Proactive Ergonomics through Digital Human Modeling and Simulation for Product Design Innovation: A Case Study

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Abstract— Now-a-days, it is a very common trend for youth to go for regular gymnasium for muscular body building or eliminating extra fat. Most of the equipments used for these purposes are generally for indoor exercises. Thus there is least scope of rigorous outdoor exercise in open air environment. An attempt has been made by the present authors to develop a concept model of Ergometer which is to be installed in open space like park. After a small user survey and brain storming, it was decided that the intended design should be unique in look; aesthetically appealing; compatible for both adult Indian male and female; easy to use and most interestingly, it would be motivational factor for people to continue their exercise for longer duration. People would feel happy because more battery (inbuilt) recharging would happen if they go for intense and longer duration exercise. Those batteries would be used in night for illuminating the park. Innovative concept model of the Ergometer was evaluated and subsequently, design was modified for anthropometric compatibility from a traditional physical ergonomic perspective necessarily involves building real physical mockups and subsequently trials with real human beings. This is time consuming and quite expensive [3]. Computer aided digital human modeling and simulation technology has emerged as the state of art expertise for human centric ergonomic evaluations and is highly useful because of many associated benefits [4]. ‘Digital human model’ (DHM) is the computer generated two dimensional or three dimensional structure of a human used to represent the complex physical and cognitive aspects of human beings. Further, it can also be considered as a digital representation of the human inserted into a simulation or virtual environment to facilitate prediction of safety and / or performance [5].

Before building the first prototype of a product or workstation/workplace, numerous trials can effectively be performed since investigations are conducted in a CAD environment. Various what if scenarios is possible to be tested virtually for aiding design optimization. A concept model of a product before being actually produced can be subjected to the severest of ergonomic investigations using DHM technology [6]. Ergonomic evaluations through simulation using digital mock-up and DHMs are economical in long run when compared with traditional ergonomic evaluation processes in typical product/process development sequences [7].

Contemporary trends indicate that variety of products are designed and manufactured for commercial purposes to meet diverse needs, requirements and aspirations of the society. Now-a-days, it is a very common tendency for youth to go for regular gymnasium for muscular body building or eliminating extra fat mass. Most of the equipments/devices used for this purpose are generally for indoor exercises. Thus there is least scope of outdoor rigorous routine exercise in open air environment. To provide some solution, an attempt has been by the present authors to develop a concept model of an ‘Ergometer’ which is to be installed in open space like park. After a small user survey and brain storming, it was decided that the intended design should be unique in look; aesthetically appealing, compatible for both adult Indian male and female, easy to use and most interestingly, it would be motivational factor for people to encourage them to continue their exercise for longer duration. Because of an in built battery unit, people would feel happy and go for intense and longer duration exercise to enable more battery recharging. Those batteries...
would be used in night for illuminating the park. However, primary aim of the present academic pursuit is an attempt to make evident the capability of digital human modeling and simulation software to successfully evaluate and validate an innovative product design concept from a physical design ergonomics/human factors engineering perspective. Such evaluations ensure good anthropometric compatibility of the product, in order to facilitate easy operation by the entire range of intended user population group without much physical discomfort, even before the construction of initial physical prototype. This approach has all the potential to establish itself as a standard validation and bench marking methodology for physical ergonomics evaluation [8]. DHM has been used advantageously for accomplishing different goals in product design applications [9] [10] [11] [12] [13] [14].

Virtual prototype of the conceptual product i.e. ergometer (fig. 1), has been subjected to intense scrutiny from a proactive ergonomics perspective using digital human modeling software. The methodology adopted for such an evaluation has been described in the following paragraphs.

Figure 1. Concept model of Ergometer.

II. METHODOLOGY

A. Study of anthropometric database

Adult Indian male and female were considered as the targeted user population for assessment of ergometer. Indian anthropometric database generated by Chakrabarti (1997) [15] was taken to account for the same. From common understanding, it can be stated that 5th percentile female and 95th percentile male represent the extreme group in a population which encompasses the smallest and largest body dimensions, respectively. Therefore for accommodating a wide range of the adult Indian population, 5th percentile female and 95th percentile male body dimensions along with 50th percentile pooled body dimensions (representative of average individual) were selected for generation of digital human model. Even though all the body dimensions of a particular individual do not necessarily fall under the same percentile category, such an ideal condition may be considered for generating human models for research purposes to solve associated constraints [3].

B. Generation of digital human model and rendering of comfort angles

‘Variable list tool’ provided in the ‘human measurements editor workbench’ of DELMIA DHM software was employed to manually input anthropometric dimensions for building required digital human models. Three digital models (5th percentile female model, 50th percentile pooled data model and 95th percentile male model) were used to represent smallest, average and largest dimensional adult Indian population, respectively.

Comfort angles were rendered over the digital human manikins. The values of the comfort angles for different body segments were adopted and suitably modified (in necessary instances) from published literatures [16] [17] [18]. Angular limitations icon, preferred angles dialog box, reset, mirror, and swap functionality were used to edit and render the comfort angles including color coding. The comfortable range of body angles were depicted green in color while discomfort angular ranges were given red color. Segment coloring was activated through coloring sub tab in the properties dialog box. This enables identification of body segments which would be in comfort and discomfort angular ranges by the visual representation of applied color code on the manikin’s body segments. The radio buttons in coloring sub tab and combo of degree of freedom and preferred angles were appropriately selected and applied.

C. Conceptualization and generation of digital prototype of Ergometer

In any product development cycle, concept initiation and its progression of development plays a very vital role before the final design is to get shape. Good design concepts help in bringing forth futuristic and innovative products. In present design-development, intention was to design a simple and elegant design. The basic idea in concept product ergometer was the ratchet mechanism on a bigger scale (fig. 2). Ratchet mechanism allowed continuous rotary motion of the ergometer wheel only in forward direction while preventing motion in opposite direction. A dynamo which was connected to the free wheel, generated electrical power following rotation and sent the same to battery for proper storage. Low level pedal with adjustable form of handle and seat was expected to enable convenient usage for both men and women.

Figure 2. Ratchet to the scale of line of pedal of bi-cycle for dynamo rotation.
A manikin developed from 50th percentile pooled data, was given a comfortable riding posture and it was used for deriving initial dimension rendering required for designing ergometer. Final design dimensions, particularly with respect to seat and handle height from the ground were finalized after evaluations using 5th percentile female and 95th percentile male manikin. Using the mechanical design option in DELMIA software, a virtual prototype of the ergometer was generated for evaluation with digital humans/manikins.

D. Interfacing ergometer with digital human model

Digital manikins with suitable working/functional posture were interfaced with CAD model of ergometer. This was performed with help of change current axis and snaps compass; distance and band analysis; measure between; posture editor; inverse kinematics mechanisms; open vision window; standard pose and create multi-view tools in ‘human task analysis workbench’ of DELMIA software.

E. Virtual ergonomics evaluation of ergometer

Following development of 3D CAD model from concept sketching of the desired ergometer, various human factor aspects were evaluated in virtual environment of DELMIA software with digital manikins’ representative of Indian anthropometric data to justify the appropriateness of proposed design for adult Indian users from a design ergonomics perspective. Purpose of ergonomics evaluation was to find out whether seat height and handle height from floor/base were suitable for easy and comfortable operation by a range of users covering from 5th percentile adult female and 95th percentile adult male body dimensions along with reach capabilities. Entire operation to complete one rotation of the ergometer wheel was taken into consideration for evaluations. The whole operation was sub divided into four steps namely foot at lower most pedal position (figure 3), foot at backward most pedal position (figure 4), foot at top most pedal position (figure 5), and foot at forward most pedal position (figure 6).

Comfortable reach to handle of the ergometer helps in maintaining a good body posture. Normally reach analysis is performed using the smallest representative of the population, namely, 5th percentile female. In this case study, since the concept model of ergometer was designed to incorporate adjustable features in handle, handle stand and seat height from ground, it was thought to be essential to perform reach analysis using compute reach envelope tool in order to assess reachability of handle for each of the manikins under study as shown in figure 7.
III. DISCUSSION AND CONCLUSION

As a result of investigations and design iterations using DHM, it was found that the maximum and minimum seat height from the ground/base level should be 829.91 mm and 767.18 mm, respectively for comfortable operation by people of varying percentile (5th to 95th) of body dimensions considered for present evaluations. Similarly, maximum and minimum height of handle grip from ground/base level was derived to be 974.68 mm and 894.68 mm. Therefore, suitable adjustable mechanisms are needed to be provided for regulating seat and handle height to assist comfortable operation of the ergometer by adult Indian users. By using the term ‘comfortable operation’ of ergometer, it was meant that all the body joint angles under consideration were found to be within the comfortable range of movement. This was indicated by the display of green color coding on body segments of human model. All the manikins considered for the present case study were found to easily reach the handle of ergometer (fig. 7), and thus were able to maintain a comfortable operational posture.

During 3D visualization of simulated mounting and descending activities by all the representative manikin models, it was noticed that inadequate space between the handle stand and wheel might pose some problem of interference and consequently discomfort for the legs. Postural discomfort during ascending or descending the ergometer were reflected through red color coding on respective body parts (particularly leg) as shown in figure 8. Therefore, it was felt necessary to alter the design of the handle stand by providing sufficient clearance space for easy mounting and descending of all the intended end users. The final abstract concept design model of ergometer, following incorporating suitable design modifications based on virtual evaluations was given shape as shown in figure 9. The ergometer is completely validated virtually for human centric design, elegant and simplistic, and at the same time aesthetically appealing and inviting too.

Commercially available ergometer (both electrically and manually operated) e.g. thread mills, bicycle ergometer etc. help people to perform physical activity like running/walking or pedaling at a particular fixed pace. User can suitably set the intensity of exercise by changing either speed/inclination angle (for treadmill) or by modifying resistance (for bicycle ergometer). Ergometer concept described in the present paper does not address the issues related to determining exercise intensity/workload as it is beyond the scope and stated aim of bringing out a concept design (evaluated with DHM software) for encouraging people to exercise for prolonged duration in open space for ultimately generating electricity. However, since the ergometer is presently at product conceptualization stage, it can be visualized to be possessing uniform resistance; thereby enabling people undertake longer duration workouts without varying the exercise intensity. Engineering design considerations accounting for material selection and its mechanical/electrical properties, machine design, component strength validations through appropriate analysis, prototyping and experimental trial runs, and comparison with existing similar products (if any) relating to this concept product are beyond the stated purpose and scope of present research endeavor.
and the digital human thereby helping the evaluations. Many ergonomic mismatches were easily identified using DHM.

Different disciplines can harness the benefits of human modeling technology application. However during this study, it was found difficult to generate manikins representing children and elderly populations as preferred by the authors. Lack of published/validated Indian anthropometric data representing the above mentioned population group is strongly felt in such product design ergonomic evaluations. Incorporation of child, adult, and elderly anthropometric data bases of different population groups across the world in DHM software will be a boon for human centric product development process. Efforts should be taken through joint collaborations among industry/software developers, academia and national governments across the world to address this issue at the earliest. This will help in the application and exploration of DHM benefits to its fullest sense in many other disciplines and promote wider adoption across countries [19] especially in developing countries where such research works are very few in number [20]. Merging ergonomic design principles into the design process proactively, can make design successful [21]. This holds true for innovative product design initiatives also as seen from the present manuscript.

REFERENCES


