Ecological Interface to Enhance User Performance in Adjusting Computer-Controlled Multihead Weigher

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Abstract. This paper presents a case study on developing a smart user interface for supporting the adjustment works on automated weighing machines of computer-controlled multihead weighers. Based upon the theoretical and practical framework of Vicente and Rasmussen's Ecological Interface Design (EID), we clarified the functional structure of the work domain in terms of the means-end relations, and visualized it on the screen displays to encourage the human operator's "direct perception" of the meanings or values of his practicable actions to those automated processes. Comparative experiments using test subjects with a variety of skill levels confirmed the effectiveness of the redesigned user interface that can facilitate unskilled operators appropriately evaluating and effectively responding to their immediate work situations, and that will take the place of the experts' knowledge and insights on the works as one of the distributed resources for cognition.

Keywords: Ecological Interface Design, Work Domain Analysis, factory automation, computer-controlled multihead weigher, user interface.

1 Introduction

A computer-controlled multihead weigher (Fig. 1) is an automated weighing machine comprised of a plurality of balances or *heads* to measure weights of article batches, some of which would be selected and combined at every measurement cycle to produce a merchandise product within specified weight range (i.e., a "combination weighing" machine). Vibrating feeders constitute its article conveyance system that allows the machine to handle a variety of products ranging from fragile food products to detergent, pharmaceuticals and metal parts, while its rapid combination calculation system delivers higher speed and increased efficiency of weighing (up to 180 measurements per minute [1]). On the other hand, there are a number of control parameters in this automation such as the amplitude and duration of vibration of individual conveyers, and human operators have to adjust them adequately to changing

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measurement conditions for the machine to go on functioning. Adjustment of the conveyance system is required when the weighers get started running with new sorts of articles or when they tend to produce more no-good products. As to this human work, significantly greater accuracy and efficiency of automatic weighing do require much higher level of skill and knowledge of the operators in conditioning the systems. Dependence of the automation performance on the individuals' ability should be dissolved by some improvements in this work domain because flexible automation involves minimized effects of such variable human factors on production management. We seek a resolution of this problem in redesign of its user interface.

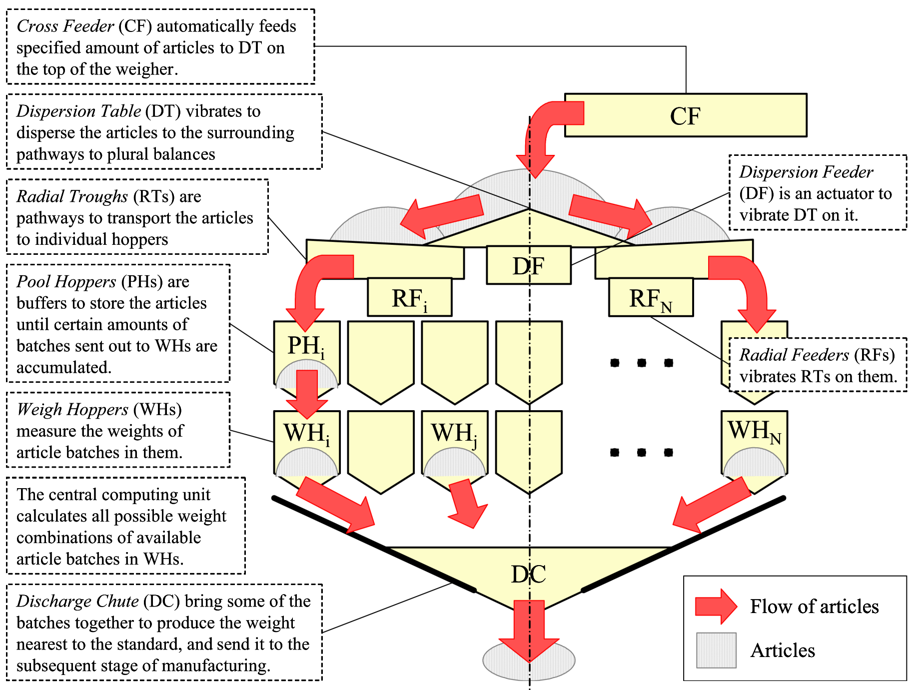


Fig. 1. Physical components of the Ishida multihead weigher [1] through which divided article batches are combined to produce a large amount of merchandise products within specified weight range with higher speed and increased efficiency

Development of a new user interface for the multihead weighers goes on the theoretical and practical framework of Vicente and Rasmussen's Ecological Interface Design (EID) [4-6]. Our former study [2] analyzed the skills of weigher experts compared with novice and intermediate operators, and it has clarified the experts' sufficient knowledge and deep insight to specify the actual state of the machine, both of which are closely associated with their available operations. This result suggests the experts have acquired the semantics of their work domain of the multihead weighers from their experiences, and thus direct our attention to the methodology of

EID. This paper presents our practical study on developing a “smart” user interface for supporting the adjustment works on the computer-controlled multihead weighers.

2 Developing Ecological Interface for Conditioning Automation of Multihead Weigher

EID is a theoretical and practical HCI design framework, which aims at embodiment of a functionally *transparent* mediator, i.e., “ecological” interface, between a human operator(s) and a complex mechanical system [4-6]. What is emphasized there is “direct perception” [7] of the *semantics* of work domains (which state the system is in now, and how much valuable possible actions are for the system’s goal) as well as “direct manipulation” [7] of those displayed elements. “Smart” interfaces ask for no mental arithmetic of human operators. Our former study confirmed the experts have acquired the semantics of their work domain (i.e., of the multihead weigher) from their experiences, and thus direct our attention to the methodology of EID.

2.1 Analysis of the Work Domain Structure

As the first step in applying EID to our design problem, the inherent functional structure of the target work domain should be clarified in the form of connections among functional elements that describe their means-end relationships. *Work Domain Analysis* sort out those functional connections into hierarchy so that concrete elements are to be specified as the means to make abstract functions effective and to compose the whole system’s behavior in the level of functional purpose [3] eventually. This analysis can give designers a useful guide for organizing the display of all relevant information variables to be “externalized” in accordance with their means-end relationships.

After a lot of discussion with an expert operator, we have gotten a *work domain model* of the multihead weigher system as shown in Fig. 2. This model describes the purpose of this system from two different perspectives: the efficiency and the accuracy of the combination weighing. The former perspective represents maximization of the productivity of the weighing process (i.e., elimination of defectives below the standard on product weight) while the latter pursues improved precision of the measured weights to meet the standard. In order to realize “accurate combination weighing,” the worker should pay attention to the number of alternatives to a combination weight because much more candidates assure higher probability of products close to the target weight. The connection between “accurate combination weighing” and “adequate pop size for combination” represents this aspect of the domain knowledge. On the other hand, effective combination weighing demands the consideration of the mass flow in this process as well as the number of alternatives because it must be controlled adequately to achieve higher throughput of the weighing machine. The two connections from “effective combination weighing” represent these relationships. All other linkages in the work domain model derive from the means-end relationships of the same kind.

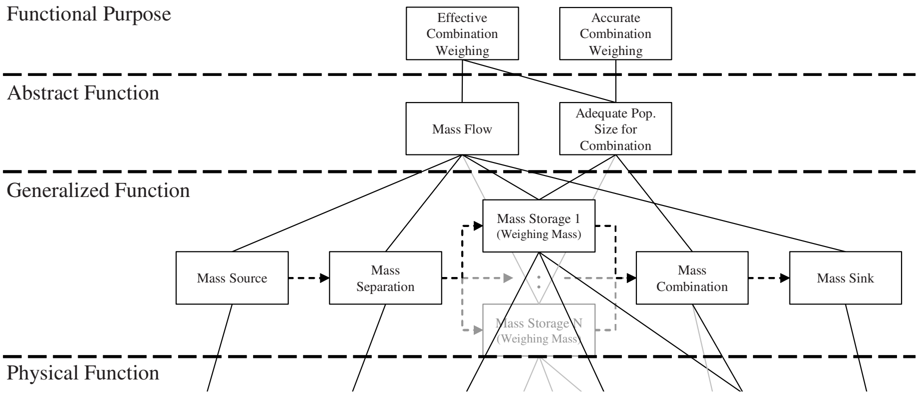


Fig. 2. Part of the work domain model for the multihead weigher derived from discussion with an expert operator

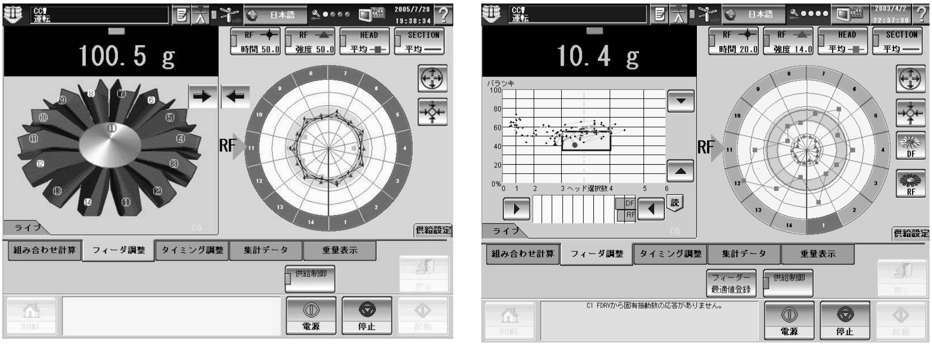
The work domain model shown in Fig. 2 was utilized to extract the basic requirements for the new version of the user interface. Table 1 is a partial list of variables extracted from this model by asking how we can measure those individual functional elements. They are to be organized in the interface display in a fashion consistent with the task demands.

Table 1. Information requirements derived from the work domain model. Variables in bold font are manipulatable by human operators.

Level	*Variables*
Functional Purpose	· Operation rate
	· Accuracy of product weight
Abstract Function	· # of heads selected for combination weight
	· Variation of batch weight among heads
Generalized Function	· Weights of batches
	· Selection of heads
	etc.
Physical Function	· **DF's vibration (amplitude & duration)**
	· **RFs' vibrations (amplitude & duration of each)**
	etc.
Physical Form	· Layout of physical components
	etc.

2.2 Development of Ecological Interface

Based on the former analysis on the work domain, we developed a new user interface for conditioning the automated weighing machine. Fig. 3 shows the two different interfaces for the control panel of the multihead weigher: the conventional version (a) and the newly developed, or ecological, version of the user interface (b). Fig. 4(a) highlights their difference, i.e., the redesigned part of the interface.

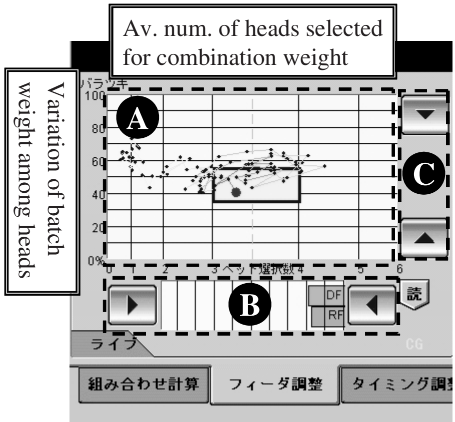


(a) Conventional UI (b) Ecological UI

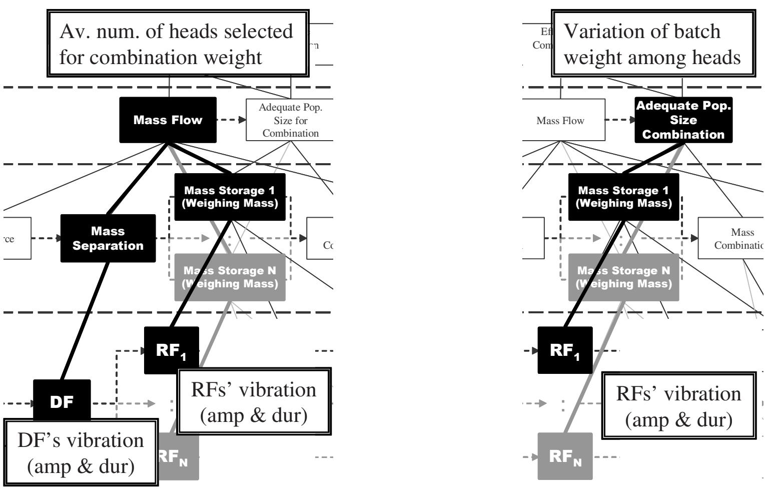
Fig. 3. Two different user interfaces for the multihead weigher: the conventional version (a) and the (newly developed) ecological version (b)

This ecological interface makes visible a couple of intermediate variables that connects several operational variables of physical components to the resultant performance of the weighing machine. They are the (average) number of heads selected for combination weight and the variation of batch weight among heads. The discussions and analysis on the work domain revealed these parameters are of importance in skillful adjustments of the automation while not available for the operators in the user interface so far. As shown in Fig. 4(a), they are used to represent the state of the weighing process in the two dimensional chart (○,A) with the target area indicating the range where high measurement performance can be expected. This representation transforms the operators' task into a more concrete work of guiding the dot of the machine state to the inside of the target frame. It is, however, still a difficult work because there is no guidance for the operators to take the system state for the better in the chart using controls they can manipulate. Some intuitive ways to act on those two variables are necessary. For this purpose, we prepared new two pairs of button controls of ○,B and ○,C, which approximately serve as the horizontal and vertical controls of the system, respectively. Fig. 4(b) accounts for the relations that the functional design of the pairwise control ○,B depends on, indicating that the operators must manipulate the vibration parameters of DF and RFs in some way to regulate the average number of heads selected for combination weight. The function of the control B is tuned so as to balance the number of heads selected for combination weight by means of modifying DF's and RFs' vibration parameters. Fig. 4(c) presents the ground for the design of the pairwise control ○,C. By means of modifying RFs' amplitudes of their vibrations, the control ○,C tries to balance the batch weights among all the heads. These controls, so to speak, provide users with media for *quasi*-direct manipulation.

On the other hand, the weigher system has much delay in responding to manipulations of any vibration parameters. This attribute makes it difficult for the operators to recognize the effects of their operations onto the automated weighing process, which might depress the usability of this system seriously. On this issue, a pseudo indicator was introduced for providing a guesstimate of the future state transition in response to the current user operations. Fig. 5 zooms in the state chart ○,A in Fig. 4(a) and illustrates this function as the mark ○,D, which also presents the target range (a thick-lined rectangle in the center of the chart) for and the transition history (points connected with gray lines) of the weighing process. The operators hereby can approximate the direction of the future state transition.



(a) Modified part in Ecological UI



(b) (c)

Fig. 4. The modified part of the display in the ecological control panel is extracted in (a), and the two pairwise controls newly introduced as for the controls ○,B and ○,C are explained in terms of the means-end relationships (b) and (c) in the work domain model, respectively

All of the graphical items newly designed in the ecological interface were summarized as above. The other parts of the display are still common to the current or conventional user interface.

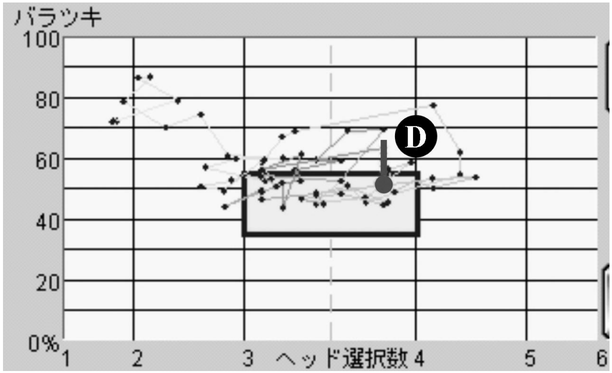


Fig. 5. The state chart representing the current state of the weighing process with the target range and its transition history. Where, a pseudo indicator ○,D provides a guesstimate of the future state transition in response to the current user operations.

3 Performance Evaluation of New User Interface

In order to evaluate the user interface newly developed, we conducted a comparative experiment of twelve test subjects [A to L] with a variety of skill levels using the two versions of user interfaces. The test operators divided into the two groups of subjects to balance the effect of order of trials. The first group of subjects (n = 6) performed one trial using the conventional UI and then another using the ecological UI (therefore labeled as “CUI → EUI”) while the second group (n = 6) did in reverse order (labeled as “EUI → CUI”). The same experimental task was used in the both UI conditions, in which subjects were required to make adjustments of the control parameters of the automated weighing to the articles to be measured without any information except through the control panel. Their work performances were evaluated in terms of the accuracy of their conditioned weighers’ performance and the amount of time required for their adjustment works, as well as their subjective workload ratings.

Fig. 6 compares the two user interfaces in the former two perspectives for evaluation, proving the successful conclusion of the new user interface redesigned for performance improvements. Fig. 6(a), on the one hand, plots mean values of product weights the weigher produced during 100 measurement cycles after conditioned (the target weight of products was 10[g]) where a whisker bar shows the plus one standard deviation for each data set. This result confirms the ecological interface can enable human operators to adjust the machine for more precise and accurate weighing than the conventional. On the other hand, Fig. 6(b) compares the two in terms of the average number of measurement cycles taken for adjustment, indicating the overall tendency that the subject operators finished their work using the ecological interface much faster than using the conventional. The both plots show smaller standard deviations, or reduced variations among individuals, in the ecological UI condition, which prove the dissolved dependence of the automation performance on one human factor, i.e. individuals’ skill level.

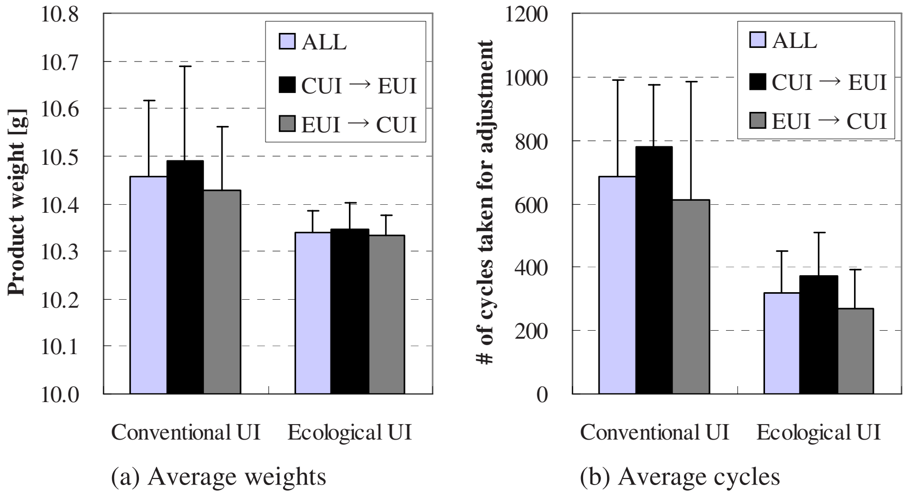
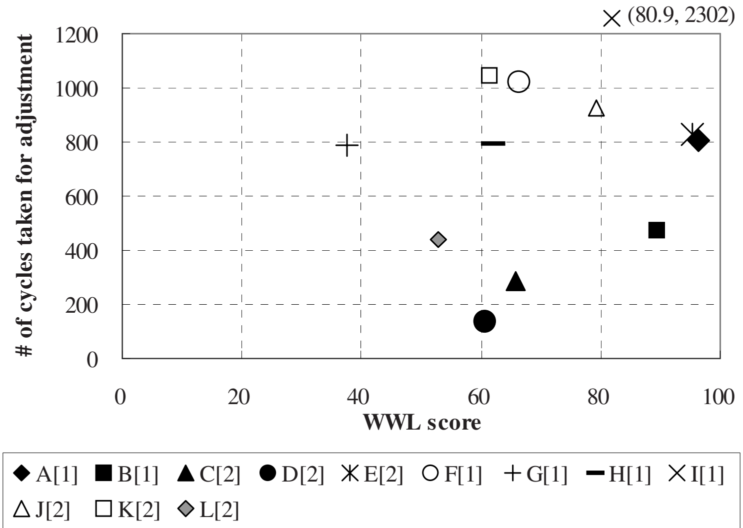


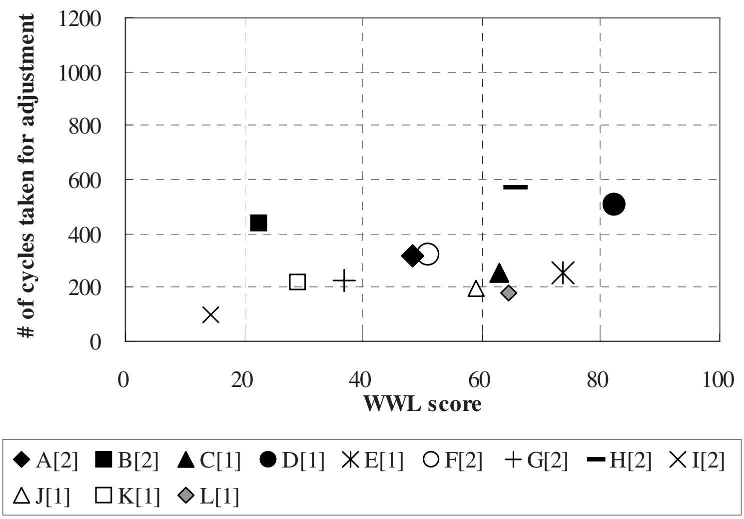
Fig. 6. Comparing the two different UIs in terms of the accuracy of the conditioned weighers' performance (a) and the time required for adjustment works (b)

Besides these objective performance measures of the subjects' conditioning the multihead weigher, we quantified the workload they felt on the adjustment works using NASA-TLX, which is one of the most popular assessment tools for subjective workload. Fig. 7 plots the results of all the subjects' works in terms of the measurement cycles required for adjustment and the weighted workload (WWL) score obtained from them. In the former work of this study [2], we have gotten a piece of knowledge that more skillful operators would rate the adjustment work through the conventional user interface as lower workload demands, and thus the WWL scores can be regarded as an index of individuals' skill. Fig. 7(a) shows this tendency again when you see the data in parts of the subjects A to E and the subjects F to L since the former group of subjects used a real machine in the experiment while the latter used a computer simulator of the weigher. The number of cycles required for adjustment increases in proportion to the WWL score. Fig. 7(b) does not show such a tendency, and confirms the alleviation of workload from the conventional adjustment work, especially for the operators unskilled.

All the results of this experiment validate the effectiveness of our ecological interface developed for the work domain of the multihead weighers. It can fairly improve the work performances of unskilled operators, thereby reducing deviations from the standard of product weight no matter who conditions the automation behavior. It can facilitate unskilled operators adequately evaluating and effectively responding to their immediate work situations. On the contrary, some of the operators who have sufficient skill with the conventional user interface put a low value on the ecological one because the latter changes the adjustment work into different one where they are required to guide a dot to the inside of the target frame. As weighings by the multihead weigher come from decisions based on combinational computing,



(a) Conventional UI



(b) Ecological UI

Fig. 7. Results of all the subjects' works plotted in terms of the measurement cycles required for adjustment and the WWL score, separated into the two UI conditions.

the dot in the state chart would often make "leaping" behaviors that might frustrate them. The current version of our ecological interface has no information resources to give them a reason for those behaviors and their mechanisms. This is the most important point we have to deal with in our future work.

4 Conclusion

This paper presented our study and development of a smart user interface for supporting the adjustment works on automated weighing machines of the computer-controlled multihead weighers. Based upon EID framework, we clarified the inherent functional structure of this work domain in terms of the means-end relations, and visualized part of it on the screen displays to encourage the human operator's "direct" perception of the meanings or values of his practicable actions to those automated processes. Comparative experiments using test subjects with a variety of skill levels confirmed the effectiveness of the redesigned user interface that can facilitate the unskilled operators appropriately evaluating and effectively responding to their immediate work situations. This externalization of core relational information will take the place of the experts' knowledge and insights on the works as one of the distributed resources for cognition.

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