A KE and FMEA Based Approach for Library Book Transfer Robot Development

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***Abstract*—The return of the book is the most annoying task for library operations,This study designs and develops mobile robot to solve book transfer and collaboration. In the past, robot-related research is primarily focused on the functionality of robots, considering product aesthetics and images have been overlooked. So that we adopted a product image analysis used in Kansei Engineering(KE) to analyze consumers' preferences regarding product design images and a Failure Mode and Effects Analysis(FMEA) for product design and production planning. An implementation of using Kansei Engineering and a Failure Mode and Effects Analysis to create mobile robot and help library to transfer books.**

***Index Terms*—Kansei engineering, failure mode and effects analysis, design and technologies, mobile robot**

I. Introduction

Product appearance is crucial in the selection process and product preferences of consumers [1] because product appearance (1) can help companies reveal, explain, or conceal changes to basic innovative technologies, (2) provides visual cues for consumers to understand product operation and purpose, and (3) stimulates the senses, which indirectly impacts the perceptions and emotions of consumers [2]In the design process,[3]employed the research concept of Kansei Engineering to understand the relationship between product model design and consumer perception. They established design models and executed product development to fulfill design needs. To avoid the hidden errors generated when using verbal survey methods to assess product designs and styles, [4] suggested using human emotion symbols as the tools for analyzing and assessing the emotional image of products. In their model design method, [5]used a shape morphing and image prediction method to construct 3D models for assisting designers with completing a variety of designs. Above literature review, we found that because of business requirements, most studies in the field of model design have focused on the connection between style design and consumers' emotions. Specifically, regarding the survey methods used for determining the relationship between styles and preferences, scholars have proposed rational verbal and nonverbal methods to construct a quantitative model for product designs [6]. Thus, in this study, we used the semantic differential (SD) method of Kansei Engineering to identify factors that satisfy consumer preferences, which can be used by designers to achieve an optimal product design. This study also adopted Failure Mode and Effects Analysis (FMEA) to evaluate the factors that cause product defects during production, thereby enabling product designs to reach perfection.

II. Methods

A. Kansei Engineering

Kansei Engineering is highly efficient for quantitatively evaluating user experiences. In design-related experiments, Kansei Engineering can be applied to assess the emotional aspect of users' needs for designing products that can closely meet user requirements[7]. The process of Kansei assessment involves engineers, designers, or users evaluating actual design processes for specific products or services by using perceptual or emotional words [8]. The major contribution of using Kansei Engineering in product design is that prior to entering the market, designers can grasp the emotional orientation of the public by conducting research to analyze competitive products. Designers can derive emotional keywords from details and then use such keywords for analyzing product designs, resulting in products that closely fulfill consumer demand. Kansei (emotion or affection) refers to the inner desires of consumers and is a keyword (adjective) that clearly defines individual emotions, which can help designers understand the emotional needs of consumers. Because engineering involves designing the most practical product appearance, material, size, color, and operating interface, most operating practices are devised by conducting questionnaires that can analyze the relationship between emotional keywords and engineering.The operation methods of the design plan proposed in this study are as follows:

(1) Compile a list of emotional keywords associated with related products by referencing the Internet and related publications.
(2) Request experts to analyze the emotional orientation that the general public exhibits toward competitive products by using image scale analysis as shown in Fig 1.
(3) Analyze the engineering conditions of competitive products.

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By using the Internet and periodicals, several security-related emotional words were collected, such as imposing, majestic, protecting, powerful, secure, reliable, advanced, domineering, tough, huge, rigid, responsive, steady,firm , and warm. After discussing with the cooperating manufacturer and experts of this study, the words related to speed and appearance were screened and classified into two groups: responsive/steady and firm/warm, which were designated as the X and Y axes for image scale analysis. These words were used for analyzing public emotional orientation toward competitive products, and 22 international and domestic robotic products were included in the analysis. The robots were used in indoor and outdoor environments. The appearance of most competitive products can be described as friendly and warm. However, products that are used for monitoring a wide range of locations must feature neat and tough outlines and sturdy body volumes as shown in Fig 1. And obtain preliminary conceptual design through semantic analysis of KE shown in Fig 2.

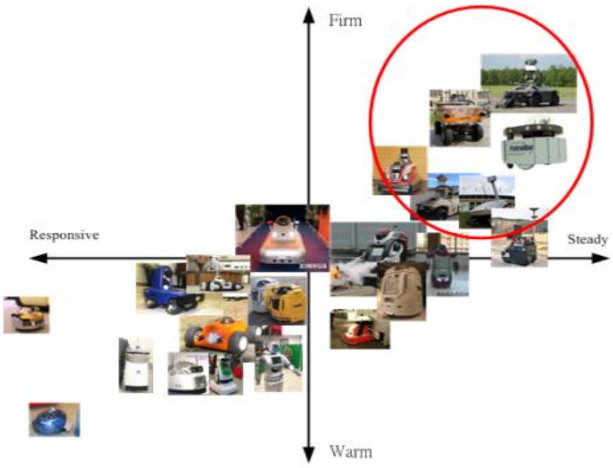

Figure 1. Image scale analysis for mobile robots.

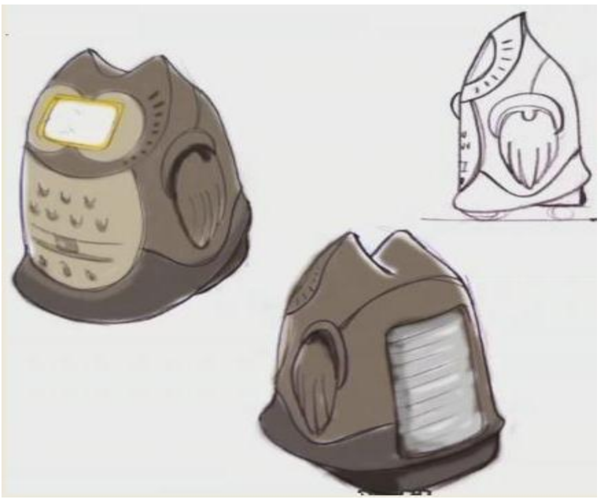

Figure 2. Semantic analysis for mobile robot preliminary conceptual design.

B . Failure Mode and Effects Analysis

FMEA is often used in the design development stage as an assessment method for systematically predicting conditions that will cause product failure and malfunction. Thus, FMEA is used for identifying the key factors that may lead to failure. FMEA enables designers to develop a countermeasure in advance to reduce the risks and uncertainties during product design and manufacturing processes. [9] attempted to establish an FMEA simulation diagnostic system that enables users to create basic models for automatically simulating and producing results. [10]adopted the Dempster–Shafer theory for reliability failure analysis to quantify the inaccuracy and unreliability in the risk priority number (RPN) of a process. [11] adopted the concept of fuzzy numbers to show three features, including the degree of severity (S), frequency of occurrence (O), and chances of detection (D). To judge RPN risk figures, [12]found that for an evaluation outcome to possess a high degree of consistency, the team must include at least two technical experts who are experienced with FMEA. Although FMEA is frequently used to assess risk at the stage of product design development.

FMEA has been widely applied in risk assessment at various stages of product production, and potential failure modes are mainly analyzed by using systems as a unit. Subsequently, the degree of severity (S), frequency of occurrence (O), and chance of detection (D) of a system were separately assessed by using a 10-point scale, in which 1 represents no effect and 10 represents the highest severity. Finally, as equation (1) is employed to calculate the RPN for understanding the degree of failure of the various stages and for proposing countermeasures.

$$RPN=S\times O\times D \tag{1}$$

FMEA involves first confirming the system that requires assessment, establishing an expert group, sketching system flowcharts (e.g., product development and manufacturing processes), and then assessing the degree of severity (S), frequency of occurrence (O), and chance of detection (D). And obtain conceptual design through FMEA analysis shown in Fig 3.

Figure 3. FMEA analysis for mobile robot conceptual design.

III. THE VERIFICATION OF THE ACTUAL EXAMPLE

A. Mobile Robot Functional Module and Key Components

In this study, we divided the functional module of a Mobile Robot into five categories: multiple sensing and obstacle avoidance capabilities, positioning and navigation functions, smart division of coordination mechanism, smart power supply, and integrated technology and mechanisms of robots and security systems. Each functional module is described as follows Fig 4.

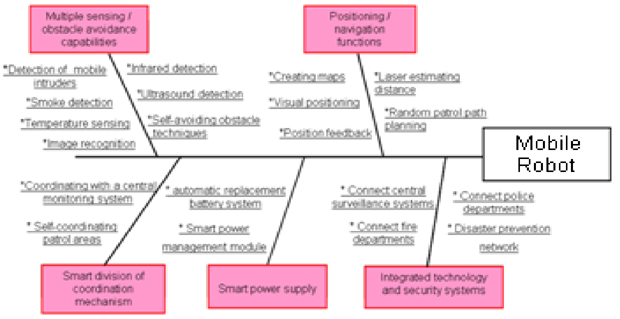

Figure 4. Functional module of mobile robot.

The key components of a Mobile Robot can be primarily divided into six major categories: distance sensing, environmental sensing, drive system, platform control, power system, and human–computer control. The components are described as follows Fig 5.

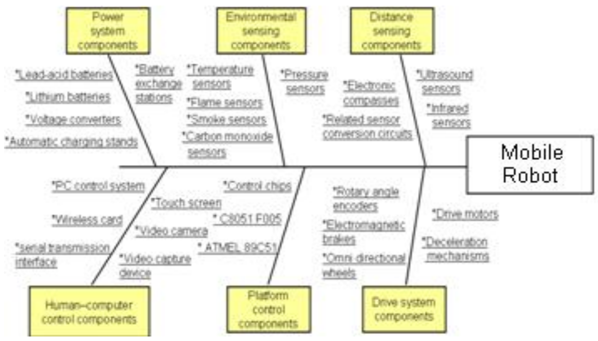

Figure 5. Key components of of mobile robot.

Based on the key movement and monitoring functions of the Mobile Robot, we further designed and planned two major modules. The bottom part, which is a mobile carrier module, and the top part, which is a monitoring module, were integrated to form the Mobile Robot as shown in Fig 6.

Figure 6. The mobile carrier module of the mobile robot.

B. Kansei Innovative Design of the Mobile Robot

The mobile carrier module that can be directly applied to robots for research purposes is currently available on the market. The top-part monitoring module is the part that directly influences consumers' visual perceptions and product aesthetics. Thus, we designed the monitoring module for integration with the mobile carrier module to construct a Security guard robot.

(1) Structural design plan of the mobile robot as shown in Fig 7.

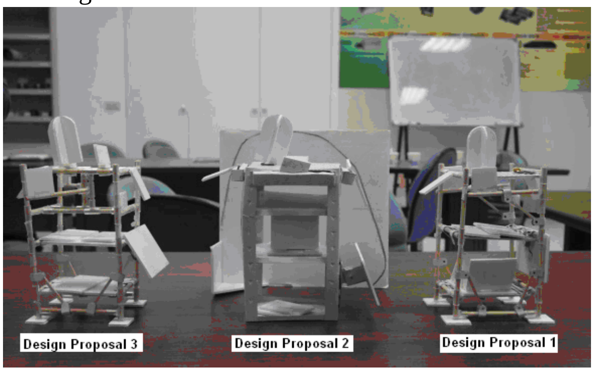

Figure 7. Model of the proposed stand design.

The photographs obtained during the monitoring test can be used to test whether the height of the top of the stand and the view from the Camera 1 are parallel, and to adjust the height of the top stand based on the actual height in the picture as shown in Fig 8. We simultaneously determined whether the angle determined from the test can achieve an unobstructed visual angle as shown in Fig 9.

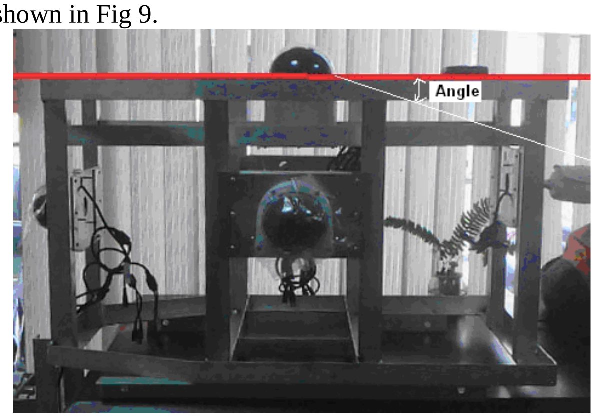

Figure 8. Test stand and camera.

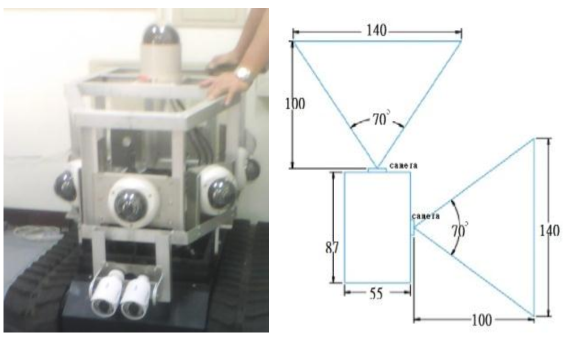

Figure 9. Schematic diagram of a panorama visual angle test.

(2) Design Outcome

In this study, we used the SD scale analysis of Kansei Engineering to understand the current needs of consumers. Moreover, after experts used FMEA to evaluate the product, appropriate product design features were planned. After the design was completed and inspected by the manufacturer, the experts reevaluated the revised design to ensure that the RPN value of FMEA has significantly decreased as shown in Table I.

TABLE I. RPN COMPARISON AND FMEA DESIGN PLANNING

Analysis of the object	Potential Failure Mode	Before Design Planning				Risk Control Strategies	After Design Planning			
		S	O	D	RPN		S	O	D	RPN
Internal Frame	Insufficient frame strength	10	2	5	100	Reinforce -ment	3	2	5	30
	Welding defects	10	2	5	100	Training	3	2	5	30
	Adverse assembly	8	5	3	120	Established SOP with Training	6	3	3	54
	Steel tube deformed	10	5	3	150	Increased steel tube thickness / Heat Treatment	3	3	3	27
	Nuts assembly not indeed	8	5	3	120	Established SOP with Training	6	3	3	54
External enclosure	Adverse assembly	8	2	5	80	Waterproof design improve-ments	3	2	5	30

Following multiple meetings with the cooperating manufacturer, during which design inspections and details were confirmed, the top monitoring module of the Mobile Robot was complete and used for actual testing. Subsequently, the mobile carrier module was integrated and the private brand logo of the cooperating manufacturer was designed to achieve a Mobile Robot for Library transfer Books as shown in Fig 10.

Figure 10. Mobile robot for library transfer books of this Study.

IV. RESULTS AND DISCUSSION

The study used KE and FMEA has been successfully developed mobile robot for Indoor use and imported into the National library of public information to transport books as shown in Fig 11, Fig 12.

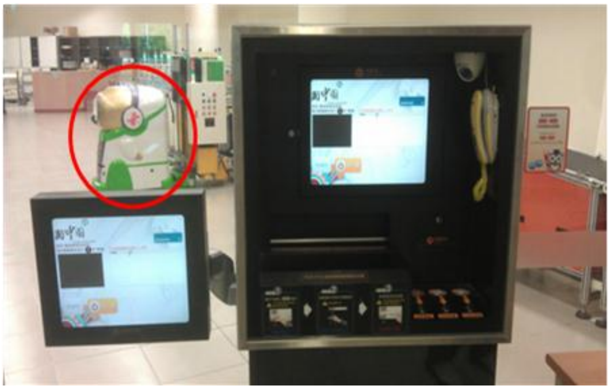

Figure 11. Mobile robot transfer books in the library.

Figure 12. Mobile robot collaboration in the library

After a series of design verification and modification and continuous consultation with the cooperating industry, we proposed the optimal design planning procedures as follows:

- By using the product image scale analysis table of Kansei Engineering, rapidly analyze the design expectations of the target customer group in a current market.
- Organize a group of experts that can use FMEA for analyzing potential design risks.
- Use RPN values obtained after implementing FMEA to propose possible risk control and management strategies.
- Based on risk management strategies, plan optimal design conditions and attend to design details.
- Constantly consult with cooperating manufactures to establish design conditions and flexibly modify design plans; meeting minutes must be retained to record the opinions of both parties.
- Construct a design planning and style profile.
- Use a proportional model to negotiate with the industry and confirm the effectiveness of the design.
- Use FMEA to reassess the RPN value of the revised design.
- Propose the final design.

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