Title:
CAD Feature Recognition as a Means to Prevent Ergonomics Issues during Manual Assembly Tasks

Authors:
Marco Marconi, marco.marconi@univpm.it, Università Politecnica delle Marche
Michele Germani, m.germani@univpm.it, Università Politecnica delle Marche
Claudio Favi, claudio.favi@unipr.it, Università degli Studi di Parma
Roberto Raffaeli, roberto.raffaeli@uniecampus.it, Università degli Studi eCampus

Keywords:
Feature recognition, Virtual product model, Manual assembly, Ergonomics, Work-related Musculoskeletal Disorders

DOI: 10.14733/cadconfP.2017.400-404

Introduction

In the last three decades, feature-based computer-aided systems have been developed in the field of solid modelling [3]. Several research activities have been done in this field, such as the definition of algorithms, methods and tools for the automatic recognition of features from 3D solid models [6]. Feature recognition algorithms seek to recognize aggregates of entities with a clear design meaning, such as pockets, holes, fillets, etc., from the B-Rep representation. Feature recognition algorithms can be divided in: (i) graph-based approaches, (ii) volumetric decomposition approaches, and (iii) hint-based approaches [2][5][8]. Most of the applications based on feature recognition focus on the machining/processing domain [2] in order to support the process and assembly planning [9].

This paper intends to extend the use of feature recognition as a means to improve the product assemblability and to prevent ergonomics issues associated to the manual assembly tasks (e.g. the Work-related Musculoskeletal Disorders - WMSDs). The prevention of WMSDs is an important goal to achieve for the modern society: (i) to maintain young workers' capability, (ii) to ensure older workers a healthy working life, (iii) to avoid workers' substitution when absent for WMSD disturbs, (iv) to avoid workers' reallocation when affected by WMSDs, and (v) to avoid workers' complaints [1] [10].

Although new technologies have been implemented in industries (e.g. robotics and automation systems), WMSDs still remain an important issue. It is well known that the exposure of workers to this risk during manual assembly operations depends on two principal aspects: (i) the product design, and (ii) the workstation layout. Currently, the standard practice is to manage ergonomics aspects through the optimization of the assembly line, mostly after illness cases occurred. These are corrective actions which only aim to minimize the cost impact for the company without actually solving the problem [4].

The goal of this study is to define a method for managing physical risk factors early in the product design and assembly planning processes. Starting from the features analysis of a 3D product model and based on the information related to the assembly process (assembly plan, needed tools, etc.), the proposed method allows preventively identifying potential ergonomic issues supporting in the definition of alternative design solutions.

Method

The analysis of the virtual model during the product development process may help in the link between the manual assembly tasks and the WMSDs. Fig. 1 depicts the main steps of the proposed method including the details for its implementation in real contexts.

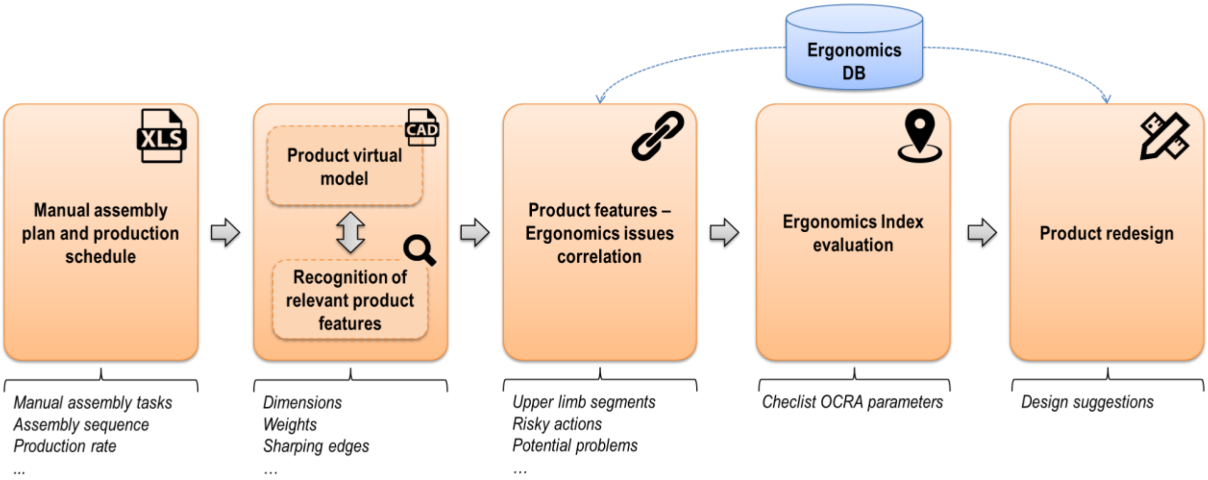

Fig. 1: Workflow of the proposed method.

1st step: Analysis of the manual assembly plan and the production schedule
The starting point of the proposed method is represented by the analysis of the assembly plan and production schedule documents, usually available during the product development process. The analysis of those project documents permits to clearly identify and characterize each assembly task in terms of: (i) items to assemble, (ii) liaison type, (iii) assembly time, (iv) frequency, (v) recovery time, (vi) necessary assembly tools, and (vii) necessary assembly equipment.

2nd step: Analysis of the product virtual model and Recognition of relevant product features
In this step, the 3D product virtual model is examined using feature recognition algorithms. Specific rules allow to extract the relevant characteristics from 3D models:

- properties of components (e.g. volume, bounding box sizes);
- global shape characteristics (e.g. axial symmetry, stacking ratio);
- relevant features for the assembly process (e.g. threaded parts, holes, pockets);
- sizes and dimensions (e.g. diameters, lengths);
- slenderness (i.e. the ratio between the surface and the volume of the component);
- sharp edges;
- typical arrangements of assembly patterns (e.g. flanges, linear or circular patterns of threaded connections).

3rd step: Product features – Ergonomics issues correlation
Data coming from the 1st and 2nd steps are used to correlate the product features and the ergonomics aspects associated with the manual assembly tasks. The link (laws) is defined starting from the classification of the upper limb segments potentially interested by the risk of overload when awkward postures and movements are performed. For example, the identification of sharp edges may affect assembly tasks performance (use of gloves, special attention during the handling, etc.), as well as the workers' ergonomics (possibility to cut fingers, etc.).

Subsequently, it is necessary to establish how such postures are related to the product features retrieved through the analysis of the 3D virtual model. The relationships among the product features, the manual assembly issues and the ergonomic aspects (body parts, postures, angles, etc.) have been classified and stored in a specific database (Ergonomics DB in Fig. 1). In addition, design suggestions have been defined to guide the redesign phase (5th step of the method) toward the WMSDs risk reduction. Tab. 1 illustrates some representative examples of the classified correlations and design suggestions stored in the database.

Product features	*Assembly issues*	*Ergonomics aspects*	*Design suggestions*
Symmetry	To orient it in the correct position after picking. To position correctly in the assembly	Elbow (Pronation/Supination) Wrist (Flexion/Extension) Wrist (Ulnar/radial deviation) Hand (Pinch)	To use notch to identify assembly side To use colors to identify assembly side
Sharping edges (distance between edges < 3mm)	To take and to keep it during picking. To hold it in right position.	Hand (Pinch)	To isolate cutting edges enclosing in not touchable parts
S-concentric faces (limited space)	To position it correctly in the assembly and to fix it.	Wrist (Flexion/Extension) Wrist (Ulnar/radial deviation) Hand (Pinch)	To reduce the height of the housings
Insertion with interference fits (chamfer)	To position it correctly in the assembly and to push it.	Shoulder (Abduction) Wrist (Flexion/Extension) Wrist (Ulnar/radial deviation) Hand (Pinch)	To design the geometrical elements with right tolerances
Screwing (threaded)	To screw it and to clamp it.	Shoulder (Flexion) Shoulder (Abduction) Wrist (Flexion/Extension) Wrist (Ulnar/radial deviation) Hand (Pinch)	To avoid (or at least standardize) threaded joints

Tab. 1: Relationship between Product features, Assembly issues and Ergonomics aspects.

4th step: Ergonomics Index Evaluation

After the definition of the link between the product features and the ergonomics issues highlighted for each specific assembly task, it is possible to calculate the Ergonomics Index. For this analysis, the chosen metric is based on the Checklist OCRA Index [7]. This index takes into account both physical and organizational risk factors and it is calculated by using the following equation Eqn. (1):

$$\mathrm{ErgonomicsIndex} = (\mathrm{F_m} + \mathrm{Fo_m} + \mathrm{Po_m} + \mathrm{Ad_m}) \times \mathrm{Rc_m} \times \mathrm{Du_m} \quad (1)$$

where F_m is the multiplier for the frequency of actions per minute, F_{Om} is the force multiplier, P_{Om} is the posture multiplier, Ad_m is an additional multiplier related to the using of tools, the exposure to vibrations or anything that could compromise the upper limbs joints and segments considered by the method, Rc_m is the recovery multiplier and Du_m is the duration multiplier.

It is worth to notice that the Checklist OCRA Index parameters are usually retrieved by the direct observation of the assembly tasks, when the assembly line/workstation is already set up. In this study, instead, the parameters involved are estimated on the basis of the assembly plan, used assembly tools, batch size, shift duration, time cycle, etc., documents commonly available at the design stage.

As described within the Checklist OCRA method, the value assumed by the Index is correlated with the risk for workers to develop WMSDs: 0 – 7.5: Acceptable risk; 7.6 – 11: Borderline risk; 11.1 – 14.0: Low level risk; 14.1 – 22.5: Medium level risk; ≥ 22.6: High level risk.

5th step: Product Redesign

The product redesign goal is to improve the product configuration based on the feedbacks derived from the previous steps. During this phase, designers are guided in this process through design rules and suggestions, stored in the Ergonomics DB. Given a target issue that needs to be removed or at least minimized, specific suggestions can be implemented to improve the product performance in terms of both assemblability and ergonomics. This step can be iterated several times with the aim to modify the product features according to suggestions and checking if the ergonomics criticalities are still present. At the end of this step, the output is a new product version (virtual model) with the relative new assembly plan (including the tools and the equipment needed to perform all the assembly tasks).

Case study

The proposed method has been tested to redesign a cooker hood assembled by an Italian company. This product has been chosen due to its complexity (e.g., high number of components, different types of connections) and the fact that all the components are manually assembled. In particular, here is proposed a focus on the blower system; an internal sub-assembly composed by three modules (electric motor, rotor and conveyor), assembled through threaded elements.

The 1st step of the method consists in the analysis of the manual assembly plan and production schedule. The production rate of the analyzed cooker hood model is 200 pieces per day (one shift).

The 2nd step of the method allows to identify the critical product features, such as the presence in the model of S-concentric faces (Fig. 2), used in the blower to create a housing for the screws. Since the height of housing (i.e. the circular face with bigger dimension) is higher than the height of the screw (i.e. the threaded part), the screw cannot be released with a certain positive location in the assembly. This issue potentially leads to an increase of the number of technical actions during the manual assembly phase, due to the necessity for operators to continuously re-position and align the screw in the housing.

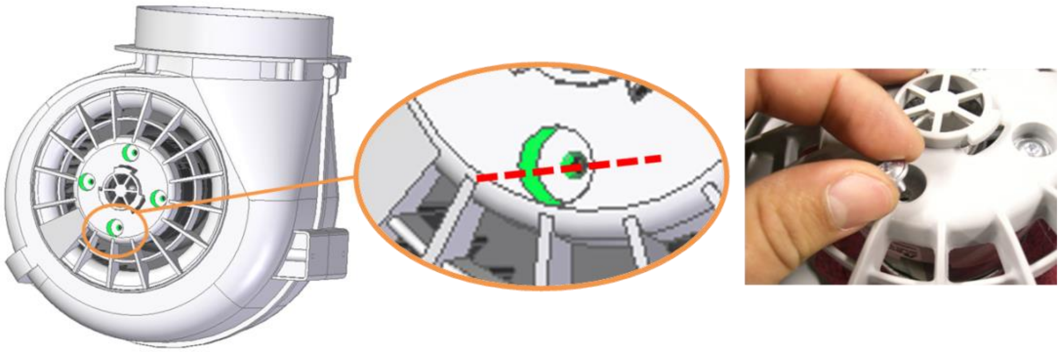

Fig. 2: Identification of the critical product feature (S-Concentric faces) for the blower system.

According to the relationships classified in the Ergonomics DB (3rd step of the method), the S-Concentric faces feature is associated to a limited space for operators during insertion operations. Such issue leads to awkward postures of the wrist and of the hand due to screw handling and positioning operations.

Based on the assembly plan and production schedule documents, the assessment of the Checklist OCRA Index has been also carried out (4th step of the method) to confirm the potential issues preventively identified with the product features analysis. The results analysis of the Ergonomics Index (Tab. 2) highlights a possible risk for workers (High level) for the right upper limb due to the high number of technical actions (33 per 25 s.). This issue is mainly due to the numerous re-positioning and alignment of the screws in the housings. The left upper limb, conversely, does not present a potential risk.

Product Feature	*Technical actions [N°]*		*Cycle time [s]*	*Ergonomics Index*
	DX	*SX*		
Handling of screws (4 screws)	4	0	25	DX = 22.6 SX= 1.3
Positioning of screws in the housing	16	8		
Insertion of screws in the housings	4	0		
Fastening of screws (with screwdriver)	9	0		

Tab. 2: Ergonomics Index calculated in the case of blower system.

A possible redesign action (5th step of the method) could consist in the reduction of the height of the housings (e.g. max 5 mm.). By implementing this simple design suggestion (contained in the Ergonomics DB), the Ergonomics index will decrease from 22.6 to 17.3 for the right side (from High level to Medium level risk). It is worth to notice that also the cycle time will decrease from 25 s to 20 s, with a clear advantage in terms of assembly time and thus production cost.

Conclusions

The paper presents an approach for product redesign which takes into account ergonomics aspects related to the manual assembly tasks. Ergonomics issues are highlighted during the product development phase by recognizing specific features of the 3D model. The step beyond the state of the art is the possibility to evaluate the potential ergonomics issues during the product design, so as to shift the problem from the production/assembly site to the design departments (prevention vs. remedial actions).

The adoption of this approach during the redesign of a cooker hood confirms the possibility to identify ergonomic criticalities through the analysis of the product features and attributes from the 3D CAD model. The case study demonstrates the effectiveness of the approach in real contexts and how redesign actions can be adopted to fix ergonomics issues and thus to decrease the risk of WMSDs.

References

[1] Garg, A.; Moore, J. S; Kapellusch, J. M.: The Revised Strain Index: an improved upper extremity exposure assessment model, Ergonomics, 2016. http://dx.doi.org/10.1080/00140139.2016.1237678

[2] Han, J.; Pratt, M.; Regli, W. C.: Manufacturing Feature Recognition from Solid Models: A Status Report, IEEE Transactions on Robotics and Automation, 16(6), 2000, 782-796. http://dx.doi.org/10.1109/70.897789

[3] Hoque, A. S. M.; Halder, P. K.; Parvez, M. S.; Szecsi, T.: Integrated manufacturing features and Design-for-manufacture guidelines for reducing product cost under CAD/CAM environment, Computers & Industrial Engineering, 66(4), 2013, 988-1003. http://dx.doi.org/10.1016/j.cie.2013.08.016

[4] Hoyos-Ruiz, J.; Martínez-Cadavid, J. F.; Osorio-Gómez, G.; Mejía-Gutiérrez, R.: Implementation of ergonomic aspects throughout the engineering design process: Human-Artefact-Context analysis. International Journal on Interactive Design and Manufacturing (IJIDeM), 2015, 1-15. http://dx.doi.org/10.1007/s12008-015-0282-3

[5] Lai, J.-Y.; Wang, M.-H.; Chiu, Y.-K.; Hsu, C.-H.; Tsai, Y.-C.; Huang, C.-Y.: Recognition of depression and protrusion features on B-rep models based on virtual loops, Computer Aided Design and Applications, 13(1), 2016, 95-107. http://dx.doi.org/10.1080/16864360.2015.1059200

[6] Niu, Z.; Martin, R. R.; Langbein, F. C.; Sabin, M. A.: Rapidly finding CAD features using database optimization, Computer-Aided Design, 69, 2015, 35-50. http://dx.doi.org/10.1016/j.cad.2015.08.001

[7] Occhipinti, E.; Colombini, D.: The occupational repetitive action (OCRA) methods: OCRA index and OCRA checklist, In Eds. Stanton N. Et al., Handbook of human Factors and ergonomics methods, CRC Press, Boca Raton, FL, 2004. http://dx.doi.org/10.1016/S0166-3615(01)00090-2

[8] Rahmani, K.; Arezoo, B.: Boundary analysis and geometric completion for recognition of interacting machining features, Computer Aided Design, 38(8), 2006, 845-856. http://dx.doi.org/10.1016/j.cad.2006.04.015

[9] Tan, C. F.; Kher, V. K.; Ismail, N.: Design of a Feature Recognition System for CAD/CAM Integration, World Applied Sciences Journal, 21(8), 2013, 1162-1166. http://dx.doi.org/10.5829/idosi.wasj.2013.21.8.2126

[10] Zheltoukhova, K.: Musculoskeletal Disorders and Work – Results of a survey of individuals living with Musculoskeletal Disorders in six European countries, The Work Foundation (Lancaster University), Great Britain, 2013.