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INDUSTRIAL DESIGN OF KANSEI ENGINEERING-BASED SENSOR FOR INDUSTRY

Taufik Nugraha Agassi, Mirwan Ushada, Atris Suyantohadi

Universitas Gadjah Mada, Faculty of Agricultural Technology, Department of Agro-industrial Technology, Indonesia

Corresponding author:
Mirwan Ushada
Universitas Gadjah Mada
Faculty of Agricultural Technology
Department of Agro-industrial Technology
Jl. Flora No. 1, Bulaksumur, Yogyakarta 55281, Indonesia
phone: +62 274 589 797
e-mail: mirwan_ushada@ugm.ac.id

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Abstract
Up to date, workload and worker performance in Small Medium-sized Enterprise (SMEs) was assessed manually. KESAN (Kansei Engineering-based Sensor for Agroindustry) was developed as a tool to assess worker workload and performance. The latest prototype of KESAN was established. As the final step prior to the full-scale mass production, an industrial design was required and must be designed based on the validation to user needs. This research proposed an industrial design for mass production of KESAN using Kano model and Quality Function Deployment (QFD). The user needs was extracted from attributive analysis of Kano model. The matrix of House of Quality (HOQ) was utilized to connect the user needs and technical requirement. The research result validated Thirteen (13) user need attributes. The most important attribute was desktop application as an integrated decision support system. Fourteen (14) technical requirement attributes were identified to fulfil the user needs. Finally, a prototype was developed based on product final specification and prioritized technical requirements. The SMEs's manager could use the prototype for workplace environmental management.

Keywords
KESAN, Industrial design, Kano model, QFD.

Introduction

Workplace environment was one of the most important factor for workers to perform their job in Small Medium-sized Enterprise (SMEs). It had significant effects to workload and worker's performance [1]. Up to date, workload and worker performance was assessed manually in SMEs. An integrated ergonomic tool for the application which was fast, easy and routinely-able-to-be-used, must be a solution for SMEs. KESAN (Kansei Engineering-based Sensor for Agroindustry) was developed as an artificial intelligence-based appropriate sensor technology to assess worker ergonomic in a work system [2, 3]. The tool was developed using Kansei Engineering conceptual model, artificial neural network and Arduino [2]. The tool was important for sustainable ergonomic application [2, 3]. It had characteristic as economical cost, portable, easy to operate and implementation of an appropriate technology. The expected user of KESAN was the manager or owner of SMEs.

The first generation of KESAN had 2 (two) serials coded as Mir-1 and Mir-2 [2]. The function of first generation was to determine integrated workload assessment. Subsequently the second generation was coded as Mir-3 and Mir-4 [3]. The function of second generation was determining temperature set points, as shown in Fig. 1 [3]. This tool had passed four (4) cycles of product developments from KESAN serial Mir-1, Mir-2, Mir-3 and Mir-4. The development itself has adapted to SMEs needs and based on technology availability. The final step of sensor development cycle was an industrial design.

The first and second generation of KESAN have fulfilled the functional aspect for SMEs. The next step was an industrial product design which optimize the function and sensor value, appearance and system. The industrial design was categorized as the final step in new product development prior to mass production [4]. It was required to define the standard model concept for mass production and the final role in sensor development [5]. Industrial design was defined as a creation of form, configuration, or composition of line and color, or combination of them to make any aesthetical impression in two or three dimension [4]. It was able to be used to produce any product, goods, industrial commodity or handcraft [4]. The success sensor development was depend on the user's acceptability.

Fig. 1. Design of KESAN Mir-2 [2].

Fig. 2. Design of KESAN Mir-4 [3].

Quality Function Deployment (QFD) has been used to understand the user's needs and acceptability [6]. It was an analysis tool to systematically deploy any sensor feature development, characteristics and the specifications (including fabrication and needed process) were in line with user's demand [7]. The function of QFD determined the best voice of user for the most detail of manufacture [8].

The description of technical requirement made it easier for mass production generating competitive product in market [9]. The research objectives were: 1) to develop an industrial design of KESAN using QFD method; 2) to develop a prototype based on the industrial design. The research benefit was to accelerate the implementation of KESAN for SMEs prior to the mass production. By using KESAN, the ergonomic parameters could be easily assessed and stored in the data base. Since the Indonesian government has initiated 4th Industrial Revolution by program of Making Indonesia 4.0, KESAN was expected to support the initiation of and information dissemination to program of Making Indonesia 4.0 in SMEs. In addition, it could change the SMEs's manager perception to sensor which was high cost, complicated and difficult to operate. By using KESAN, information technology could be applied more easily and precisely for workplace environmental management in SMEs's production system.

Material and methods

Functionality of KESAN

The object of industrial design was the functionality of KESAN. The function of KESAN was to assist the manager of SMEs in managing workplace environment. The good management practices of workplace environment could provide the comfortable work system. The input of KESAN was parameters value of heart rate, workplace temperature, distribution of relative humidity and light intensity. The input parameters were measured separately from KESAN, using available commercial sensor. KESAN was operated daily before and after work in each workstation. The periods of measurement and workers sampling was determined specifically based on the management goals as promotion, mutation and workload balancing. The managers identified the actors in a work system who could apply KESAN. The actors consisted of human resource officer, data enumerator for worker and workplace environment, team leader, worker and data analyst.

Respondent profiles

The user respondent were 30 sample manager/owners from an association of regional manager for food and beverages SMEs in Sleman Regency, Special Region Yogyakarta. Respondents were selected using purposive sampling based on their prior experience to KESAN. The respondent had the sufficient knowledge and familiarity to the ergonomic, digital ergonomic and understanding of ergonomic impact to the sustainability of food and beverages SMEs. This research was conducted from August 2017 to October 2017. Most of the respondents were SMEs manager/owner which employed 1 (One) to 4 (Four) workers. Most of the worker pursued their job in the scope of production system. Most of the worker age ranged from 35 to 44 and 55 to 64 years old. 25 respondents had the experience running their business more than one (1) year and committed to sustainably produce based on user demand. Twenty two (22) respondents graduated from university and this educational background could assisted them in managing the implementation and further improvement of KESAN.

The respondents of designer were the four (4) inventors and seven (7) research assistant related to development of KESAN from Laboratory of Production Systems, Systems Analysis and Simulation, Faculty of Agricultural Technology, and Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada. The three (3) inventors and seven (7) research assistants had educational background in agro-industrial technology and one (1) inventor had educational background on instrumentation and information technology. The in-depth interview was pursued periodically in line with weekly meeting of research group in Kansei/Affective Engineering and Design.

Research methodology

The methodology of industrial design was defined as follow.

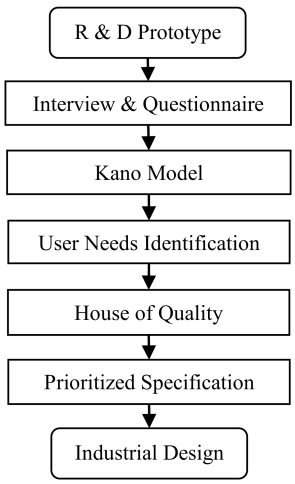

Fig. 3. Research methodology.

User needs analysis using Kano model

As the first step, an in-depth interview was pursued to manager of SMEs. The goal was to attain information related to important indicator and things which are required by user to determine design specification of KESAN. This method acquired data of attributes needed by user embedded on the KESAN. These data were analyzed and classified by Kano model [10]. The research results mapped seven (7) attributes for category of one dimensional, four (4) attributes for must be and two (2) attributes for attractive [10]. These attributes were utilized as user needs in House of Quality (HOQ) of QFD analysis.

Based on analysis of Kano model in Table 1, two (2) attributes which were categorized as indifferent and not be used in the industrial design of KESAN [10].

Table 1
Result of Kano categories [10].

No	User needs attributes	Categories
1	Comfortable display colour	Must Be
2	Compact size	One Dimensional
3	Easy to handle	Indifferent
4	Square forms which each sharpen edges	One Dimensional
5	Ergonomic keypad size	Must Be
6	Informative keypad	One Dimensional
7	Position of KESAN logo in front sides	One Dimensional
8	Desktop application as a complementary to KESAN in displaying information and documentation	One Dimensional
9	Holder for KESAN	One Dimensional
10	Ergonomic display size	Must Be
11	Functional display color	One Dimensional
12	Bright colour of KESAN	Indifferent
13	Readable display font	Must Be
14	Clear side of KESAN	Attractive
15	Position of manual procedure at the backsides of KESAN	Attractive

Industrial design using QFD

The process of QFD was started with a list of purpose which contains the user needs or they expect to attain in any specific product features. These user needs were obtained from the result of Kano model attribute. Subsequently, the technical requirement were identified by designer team of KESAN using in-depth interview. This relationship among technical requirements was defined by correlation matrix. Subsequently, the user needs and technical requirement were compared to determine the relationship.

The priority of user requirement was the relationship of each user's needs and competitive scoring (Right side of HOQ matrix). The column for priority of user's requirement consisted of user's interest, future goals, sales point and improvement ratio. The priority list of technical requirement consisted of relationship among requirement in HOQ matrix (Upper side of HOQ matrix).

Conceptual prototype of sensor

The final step in the research was pursuing analysis to modify conceptual prototype. The 3-D visualization was developed by using Adobe Illustrator. The conceptual design was developed based on sensor dimensional, material and production phase. The development of conceptual model consist of functional and structural phase. The goal of functional phase was identifing the bill of material from conceptual prototype. The structural phase was to determine the prototype layout based on the bill of material.

Result and discussion

The level of user interest

The user need attributes were classified using Kano model. In addition, the level of user interest indicated the level interest of any attribute to user's needs. Result of interest level and priority of KESAN Mir-4 development is shown at Table 2. The most important attribute was desktop application since it could display information and documentation with the value of 16.85. Respondents stated that it assisted them to understand the situation of their production station and could be a decision support system. The most not important attribute was plain color on the side part of tool with the value of 3.16. These attributes must be considered by technical requirement for the effective and applicable KESAN.

Future goals, sales point and improvement ratio

HOQ was utilized to define the relationship of technical requirement for each user needs. The relationship directed the process of tool improvement [11]. Table 3 indicated the value of improvement ratio, future goals and sales point. The value of future goals was expected by inventor of Mir-4 in fulfilling the needs and the vision of SMEs. Majority attributes had the value of four (4) scales which indicated the importance of improvement on attribute. The scaling value of five (5) on attribute indicated very important to do any improvement. The value of 3 (three) indicated no need any improvement because of sufficient target has been achieved.

The value of improvement ratio was the comparison between target values to scoring point of KESAN performance. The entire attribute had improvement ratio more than 1 (ratio value between 1.05–1.58) except the attribute of plain color of side part which attained the value of 0.92 and keypad color which adapts to every function attained value of 0.99. Subsequently, the improvement ratio which had value of 1 and under 1 showed that the tool had able to satisfy user needs [12]. This indicated that the two (2) attributes had satisfied users. In other side, the attribute of improvement ratio was more than value of one (1) and being priority on the improvement and the development of Mir-4 afterward.

The sales point indicated how good the attribute of user needs contributed in sales [13]. It had value of 1.5 which showed that it strongly affected to sales of Mir-4. The largest sales point was at value 1.2 and indicated that this attribute had an effect to sales.

Level of user satisfaction

Kotler [14] stated that user satisfaction as the level of personal feeling after comparing any performance or the result based on the gap between needs and expectation. The comparison of user's satisfaction were pursued between Mir-4 as second generation and competitor product is shown at Table 4 and right parts of HOQ in Fig. 4. Second generation's competitor was Mir-2, the first generation.

Table 2
The level of user interest.

No	Attribute	User interest scale	Normalization of user interest scale
1	Desktop application as a complementary to tool in displaying information and documentation	18.49	16.85
2	Compact size	12.18	11.10
3	Placeholder as a place to keep tool	11.37	10.36
4	A rounded rectangle shape on every side	11.06	10.08
5	Position of logo in front sides	9.36	8.53
6	Comfortable display colour	8.14	7.42
7	Ergonomic display size	7.37	6.72
8	Readable display font on screen	6.30	5.74
9	Ergonomic keypad size	6.18	5.63
10	Informative embedded font on keypad	5.56	5.07
11	Position of manual instruction at the backsides of KESAN	5.45	4.97
12	Keypad color which represent to each function	4.80	4.37
13	Plain color on the side part of tool	3.47	3.16

Table 3
Table of Future Goals, Sales Point and Improvement Ratio.

No	Attribute	Future goals	Sales point	Improvement ratio
1	Desktop application as a complementary to tool in displaying information and documentation	5	1.5	1.58
2	Compact size	5	1.5	1.38
3	Placeholder as a place to keep tool	5	1.5	1.34
4	A rounded rectangle shape on every side	5	1.5	1.28
5	Position of logo in front sides	4	1.5	1.20
6	Comfortable display colour	5	1.2	1.29
7	Ergonomic display size	4	1.5	1.12
8	Readable display font on screen	4	1.2	1.14
9	Ergonomic keypad size	4	1.2	1.13
10	Informative embedded font on keypad	4	1.2	1.05
11	Position of manual instruction at the backsides of KESAN	4	1.2	1.12
12	Keypad color which represent to each function	4	1.2	0.99
13	Plain color on the side part of tool	3	1.2	0.92

Table 4
Table of Performance Comparison.

No	User needs	Mir-4	Mir-2	Value target
1	Desktop application as a complementary to tool in displaying information and documentation	2	2	5
2	Compact size	3	2	5
3	Placeholder as a place to keep tool	3	3	5
4	A rounded rectangle shape on every side	3	2	5
5	Position of logo in front sides	3	3	4
6	Comfortable display colour	3	3	5
7	Ergonomic display size	3	3	4
8	Readable display font on screen	3	3	4
9	Ergonomic keypad size	3	3	4
10	Informative embedded font on keypad	4	4	4
11	Position of manual instruction at the backsides of KESAN	3	3	4
12	Keypad color which represent to each function	4	4	4
13	Plain color on the side part of tool	3	3	3

Table 3 indicated the two (2) attributes which have fulfilled the designer target in both KESAN serial as "Informative embedded font on keypad" and "Keypad colour which represent to each function". This result indicated the KESAN has fulfilled the user satisfaction on keypad functionality.

Table 3 indicated that Mir-4 have better level of user's satisfaction than Mir-2 on attributes of "Compact size" and "A rounded rectangle shape on every side". This result indicated that respondents more satisfed with Mir-4 rather than Mir-2 on aspect shape functionality due to the thinner shape of Mir-4 than Mir-2.

Table 3 indicated both KESAN serial Mir-4 and Mir-2 had same level of user satisfaction. There were 11 from 13 attributes which indicated the same performance values. However, respondents have not reached the satisfaction level both Mir-4 and Mir-2 on the most important attribute of "Desktop application as a complementary to tool in displaying information and documentation". The performance score of 2 was much lower than targeted value of 5 by designer team of KESAN.

The relationship between technical requirement and user needs

Fourteen (14) technical requirement were a response to designer which connects technical factor of the sensor making to user needs. Analysis on user needs and technical requirement aimed to identify whether technical requirement could fulfill user's needs. User needs had many possibilities to affect more than one technical requirement. This relationship was classified into some categories as strong, medium, weak, and no relationship (Fig. 4). The at-

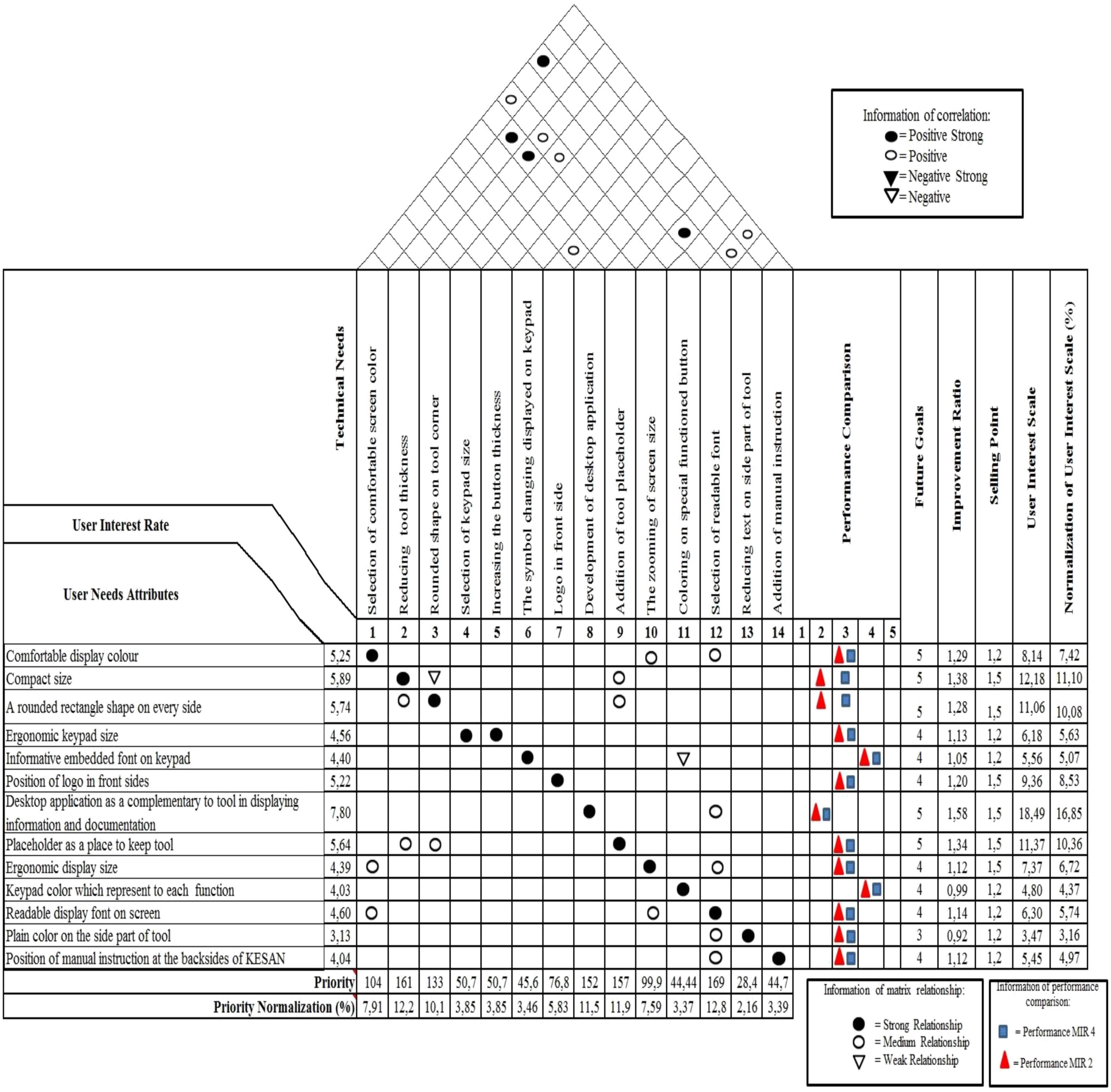

Fig. 4. House of Quality (HOQ) for industrial design of KESAN.

tribute of readable font had strongly effect to attribute of user needs. It had one strong relationship with one attribute in user needs, and it had five (5) medium values on the attribute of user needs.

The matrix correlation used for which technical requirement mutually support and contradiction with each other. Figure 4 shows the relationship between technical requirement. A strong positive relationship was a very strong one-way relationship. The addition of tool placeholder had a strong positive relationship to the reducing tool thickness. The addition of tool placeholder made the tool thickness increase. This indicates that the addition of tool placeholder must be adjusted to the size of KESAN. The relationship between the needs was highlighted in Fig. 4.

The priority of technical requirements

Prioritization of technical requirement was required to trade-off between precise function and economical cost in mass production. The precise function was the target of KESAN performance as an appropriate technology for manager of SMEs to assess the ergonomic condition. The economical cost was the target of KESAN attractiveness for the manager of SMEs to buy and implement in a production system. Subsequently, the prioritized attribute was accommodated to development of industrial design.

Table 5
Table of technical requirement priority.

No	Technical requirement	Priority	Prioritized normalization
1	Selection of readable font	169.00	12.83
2	Reducing tool thickness	161.21	12.24
3	Addition of tool placeholder	156.81	11.91
4	Development of desktop application	151.63	11.51
5	Rounded shape on tool corner	132.93	10.09
6	Selection of comfortable screen color	104.13	7.91
7	The zooming of screen size	99.92	7.59
8	Logo in front side	76.80	5.83
9	Selection of keypad size	50.69	3.85
10	Increasing the button thickness	50.69	3.85
11	The symbol changing displayed on keypad	45.60	3.46
12	Addition of manual instruction	44.71	3.39
13	Coloring on special functioned button	44.44	3.37
14	Reducing text on side part of tool	28.44	2.16

The absolute score of technical requirement was obtained from the multiplication between user interest level on each user needs and symbolic value on the relationship matrix of user needs and technical requirement. The step was used to determine the priority of technical requirement for developing the prototype. It was indicated at Table 5 and Fig. 4. The attribute selection of readable font attained the highest value of 12.83. This result indicated the selection of readable font was on top priority on the development and improvement for industrial design of KESAN.

Mir-4 development

The final step in the research was analysis on the modified concept. The 3D visualization was developed by using Adobe Illustrator. Evaluation to the design was pursued by evaluating the fitness between design and applied sensor specification. The final specification of KESAN after QFD analysis was applied in Table 6.

Mir-4 industrial design

As the final step of industrial design, a prototype was developed. It was made into professional design

Table 6
Table of final specification of KESAN.

No	Technical requirement	Unit	Specification
1	Selection of readable font	Font	Custom
2	Reducing tool thickness (Length × Width × Height)	Cm	$15 \times 9 \times 2.5$
3	Addition of tool placeholder (Length × Width × Height)	Cm	$10.2 \times 9.6 \times 2.8$
4	Development of desktop application	Application	Software
5	Rounded shape on tool corner	Radiant	1 rad
6	Selection of comfortable screen color	Color	Blue
7	The zooming of screen size (Length × Width)	Character	16×2
8	Logo in front side	List	Symbol
9	Selection of keypad size	Matrix	3×4
10	Increasing the button thickness	Mm	3
11	The symbol changing displayed on keypad	List	Symbol
12	Addition of manual instruction	List	Availability
13	Coloring on special functioned button	Color	Red
14	Reducing text on side part of tool	List	Less text

in three dimension (3D). It was made based on fourteen (14) prior specification in Table 6. The sensor could be successful when it attains positive response and followed by the desire to buy [15]. The design was shown in the following pictures.

a) b)

Fig. 5. Industrial design of KESAN: a) front look, b) side look [2].

The larger size of font was embedded in the display for the readable. The thickness was reduced compared to the first generation [2] and second generation of KESAN [3]. The placeholder was embedded to strengthen the hand grip. The desktop application was developed as a prototype of integrated ergonomic assessment system [16]. The rounded shape on tool corner was embedded with 1 rad. The blue color of comfortable screen was embedded. The screen size was improved with 16×2 character. The logo in was developed as symbol in front. Keypad size was developed using 3×4 matrix. The button thickness was increased to 3 mm. The manual instruction was added. The red color was customized on special functioned button. The amount of text was reduced on side part of tool.

Functionality of KESAN for management

The industrial management/owner could manage the users of KESAN for application in a production system. Table 7 indicated the actors in a work system who could apply KESAN. The users consisted of human resource officer, data enumerator for worker and workplace environment, team leader, worker and data analyst.

Table 7
Users of KESAN (adapted from [17]).

No	Actors	Process	Decision
1	Human resource officer	Retrieving worker database	Data of worker career
		Setting up the decision	Promotion/mutation/balancing workload
		Selecting data enumerator	Data enumerator assignment
		Selecting team leader	Team leader assignment
		Accessing the measurement result	Feedback to management
2.	Data enumerator for worker	Preparing commercial data logger	Measurement of heart rate
		Preparing questionnaire for POMS data	Measurement of mood
		Callibration of KESAN	KESAN
		Operating KESAN	Workload status
3.	Data enumerator for environment	Preparing commercial data logger	Workplace environment
		Calibration of KESAN	KESAN
		Operating KESAN	Temperature set points
4.	Team leader	Determining periods of measurement	Days/weeks/months
		Selecting the worker	Worker assignment
		Setting up worker evaluation	Shift schedulling
5.	Worker	Provide the data	Input of KESAN
		Provide the feedback workload	Input of interpreter
6.	Data analyst	Downloading the data from KESAN	Measurement data
		Analysing the data from KESAN	Measurement data
		Uploading the analysed data to database	Measurement data
7.	Manager/Owner	Deciding the value of temperature set points for workplace environmental management based on the analysed data	Decision

Application of KESAN for the management consisted of several steps. The first step, the human resource officer retrieved the data base of worker. The officer set up the decision of measurement as directed by management as promotion, mutation, and workload balancing. The officer selected the appropriate data enumerator and worker sampling. After the measurement, the officer had the exclusive right to access the measurement data.

The second step, the data enumerator prepared the commercial data logger for heart rate and questionnaire for mood measurement. Prior to measurement, the enumerator calibrated the data. In the parallel time, the enumerator for workplace environment pursued the similar task for workplace environment. The third step, the management assigned the team leader to determine the periods of measurement, worker selection and evaluation. The data analyst downloaded, analyzed the data from KESAN and provided the feedback by uploading the data to human resource officer. The last step, the manager could decide the value of temperature set points for workplace environmental management based on the analyzed data.

Managerial implications

KESAN could be applied to support evidence-based policy for manager to develop an ergonomic work system based on environmental ergonomics. Subsequently, the policy could be technically implemented to several ergonomic programs as environmental ergonomics analysis [18], ergonomic risk assessment [19], affective environmental control [20] and work incentives [21]. These programs could be executed as air conditioner procurement, work sampling, time and motion study. It expected to imply a better workplace environmental management for manager of SMEs.

Research limitations

The limited feature of sensor was the data inputting. The data was input manually by keypad and not automatized. The application required times which could be a bias for the worker and workplace environmental measurement. Therefore the measurement was suggested Fifteen (15) minutes before and after work office hours.

Future works

The future works proposed the transformation of KESAN from hardware platform of sensor to an integrated decision support system using android and connected to Radio-frequency Identification (RFID). The platform of RFID will overcome the recent research limitation related to measurement time and bias by real time measurement. The platform of system will integrate the entire data to database and could be retrieved for continuous measurement.

Conclusions

The research result validated Thirteen (13) user's needs for industrial design of KESAN. The most important need was the availability of desktop application for information and documentation as decision support tool. QFD analysis indicated that the recent design of Mir-4 was not fully able to fulfill user satisfaction. User indicated more satisfy with Mir-4 rather than Mir-2. However, respondents have not reached the satisfaction level both Mir-4 and Mir-2 on the most important attribute of desktop application as a decision support tool. The improvement was required due to expectation to the existing attribute in industrial design. The improvement of industrial design was developed based on user needs and specification of fourteen (14) technical requirement. A prototype was developed based on sensor final specification and prioritized of technical requirement. The SMEs's manager could use the prototype for workplace environmental management. The further research will focus on the development of desktop application as embedded feature prior to mass production of KESAN.

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