Health Management Technology as a General Solution Framework

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Abstract: Health maintenance and improvement of humans, artifacts, and nature are pressing requirements considering the problems human beings have faced. In this article, the health management technology is proposed by centering cause-effect structure. The important aspect of the technology is evolvement through human-machine collaboration in response to changes of target systems. One of the reasons why the cause-effect structure is centered in the technology is its feature of transparency to humans by instinct point of view. The notion has been spreaded over wide application areas such as quality control, energy management, and healthcare. Some experiments were conducted to prove effectiveness of the technology in the article.

Key Words: equipment management system, energy management system, healthcare system, human-machine collaboration, causality, cause-effect structure.

1. Introduction

Human beings have faced many serious problems such as global warming, depleted resources, declining birth rate, and so forth. An essential and simple observation of the world reveals that it can be considered as comprising humans, artifacts, and nature. Even though the values of the entities are given by humans, they seem to have completely different directions. Examples of such values are comfort and safety for humans, efficiency and effectiveness for artifacts, and environmental enhancement for nature. The problem is that these values come into conflict with each other. Examples of conflicts in a factory are as follows. Productivity related to efficiency and effectiveness is the most important value in manufacturing lines. However, the focus only on productivity will increase the emission of carbon dioxide and other contaminants that will negatively influence the safety and comfort of human operators in the manufacturing line. Thus, the conflicts of values among the respective entities cause serious problems in important areas such as the environment, agriculture and food, security and safety, and human health these days. In this sense, harmonization among them might be required based on good health condition of each entity for realizing a desired next society. Although this vision might look grandiloquent, health management of each entity is considered as important activity as steady steps toward the bright future.

In this article, the health management technology is proposed in response to the requirement with considering the change of target systems. The technology consists of four functions and provides the solution of cyclical evolvement based on the notion of causality which illustrates conditions of target systems. Here, the words of causality and cause-effect structure denote problem-solving knowledge, which is composed of feature attributes extracted from sensing data and intermediate characteristics. In this sense, cause-effect structure could evolve and could be updated according to sophistication of sensing and control mechanisms. Because the cause-effect structure is transparent to humans, the structure can be easily improved through human-machine collaboration. This feature of the technology is quite important because the integration of human knowledge and sensing data will bring a powerful and sophisticated solution for complex problems.

In Chapter 2, the notion of health management technology is introduced with its four main elemental functions. While the health management technology could be applied to various systems such as human, machine, and nature, the first applications are introduced and discussed in Chapter 3. These applications are: quality control of substrate manufacturing processes for machine health, energy consumption management for nature health, and visceral fat estimation for human health management. Experiments were conducted to prove the effectiveness of the proposed technology applied to each application. Chapter 4 concludes this article with summaries.

2. Health Management Technology

In this chapter, the notion of the health management technology is introduced to discuss its basic mechanisms and the four functions defined in the technology framework. It employs causality as an essential solution component in the technology.

2.1 Basic Mechanisms

Figure 1 shows an overview of the health management technology based on causality. The objective of the technology is to estimate the health condition of humans, artifacts, and nature to improve their health. Because the target system continuously changes and their health management systems must adapt to these changes, the cause-effect structure must evolve cyclically and continuously according to sophistication of both the target system and its management side.

Health management could be realized based on causality among measurements of target systems. The example of human health management is introduced to use time series sensing data and their cause-effect structure as follows. It is said to be important for us to manage our exercise, diet, and sleep because they are essential activities in our daily life. The sensing
data are used for composing the causality that can be applied to prevent diseases and to improve health. Among biologic information, blood pressure is usually used as a reference index of health condition because it is closely associated with cardiovascular events such as brain infarction, stroke, myocardial infarction, and heart failure. Besides other important factors such as total cholesterol, casual glucose, etc., blood pressure is easy to measure at home and medical facilities. There are also easy and useful indices; body composition, active mass, and sleep condition. The composition of muscle and fat is measured by a body composition monitor. The measure could be used as one of alternative reference indices for quality and quantity of diet in our life. An active mass monitor or a pedometer could measure quality and quantity of exercise in daily life. A sleep monitor measures quality and quantity of sleep. The time series data of blood pressure, body composition of muscle and fat, active mass, and quality and quantity of sleep are obtained by these sensing devices. Cause-effect structure derived from the data will provide important knowledge for diagnosis and prognosis of health condition for individuals. For instance, continuous and well active mass seems to have good influence on the body composition and sleep to realize the stability of blood pressure.

2.2 Four Functions and Cyclic Evolution

In the health management technology, four functions are defined for cyclically evolving the model as shown in Fig. 2.

- **Measurement** is the quantification of phenomena to arrive at a value from analyzing signals from sensors. The function is realized by the elemental technologies of feature extraction, feature selection, and feature evaluation.

- **Recognition** is to identify the condition of the target system using the measured value. The function is based on the pattern recognition technologies such as discrimination, classification, and identification.

- **Estimation** is to project the past and future status of the system. The functions of diagnosis and prognosis are realized by employing cause-effect structure. The elements of technology for realizing this function are probability graphs and causal models such as Bayesian network, structural equation model, etc.

- **Evolution** is to improve the target system and to update causality by the discovery of new events and make changes in the target system. The function should be realized by human-machine collaborative design and control.

Based on cause-effect structure, **Measurement**, **Recognition**, **Estimation**, and **Evolution** are cyclically and continuously executed to improve causality for better health. For instance, a new sensing point could be found according to evolution of the cause-effect structure. As a result, it makes performance of health management more powerful and precise.

2.3 Discussions on Causality

In this section, one of the modeling methods for a causality-based solution is introduced. Many studies have been done related to causality. These studies cover quite a wide area from psychology and philosophy [1],[2] to image processing and bioinformatics [3]. Theoretical basics were also deeply studied [4] and some studies covered wide areas [1],[5],[6].

In this article, the path analysis that is one of principle causal analysis methods is employed to realize the health management technology as a first step of the technology because of its simple but powerful solution nature. Besides introduction to the method, acquisition and improvement of cause-effect structure are discussed.

2.3.1 Cause-effect Structure Analysis

As one of cause-structure acquisition, the path analysis [7] or the structural equation model [8] is introduced here. The cause-effect structure is described by a cause-effect diagram shown in Fig. 3. The cause-effect diagram is formulated by the structural equations 1, 2, and 3. A causal relationship between variables is quantified by the coefficients $\alpha_{XX}$ which are called causal effect or path coefficient. The paths from $X_1$ to $X_4$ are the direct effect of $X_1 \rightarrow X_4$, the indirect effects of $X_1 \rightarrow X_2 \rightarrow X_4$ and $X_1 \rightarrow X_3 \rightarrow X_4$. The sum of the direct and indirect effects is called total effect which is calculated by the equation 4. By using these effects, the cause-effect structure can be quantified. Sometimes for simplification, means and variances of variables used in the cause-effect structure are normalized to 0 and 1 respectively.

\[
X_2 = \alpha_{21}X_1 + \epsilon_1 \quad (1)
\]
\[
X_3 = \alpha_{32}X_2 + \epsilon_2 \quad (2)
\]
\[
X_4 = \alpha_{41}X_1 + \alpha_{42}X_2 + \alpha_{43}X_3 + \epsilon_3 \quad (3)
\]
\[
E_{T41} = \alpha_{41} + \alpha_{21}\alpha_{42} + \alpha_{21}\alpha_{32}\alpha_{43} \quad (4)
\]
3. Application Studies

In this chapter, three kinds of applications are selected to discuss a causality-based problem solving approach. The first one is quality control in a substrate manufacturing process. In this application, cause-effect structure is composed of inspection criteria and intermediate characteristics. Based on the cause-effect structure, the control criterion of fillet length is discussed, viewed from the aspect of quality control because the criterion has serious influence on reliability of the substrate.

The second application is energy management for facilities such as schools, offices, hospitals, etc. The applications aim at energy saving in these facilities by using sensing data of energy consumption, temperature, and humidity. By using the sensing data, the cause-effect structure of energy consumption is acquired to be used for energy consumption simulation. The simulation results would make a decision easier for person of energy management.

The last one is the estimation algorithm embedded in visceral fat measurement equipment. In this application, the cause-effect structure is composed of physical and bioimpedance measurements to estimate visceral fat area in an abdominal cross section.

3.1 Quality Control in a Substrate Manufacturing Process

Complex manufacturing processes like substrate manufacturing require qualified operators for maintenance and improvement of the processes. In these sorts of manufacturing processes, relationships among QCD (Quality, Cost, and Delivery) as goal and performance indices and 4M+E(Man, Machine, Material, Method, and Environment) as factors in manufacturing would not be quantitatively and qualitatively clarified. However, the qualified operators apply their tacit knowledge accumulated for a long time and sophisticated experience to solve the faults happened in the manufacturing process and to improve it. Still, dependence just on human experts would cause other problems such as variance in product quality and inconsistency in maintenance of manufacturing processes among experts. Moreover a consistent employment of experts is difficult, taking lack of them in overseas factories and retirement of the baby boomers’ generation into consideration.

Given these reasons, a human-machine collaborative solution should be strongly required in improvement of manufacturing processes. In this section, the solution employing health management technology is proposed to realize causality-based quality control.

3.1.1 Overview of a Substrate Manufacturing Process

A substrate mounting process consists of a solder printing process, an electronic parts mounting process, and a reflow process for welding solder, which are called P, Z, and S processes respectively, as shown in Fig. 4. This manufacturing process has been standardized in all over the world. The substrates manufactured in the process are used in home appliances, mobile phones, automobiles, etc.

Automatic inspection machines are deployed after each of the P, Z, and S process. They employ an image sensing technique to realize detection of product defects. The inspector measure various types of inspection criteria to detect defects. The examples of inspection criteria for each process are as follows; printing areas of solder paste for the P process, displacement lengths of parts alignment for the Z one, and lengths of reflowed solder for the S one.

It is said that realizing and keeping defect ratio at ppm (parts per million) level are quite tough because substrate manufacturing processes are highly complex. For example, humidity would have some influence on stickiness of solder paste in the P process. The parts in the Z process are very small, in the range of a fraction of a millimeter. The S process has also some
difficulties because of its complicated temperature control.
Against these kinds of problems, quality control can be designed based on the cause-effect structure which is composed of the sensing data gathered by the inspectors and other sensing data such as temperature and humidity. The inspection criteria in the S process like fillet length have direct influence on product quality. They can be decided directly from target product quality and a defect rate. On the other hand, even though the criteria in the P and Z processes have also substantial influence on the quality, it might be difficult to decide them. Because their influence on the final quality is unclear for an indirect connection with the final inspection criteria. The cause-effect structure will be applied to solve this problem.

Among many inspection criteria, fillet length which is a lead-apical length of reflowed soldering forms to glue part on a substrate is selected as a main target criterion in this section because it has serious influence on the reliability of substrate products.

3.1.2 Anomaly Diagnosis
Once a defect could happen, anomaly diagnosis will be applied to find the cause of anomaly. As mentioned above, there are extremely huge numbers of the variables that could be the causes. Even though the criterion is limited to fillet length, there possibly exists around sixty variables. At the manufacturing process field, anomaly diagnosis is expected to shorten the break-down time caused by defects in products.

Anomaly diagnosis consists of three functions as follows.

- **Control criteria setting**: A control criterion for each variable is derived by using cause-effect structure and cause effect.
- **Anomaly detection**: An anomaly of each variable is detected by applying the control criteria.
- **Deviation evaluation**: A deviation of the anomalous variable is evaluated based on the notion of process capability [13].

(1) **Control criteria setting**
Control criteria in the S process which is the final one are settled to detect defects. At a highly sophisticated substrate manufacturing line, defect rate is settled at ppm level as mentioned above.

The specificaton of inspection criteria such as fillet length is given by the equations 5 and 6.

\[ U_{X_m} = M_{X_m} + P\sigma_{X_m} \quad (5) \]

\[ L_{X_m} = M_{X_m} - P\sigma_{X_m} \quad (6) \]

where \( M_{X_m} \), \( U_{X_m} \), and \( L_{X_m} \) are target mean of the inspection criterion, upper control criterion, and lower one respectively, \( \sigma_{X_m} \) is the standard deviation of the inspection criterion. \( P \) is the two-sided cumulative probability. When the target defect rate is settled to 100 ppm, \( P \) is 3.891 in the case of \( \infty \) degree of freedom. These statistical parameters are calculated based on the data gathered via normal manufacturing.

As a final control criterion like fillet length, control criteria setting of intermediate variables in the \( P \) and \( Z \) processes are required for anomaly diagnosis and prognosis. The notion of transformation between variables is shown in Fig. 5.

Assume that \( X_m \) is a target criterion like fillet length and \( X_l \) has a causal relationship with the variable \( X_m \). The causality among the variables is given by the equation 7.

\[ X_m = \beta_{ml} X_l + \epsilon_0 \quad (7) \]

where \( \beta_{ml} \) is the total effect from \( X_l \) to \( X_m \). The standard deviation of \( X_l \) which achieves the target defect rate for \( X_m \) can be calculated by the equation 8.

\[ \sigma_{X_l} = \sigma_{X_m}/\beta_{ml} \quad (8) \]

The control criteria for \( X_l \) are obtained by the equations 9 and 10, upper and lower criteria respectively.

\[ U_{X_l} = M_{X_l} + P\sigma_{X_l} \quad (9) \]

\[ L_{X_l} = M_{X_l} - P\sigma_{X_l} \quad (10) \]

where \( M_{X_l} \) and \( M_{X_m} \) are mean values for the variable \( X_l \) and \( X_m \) respectively, \( U_{X_l} \) and \( L_{X_l} \) are upper and lower control criteria for \( X_l \) respectively, and \( P \) and \( \sigma_{X_l} \) are the two-sided cumulative probability and the standard deviation of \( X_m \).

For example, according to the transformation above, the control criteria of printing areas are derived from the specification of fillet length.

(2) **Anomaly detection**
This function detects anomalies of a manufacturing lot by using inspection criteria which are determined by the distribution difference between a normal manufacturing lot and an inspection target one. The detection is performed by using the statistical parameters, mean and variance. These parameters are tested by \( t \)-test and \( \chi^2 \)-test [14] respectively according to the target defect rate. If either one would be anomalous, the lot is detected as an anomaly.

(3) **Deviation evaluation**
This function calculates a deviation from the control criterion by using a process capability index. The deviation is also evaluated by applying two statistical parameters of mean and variance. They are evaluated by \( C_{PK} \) and \( C_P \) respectively given by the equations 11, 12, and 13.

\[ C_{PK} = \begin{cases} (1 - K)C_P & 0 < K < 1 \\ 0 & K \geq 1 \end{cases} \quad (11) \]

\[ K = \frac{|M - \bar{X}|}{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{2}} \quad (12) \]

\[ C_P = \frac{S_U - S_L}{6\sigma} \quad (13) \]
where $S_L$ and $S_U$ are the lower control criterion and the upper control criterion respectively, $M, \overline{X}, \sigma$ are the target mean value, the mean and the standard deviation respectively.

3.1.3 Experiments

Experiments were conducted to prove the performance of the proposed cause-effect structure acquisition and anomaly diagnosis. There are three data sets gathered at the experimental manufacturing line and each set has data gathered by eighteen substrates manufacturing. The first set is for composing cause-effect structure. This set consists of data gathered by different parameter conditions with three levels. The remaining two sets are for testing anomaly diagnosis and have been collected under a normal and an anomalous manufacturing conditions. The anomalous condition is realized by controlling the humidity in the $P$ process by $48-64\%$ in contrast with the normal condition by $40-48\%$.

Firstly, the cause-effect structure is acquired by applying the method described in the section 2.3.1. Even though fillet length as the final effect is narrowed down to be selected, its cause-effect structure consists of around sixty variables. The acquired cause-effect structure was verified by a human expert who has long term experience, at least one and a half decades, with the maintenance of the whole substrate manufacturing process. The expert checked the cause-effect structure for any lack of variables or relationships among variables. Besides the structure, he also checked the causal effects. The results were well and understandable by his inspection.

For simplification, three variables including fillet length are chosen to compose the cause-effect structure which is shown in Fig. 6. The structure is formulated by the equations 14 and 15.

$$X_{FL} = \beta_{31}X_{PA} + \epsilon_4$$

$$X_{PA} = \beta_{32}X_{H} + \beta_{33}X_{SP} + \epsilon_5$$

where $X_{FL}$, $X_{PA}$, $X_H$, and $X_{SP}$ are fillet length, a printing area, humidity in the printing equipment, and squeeze push-down length, which is one of the control parameters of the printer. The squeeze is used for printing solder paste on a substrate which is shown at the lower left in Fig. 4. $\beta_{NM}$ and $\epsilon_i(i = 4, 5)$ are causal effects from $M$ to $N$ and error terms respectively.

For example, according to the causal-effect structure, following knowledge were extracted for prognosis and control.

- If humidity increases by $20\%$, a printing area will increase by $0.03\text{mm}^2$ and then fillet length will lengthen by $1.8\text{mm}$.
- In order to keep the printing area fixed, increase squeeze push-down length by $0.4\text{mm}$ when humidity increases by $20\%$.

For anomaly detection, normal and anomalous lots were used to test for two types of errors; i.e., false positive and false negative. As shown by experimental results, there were no error of false positive and false negative. In the case of anomalous lots, anomaly diagnosis could find the anomalies of fillet length, printing area, and humidity according to the capability indices calculated in the equations 11, 12, and 13.

3.2 Energy Consumption Management

In this section, energy consumption management is introduced based on cause-effect structure and health management technology. It aims at coping with both economical and ecological methods with independence from human experts such as a qualified person for energy management. A workflow of energy management is shown in Fig. 7.

- **Step 1**: A facility map creation acquires the equipment information and creates their map according to an electric power consumption system. The mapping of equipment such as air-conditioning and lighting, which is depending on the business is the first key to an energy management. For instances of business dependency, convenience stores use refrigerators, manufacturer uses production equipment and so on.
- **Step 2**: Data measurement and collection use sensors for measuring energy consumption and environmental data such as temperature and humidity.
- **Step 3**: Data analysis and target decision analyze the collected data to find anomalous energy consumption facilities.
- **Step 4**: Saving energy plan provides some action plans for saving energy according to the decided target. Experts apply their know-how and experience to predict the effectiveness of each plan to select a suitable one.
- **Step 5**: Action for improvement executes the selected plan. Then, cyclical improvement will be performed from step 2 to step 5.

3.2.1 Functions of Energy Consumption Management

Based on the notion of health management technology described in Chapter 2, the four steps of energy consumption management are defined as shown in Fig. 8.
• **Energy consumption measurement** gathers sensing data using the facility map represented by the cause-effect structure. The sensing data indicate energy consumption for each equipment and environmental information such as indoor and outdoor temperature and humidity of the target building.

• **Anomaly detection of energy consumption** compares measured energy consumption amount with standard energy consumption. There are various ways for calculating the standard energy consumption. The simplest one uses the electrical power consumption per unit time and operating time. According to the comparison results, the candidates of target equipment will be selected as energy saving plan.

• **Effectiveness simulation of energy saving plans** uses the cause-effect structure to predict the quantitative effectiveness of the plans.

• **Execution of the selected energy saving plan** enables a person who is in charge of energy management to easily select and to execute the best plan according to the simulation result even though he or she is not a sophisticated expert.

The cause-effect structure used in the energy consumption management is shown in Fig. 9 and its cause-effect structure are represented by the equations 16, 17, and 18.

where $X_{ET}$, $X_{EH}$ are the amount of energy consumption related to temperature and humidity respectively. $X_E$ is the amount of total energy consumption. $X_{TO}$, $X_{TI}$, and $X_{TP}$ are temperatures of outdoor, indoor, and presetting of an air conditioner respectively. $X_{HO}$ are $X_{HI}$ are humidity of outdoor and indoor respectively. $\gamma_{NM}$ and $\epsilon_i$ $(i = 7 \sim 9)$ are causal effects and error terms respectively.

### 3.2.2 Experiment

The experiments were conducted for investigating the effectiveness of the proposed method. The target is the security guard room because of its functionality such as a 24 hours system, a reasonable size of the building, and so forth. The cause-effect structure used in the experiment is described above. The objective of the simulation is to predict the total energy consumption in the case of changing preset temperature of the air conditioning system. The experimental conditions are as follows:

- The data during two weeks are gathered each in summer, winter, and fall in 2007.
- The first week data for each season are used for training the cause-effect structure for each and the last part for a test of the simulation.
- Each week has different preset temperature of the air conditioning system.

Experimental results are shown in Table 1. As for the name of column, **Term** denotes the term of predicting energy consumption. **Preset Temp** is the average of preset temperature differences between the weeks of six indoor air conditioning controllers. **Real EC** and **Predicted EC** denote real energy consumption and predicted one respectively. **Err** is the error between them. As a result, the absolute error mean between predicted and real energy consumption is around 2%. The performance would be good because the requirement for the prediction error of energy consumption is less than 10% in general.

### 3.3 Visceral Fat Estimation

In this section, a visceral fat estimation method is introduced. The term “metabolic syndrome” is well known recently in all over the world. The problem to be solved here is to provide an easy but accurate solution of visceral fat volume estimation against waist measurement and X-ray CT. Although waist measurement is generally employed because of its simplicity, it could not differentiate volumes of each visceral fat, subcutaneous fat, and a lean body area. This is because it could not distinguish the body types of well-muscled and fatty. On the other hand, X-ray CT can measure body composition accurately but it requires high costs and has a serious problem of radiation exposure. Therefore, the functionality of low or non invasion in measurement is quite important for realizing continuous
health management. These are the reasons why bioelectrical impedance and other physical measurement are employed for estimating visceral fat volume. The reference values are provided by X-ray CT measurement. The measurement principle of the visceral fat area is formulated by the equation 19.

\[ VF_P = AC - LB - SF \]  

(19)

where \( VF_P \), \( AC \), \( LB \), and \( SF \) denote the visceral fat area, abdominal cross-section area, lean body area, and subcutaneous area respectively. These areas can be calculated by using the image obtained by X-ray CT.

A low invasive sensing method using bioelectrical impedance to estimate the visceral fat area is proposed by Shiga et al. [15]. Besides the instrumental principle, visceral fat estimation methods are discussed by Yoneda et al. [16]. The study discussed the composition method of the cause-effect structure for visceral fat estimation. In the method, firstly, various types of feature attributes are prepared, in response to human body’s diversity. Then, the Akaike Information Criterion is employed to select suitable feature attributes to construct the cause-effect structure considering the optimal balance between the model simplification and the data fitness. According to the study, there are two types of visceral fat estimation models shown in Fig. 10. One by using the waist circumference provided by the composition of the equations 20, 21, 22, and 23. The other is width and height at umbilical level formalized by the composition of the equations 22, 24, 25, and 26. The first one is called Waist model and the second Proportion model. Note that preprocessing and feature extraction of the variables obtained via biomedical impedance and physical measurement were performed in order to sophisticate accuracy of the estimation; e.g., square operations for physical measurements and fractions for bioimpedance.

where \( X_{VF_P}, X_{AC_U}, X_{SF_P}, \) and \( X_{LB} \) are the areas of visceral fat, abdominal cross-section, subcutaneous fat, and lean body for Waist model. \( X_{VF_P}, X_{AC_U}, \) are \( X_{SF_P} \) are the areas of visceral fat, abdominal cross-section, and subcutaneous fat for Proportion model. \( X_W, X_A, \) and \( X_B \) are waist, width, and height at umbilical level respectively. \( \delta_{NM} \) and \( \epsilon_i (i = 10 - 16) \) are the causal effects from \( M \) to \( N \) and error terms respectively.

The experiments were conducted by using the sample database which consists data for 50 males and 40 females. Males are 24 to 72 years old and females are 25 to 55. The performances of each cause-effect model were measured by using LOOCV(Leave-One-Out Cross Validation) method. The results are shown in Table 2.

Table 2 Performance results of cause-effect structure.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Coefficient of correlation</th>
<th>Mean error</th>
<th>Standard deviation of error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waist</td>
<td>0.82</td>
<td>20.37</td>
<td>26.70</td>
</tr>
<tr>
<td>Proportion</td>
<td>0.87</td>
<td>17.55</td>
<td>22.96</td>
</tr>
</tbody>
</table>

Two different types of bioelectrical impedance, \( Z_T \) and \( Z_S \) could represent the areas of lean body and subcutaneous fat with their coefficients. The alternative measurements of back-front direction and left-right at umbilical level respectively are employed against the waist measurement. The feature attributes \( X_A \) and \( X_B \) bring more information amounts than \( X_W \) with the shape of the abdominal cross-section area.

4. Summaries and Conclusions

In this article, the notion of health management technology is proposed as a general solution framework. It consists of four functions: Measurement, Recognition, Estimation, and Evolution. The notable functionality of the technology is cyclical evolvement based on cause-effect structure-based representation. The cause-effect structure brings the important feature of transparency to human experts. This capability should be an extremely powerful solution because it could realize human-machine collaboration based on causality. Three different applications are introduced and discussed with concentrating on the causality feature of them. The first one is quality control in a substrate manufacturing process. Manufacturing processes seem to be alive because the factors of manufacturing such as QCD (Quality, Cost, and Delivery) which are objective and result indices should actualized in response to the requirement from markets and manufacturing plans. The cause-effect structure is acquired from data of real a manufacturing line in experimental usage. By applying the cause-effect structure, prediction and control could be realized to optimize the fillet length that is one of the key inspection items for reliability of substrates.

The second one is an energy management system, which is quite an important activity for environmental protection issues. The cause-effect structure consists of energy consumption equipment in a facility, indoor and outdoor temperature and humidity. According to the cause-effect structure for summer, winter, and fall seasons, the amounts of energy consumption were predicted with high accuracy around 2%.

The last application is a visceral fat estimation method for
the equipment in a medical field. In the application, the cause-
effect structure has a different role from previous applications. 
The role is to estimate visceral fat volume according to the sim-
ple principle depicted by the equation 19. The issue on accu-
rracy of the principle is to adapt to diversities that individuals 
have essentially. Firstly, based on the human experts’ knowl-
edge, the preparation of feature attributes was done from vari-
ous points of view. Then, the suitable feature attributes are 
selected with the Akaike Information Criterion. Finally, the 
cause-effect structure could be acquired via statistical analysis 
with keeping the theoretical notion in the causality.

Even though the technology and the application studies 
should be more sophisticated in the future, the authors be-
lieve that the causality-based solution must be useful against 
real and more complicated problems in such the applications 
as discussed in the article. From the viewpoint of technology 
 improvement, the dynamic evolvement method of causalities 
might be strongly required for more seamless evolution and for 
more complex applications.

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