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ScienceDirect

Procedia Manufacturing 3 (2015) 6305 – 6312

Procedia MANUFACTURING

6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE 2015

Principles to develop size ranges of products with ergonomic requirements, using a robust design approach

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Abstract

This paper presents an approach to developing size ranges of products that have ergonomic requirements. Ergonomic requirements are a main source of semi-similarity in size ranges. This approach is based on a process model for uncertainty analysis, the size range development methodology of Pahl and Beitz, and robust design principles.
The process model captures the interactions between user, the man-machine interface and the scaled product (the appliance). Interactions between user, man-machine interface and appliance can be classified as planned interactions or disturbances, and either influence or impact a variation. Using three robust design principles for elimination of disturbances and elimination or reduction of disturbance influence or impact, the synthesis of solutions for man-machine interface design can be supported. The robust design principles are adapted to the interactions of the user and the man-machine interface with the size range. The outcome is integration of the two disciplines, ergonomics and size range development.

Peer-review under responsibility of AHFE Conference

Keywords: Size range, scaling, robust design, ergonomics

1. Introduction

Size ranges are very common in products. They are found almost everywhere – machine elements like bolts, feather keys or gear wheels, consumer goods like TVs, refrigerators, gas turbines, aircrafts and machining centers.

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Peer-review under responsibility of AHFE Conference
doi:10.1016/j.promfg.2015.07.944

This means that many products that are developed into size ranges have man-machine interfaces (MMI) or are part of an MMI. In general, products can be scaled in size, power, capacity, speed, force, etc., to satisfy various specifications of customer need. A size range is, according to Pahl and Beitz, a product that fulfills the same purpose but is available in different sizes to cover a wide range of usage, has the same technical solution and is manufactured as similar as possible [1]. Since the geometric scaling of a product does not necessarily lead to satisfying solutions the designer has to modify the product, which leads to semi-similar series [2]. One of the most common reasons for semi-similarity is that the product has MMIs. This can be illustrated using different sized airplanes – though neither the seats nor the control stick is scaled with the plane, and the operating forces should not be scaled too much either.

Literature about size range development using laws of growth shows that ergonomics are "overriding standards" that lead to semi-similarity [3,4,5,6], though there is no specific guideline or approach to deal with ergonomic requirements in a structured way. It is only for spatial requirements that size range methodology gives instructions on how to deal with overriding standards. The situation is little better when using dimensional analysis as a method of scaling. Since dimensionless numbers can include biomechanical parameters [7], there is more support for the integration of ergonomic requirements into scaling. Nevertheless, dimensional analysis is not as efficient in size range development as laws of growth integrate preferred number diagrams and allow efficiently structured development of a size range [2].

The literature on research in ergonomics, human centered design and anthropometry has similar findings. Human capabilities (physical and informational) are described well [8,9,10], and guidelines are given for the design of workplaces, MMIs and tasks [11,12,13] or the analysis of work (only literature relevant to mechanical MMI is the focus of this paper; cognitive work is not considered here). Ergonomics and human centered design do not look at the way that fulfillment of requirements is ensured technically within a size range. Scalability in ergonomics is understood as fitting an interface or task to humans of different size, physical strength, etc. [14], not about scaling the product to fit non-ergonomic customer requirements. Usually, design of the interface is carried out. This design then hopefully fulfils requirements. Scalability, together with the product that is controlled through MMI, is not considered.

From these two perspectives the question arises of how the synthesis of size range products involving MMI can be more efficient. This paper presents an approach to structuring the dependencies between man-machine interfaces and scaled size range products. This is done using models and classifications from robust design, since scaling of the product can be modeled as disturbance to the input-output relation targeted by the MMI. The benefit of a new approach is that time and cost-intensive procedures required to develop MMI [15,16] can be simplified for sequential designs of a size range because an MMI for a basic design can be transferred with less uncertainty to a sequential design.

2. Models and Methods

The models and methods used in size range development of MMIs are given in this section. First, the size range development methodology of Pahl and Beitz [2] is introduced briefly. Modeling of processes and functions is then explained. Finally, the robust design principles used to create the procedural models for size range development, including MMI, are introduced.

2.1. SizeRange Methodology

The underlying size range methodology in this paper is the six step methodology of Pahl and Beitz [2]. Physical relations are determined and written in a dimensionless form using step factors that are ratios that describe the growth of a parameter, from basic design to sequential design. The dimensionless form of physical relations is called a law of growth. Laws of growth can be found for physical phenomena [2,5], costs [3,4] and environmental impacts [6]. The main steps of this methodology are shown in Fig. 1a. The emphasis on ergonomics is in steps four and five, where the aim is to support the synthesis of MMI in size range products already within the basic design phase. Also in this methodology, deviation of parameters or disturbances (i.e. uncertainty) can be integrated into laws of growth [17,18]. This is useful for additional modeling of the distribution of body measurements when integrating anthropology into laws of growth.