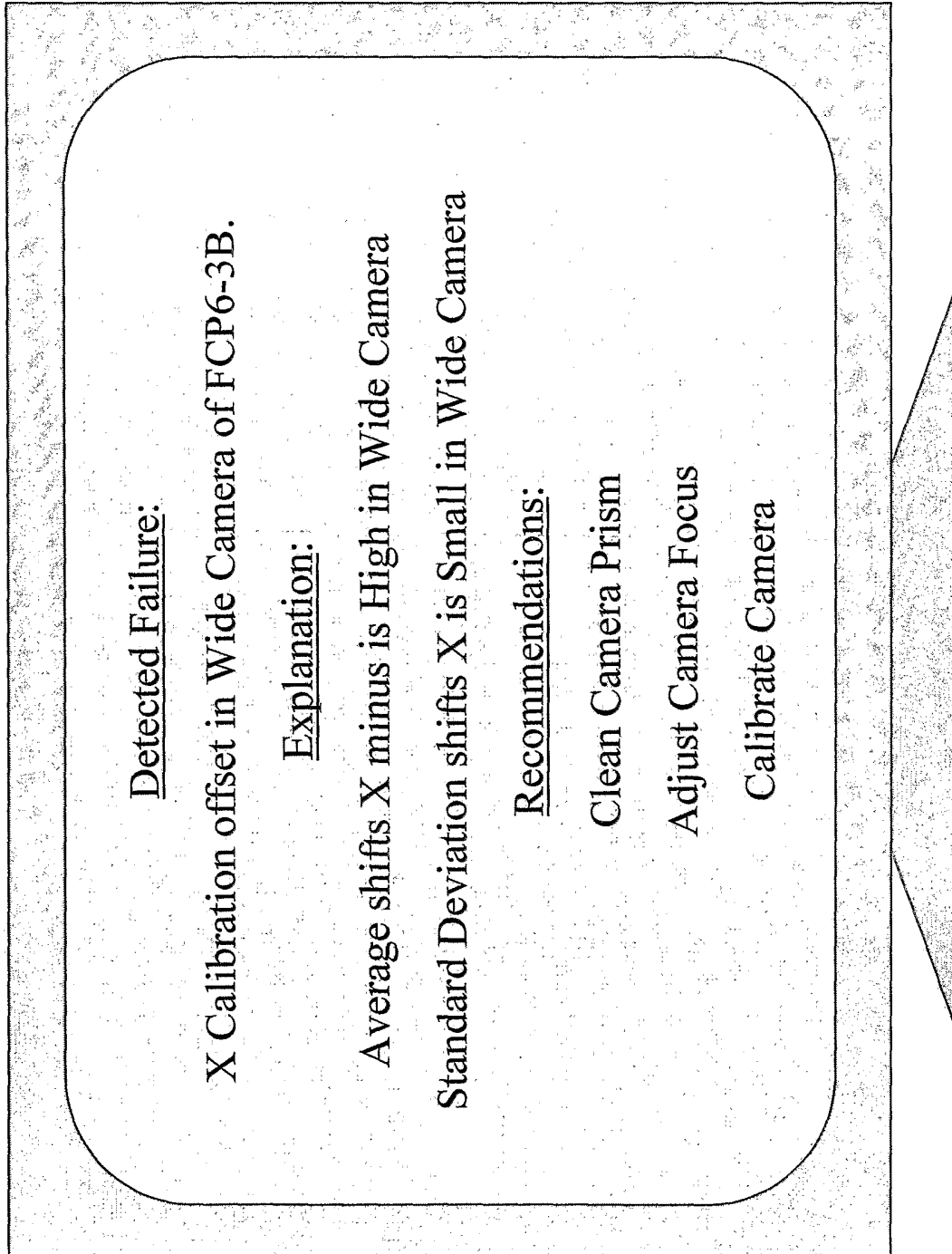


Figure 9

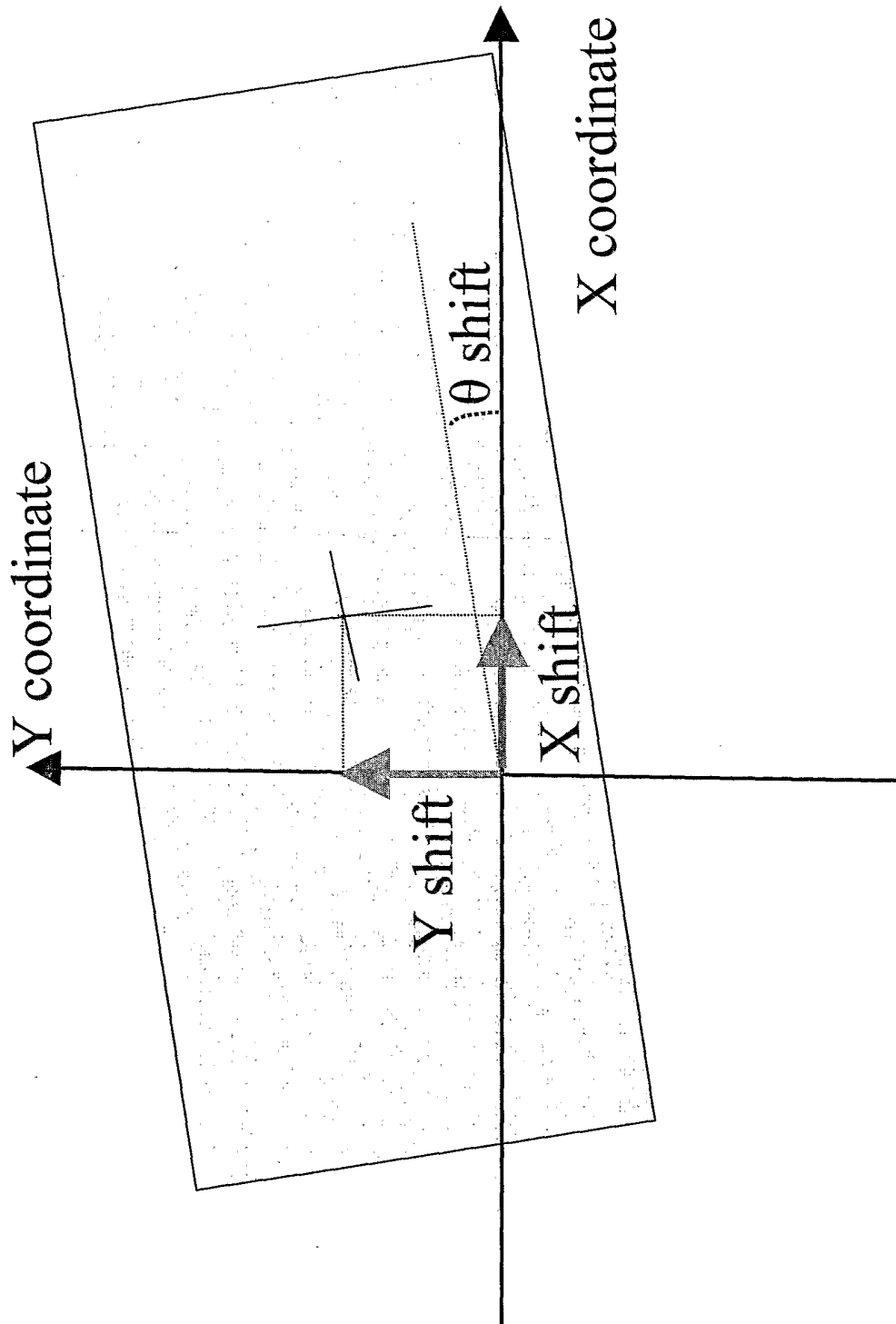


Figure 10

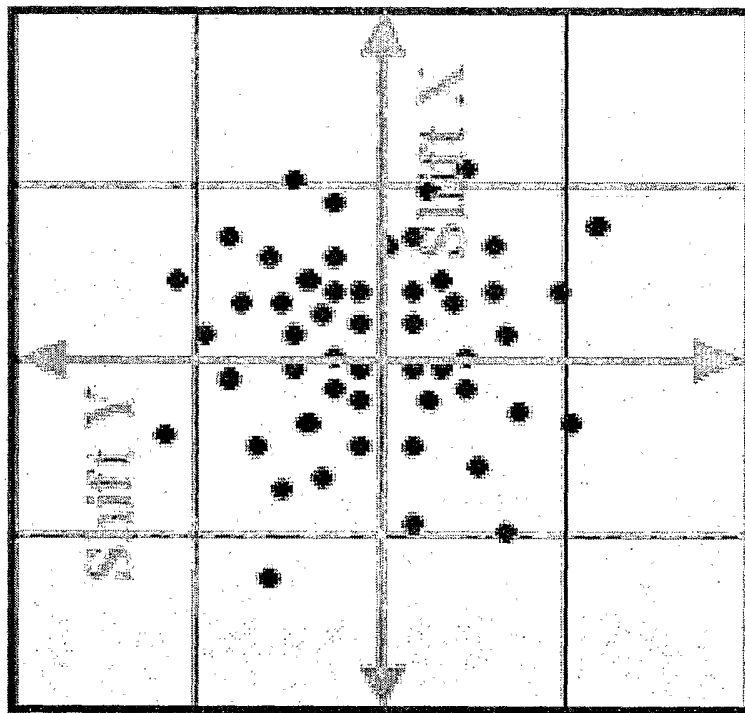


Figure 11

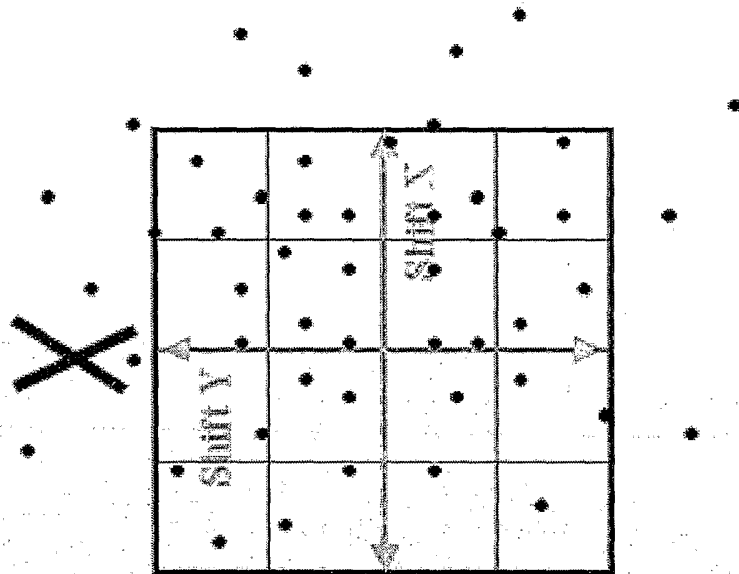


Figure 12b

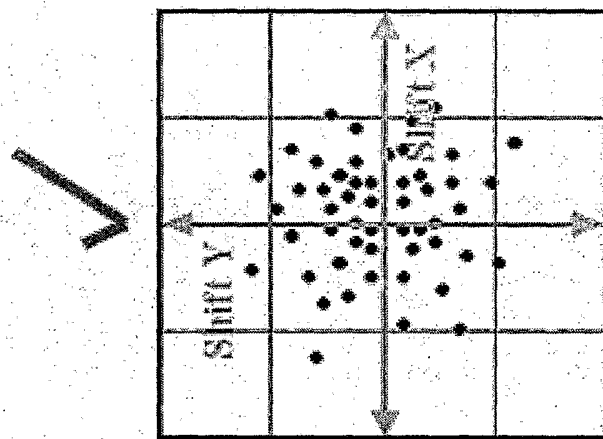


Figure 12a

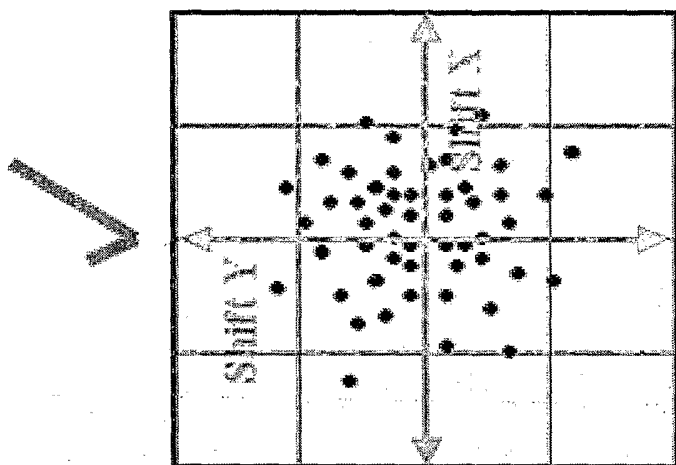


Figure 13b

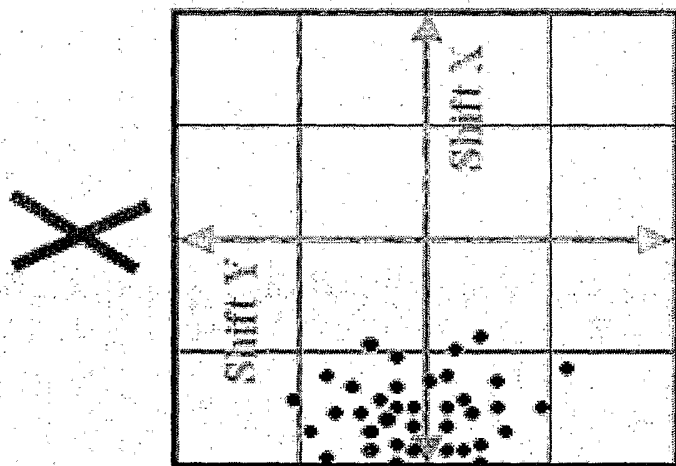


Figure 13a

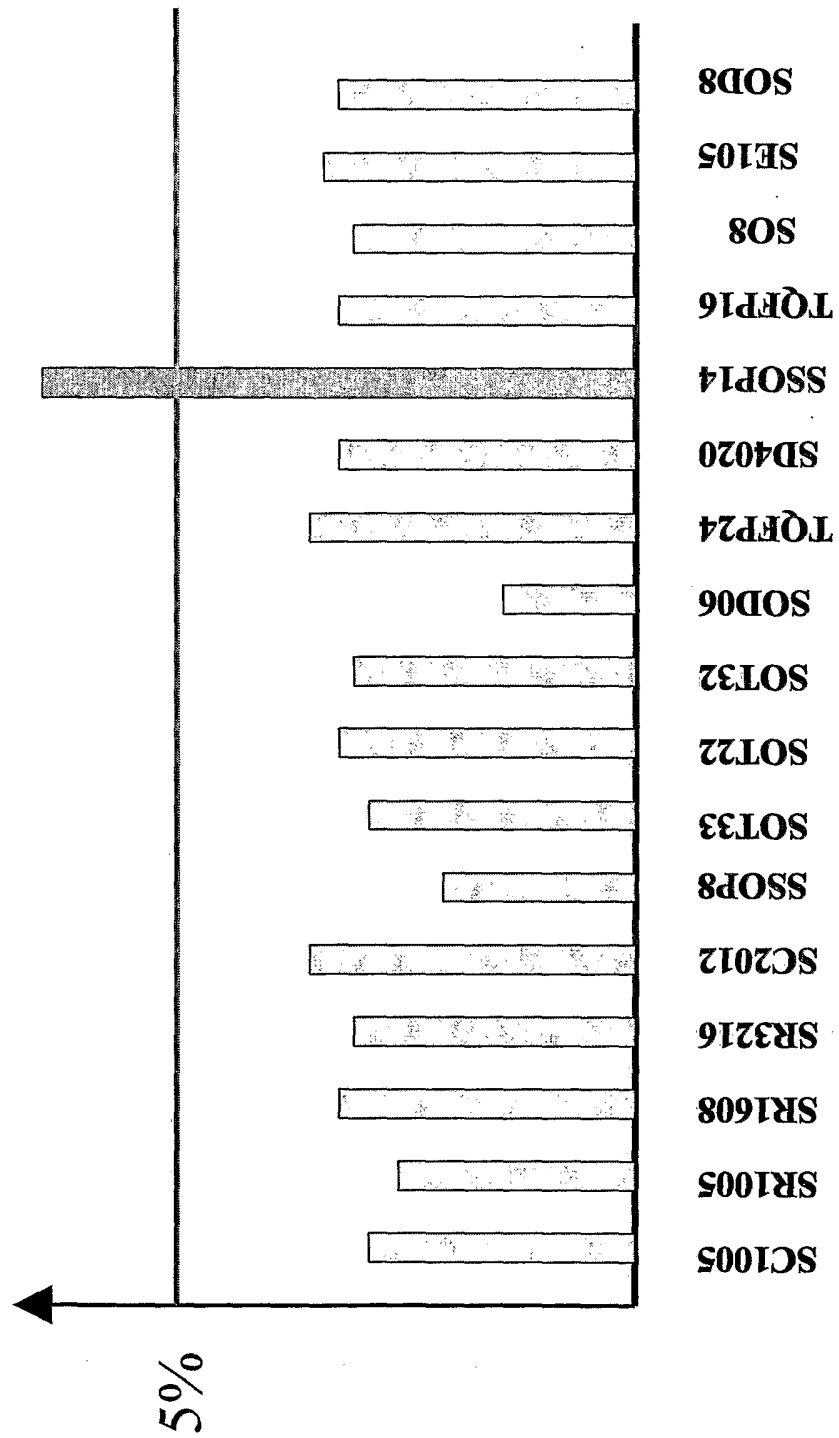


Figure 14

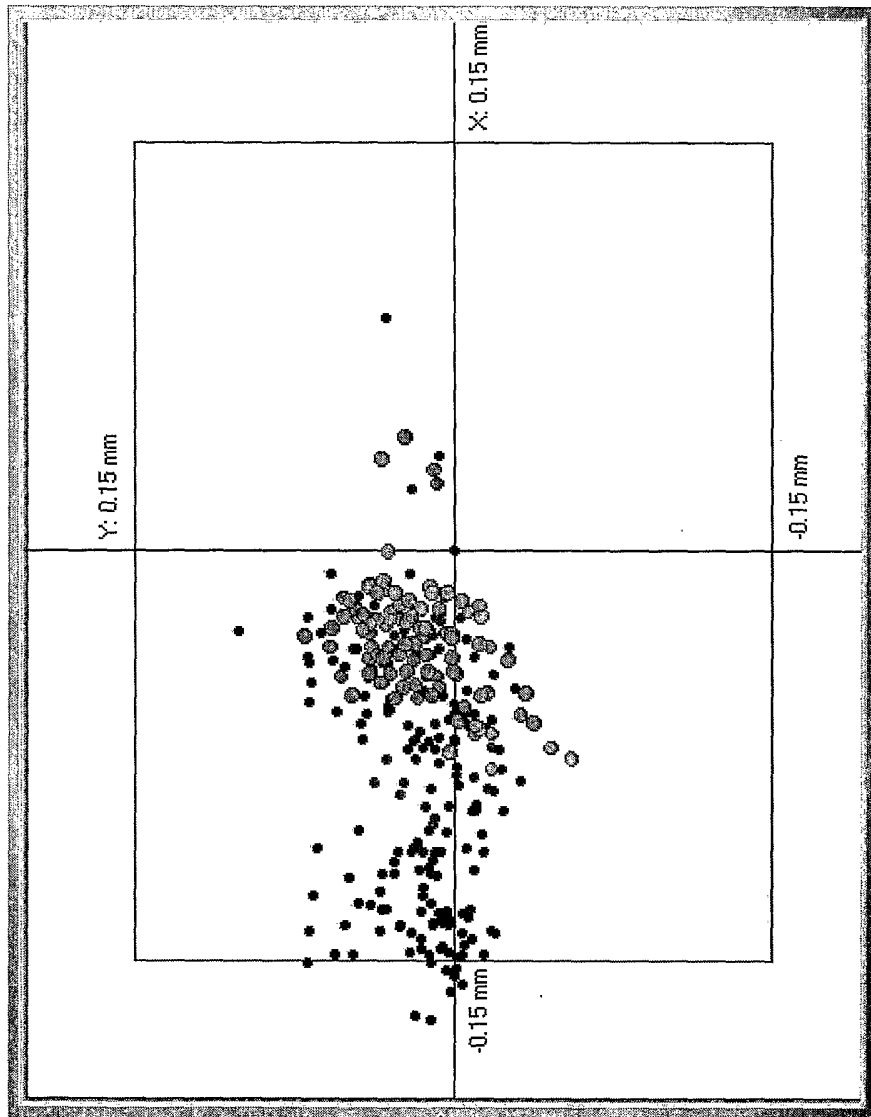


Figure 15

Unit	AvgX	SDX	AvgY	SDY	Missings	Rejections
FCP6A	-.067	.046	.016	.024	1	0
HEADA	-.06	.045	.001	.016	0	0
HEADB	-.093	.043	-.004	.013	0	0
HEADC	-.091	.035	-.014	.017	0	0
HEADD	-.077	.049	-.004	.014	0	0
HEADE	-.087	.044	-.007	.015	0	0
HEADF	-.071	.049	0	.016	0	0
HEADG	-.074	.052	.012	.012	0	0
HEADH	-.033	.049	.026	.025	0	0
HEADI	-.064	.038	.033	.018	0	0
HEADJ	-.066	.052	.019	.016	0	0
HEADK	-.062	.045	.046	.017	0	0
HEADL	-.074	.047	.038	.02	1	0
HEADM	-.054	.05	.018	.018	0	0
HEADN	-.089	.043	.018	.018	0	0
HEADO	-.065	.039	.029	.022	0	0
HEADP	-.052	.049	.012	.02	0	0
HEADQ	-.076	.042	.033	.013	0	0
HEADR	-.064	.045	.033	.017	0	0
HEADS	-.053	.042	.022	.02	0	0
HEADT	-.063	.044	.02	.019	0	0

Figure 16

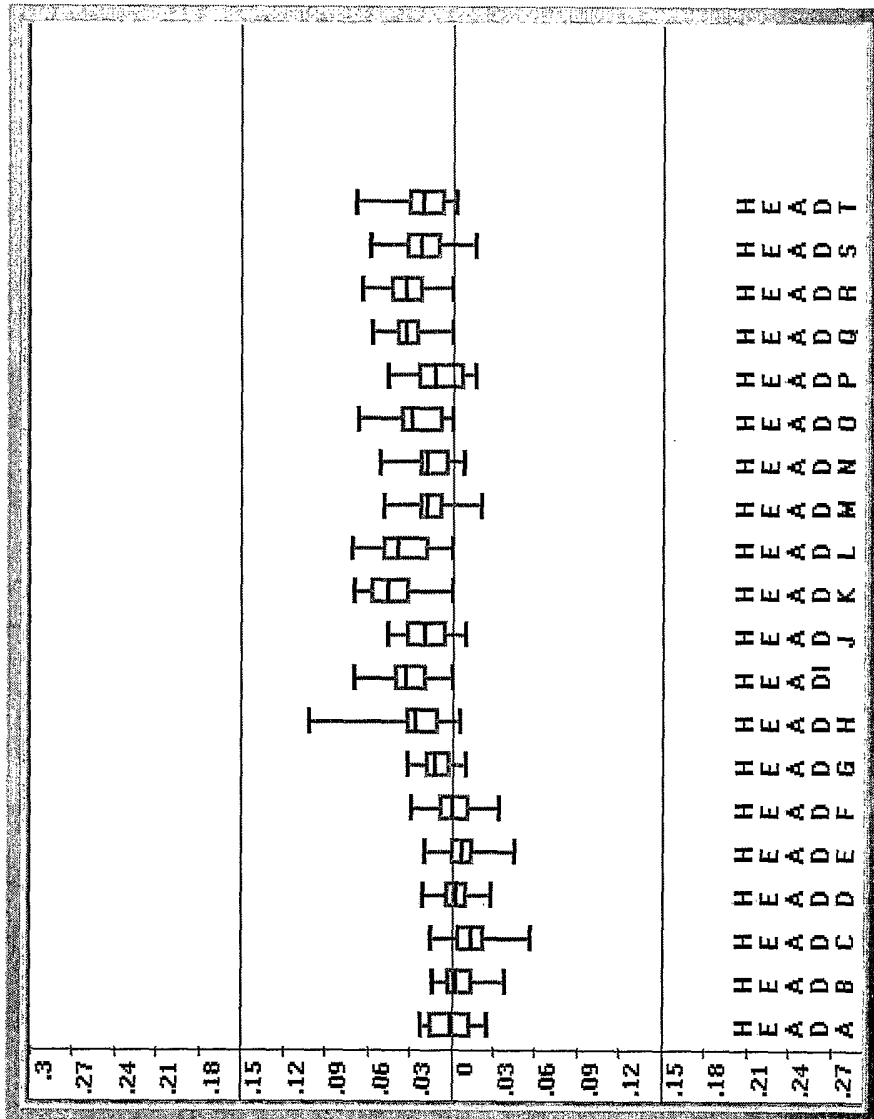


Figure 17

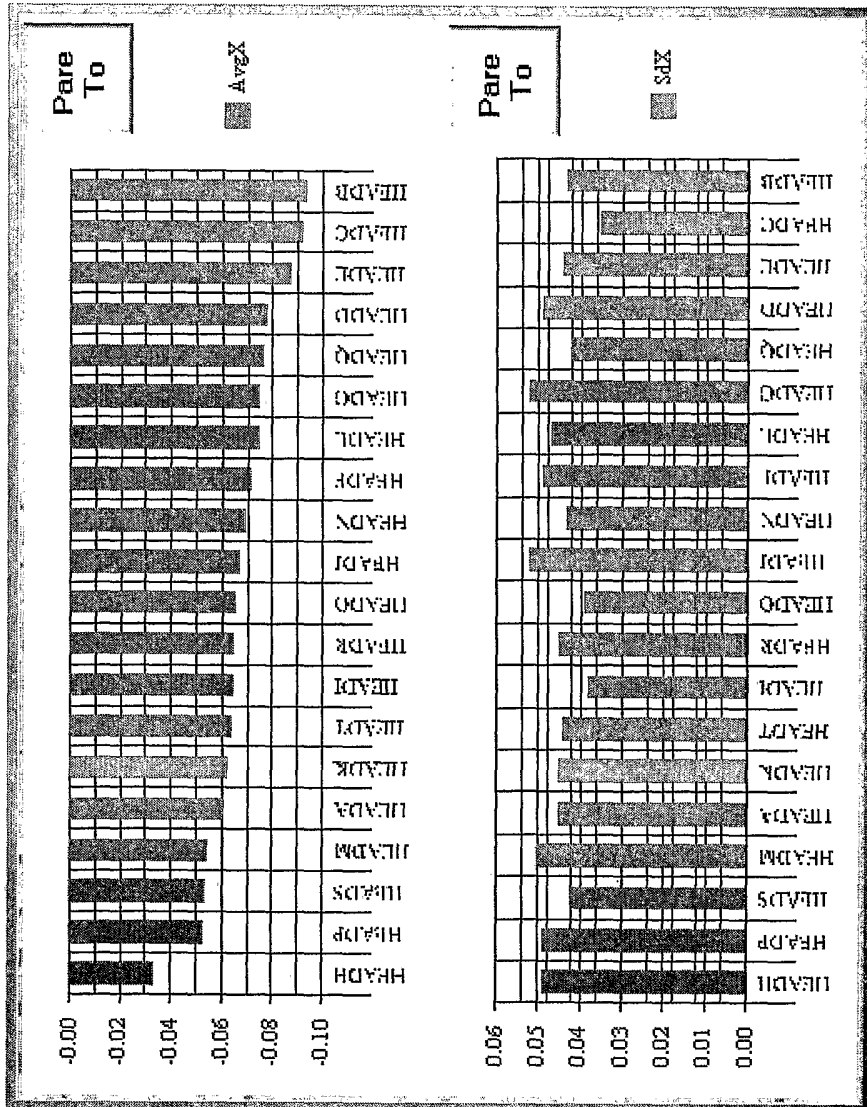


Figure 18