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Intelligent Decision Support System for Ergonomic Product Design

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Subject review

In general, computer tools for ergonomic CAD do not assist designer with higher level advice when performing ergonomic design. Designer has to possess expert knowledge and experience in many fields of engineering design including ergonomics in order to deliver successful designs. Such multi-level experts are rare and usually occupied. Two alternative ways are used to substitute these experts: teams of experts covering different areas of knowledge are established or some intelligent computer programs with expert knowledge are applied. In the second case, expert knowledge has to be collected, organized and encoded into the knowledge base of the system. An intelligent decision support system has been developed in order to overcome this bottleneck. This paper presents a knowledge base, containing ergonomic design knowledge specific for hand tools design. A pneumatic hammer handle design is used as a case study to show how ergonomic design knowledge built in the system is used to improve the ergonomic value of the product.

Inteligentni sustav za podršku odlučivanja u procesu ergonomskoga dizajna

Pregledni rad

Postojeći računalni alati za ergonomski dizajn nisu u mogućnosti pomoći dizajneru savjetom više razine. Konstruktori moraju imati znanje i iskustvo iz više područja dizajna, uključujući ergonomiju, kako bi dizajnirali proizvod, uspješan na tržištu. Takvi su stručnjaci rijetki i obično vrlo zauzeti. Kao zamjena za ove eksperte, navode se dvije alternative: to su ekipe eksperata iz različitih područja ili inteligentni računalni sustavi, koji imaju ugrađeno ekspertno znanje. U drugom slučaju, to znanje mora biti prikupljeno, organizirano i programirano u bazu znanja. Inteligentni sustav za podršku odlučivanju je razvijen u cilju preovladavanja ovog uskog grla. U radu je prikazana baza znanja, koja uključuje "ergonomsko" znanje specifično za ručne alate. Dizajniranje ručke pneumatskog čekića koristi se kao primjer prakse, kako bi se pokazalo korištenje znanja iz područja ergonomskog dizajna, koje je ugrađeno u bazi znanja da bi se poboljšala ergonomska vrijednost proizvoda.

1. Introduction

In order to deliver suitable design solutions, design engineer has to consider a wide range of influential factors. Ergonomic value of the product is certainly one of the issues that need to be addressed. Less experienced designer could meet several problems to find ergonomically appropriate design solution. Although the existing ergonomic Computer Aided Design (CAD) software that is discussed in Section 1 can provide some assistance in ergonomic design evaluation, the designer still has to possess a substantial experience and knowledge in field of ergonomics in order to choose and carry out the adequate design actions to improve the ergonomic value of the product in reasonable time.

Product ergonomics is an interdisciplinary scientific discipline concerned with the understanding of interactions among humans and other elements of a system. In this context, the user has a central role in product development process [1]. Product ergonomics applies theory, principles, data and methods to optimize human well-being and overall system performance.

The ergonomic quality of a product can be defined by a match between anthropometric data and formal attributes. However, quality of ergonomics is not only based on anthropometrics, as the field of human factors has been realizing over the past thirty years [2]. Cognitive and experiential processes play a major role in deciding whether a design is usable, efficient, satisfying, easy to use, or comfortable.

On the other hand, ergonomic solution must not adversely affect other characteristics of the product. Among others, ergonomics is very much connected to aesthetic appearance of the product and seeking an optimal balance is a delicate manner [3]. Exactly that kind of skill a good designer needs to have: finding the optimal balance between the two aspects.

In order to support a decision making process when performing this task, a prototype of the intelligent advisory system, which is briefly presented in Section 3, is being developed. In continuation of this paper we will concentrate on ergonomic part of the system.

Ergonomic design knowledge is discussed in Section 4 by presenting important ergonomic design goals and corresponding design recommendations. Ergonomics is important for a wide range of products, from the most simple ones to those which are more sophisticated, as for example the modern agricultural tractors [4]. We have limited our research to certain group of products – hand tools, as representatives of ergonomically very important products that are manipulated with upper extremities like many household appliances, etc.

A case study of knowledge base application is presented in Section 5 and concluding remarks are given in the last section.

2. Existing ergonomic CAD tools

In the field of ergonomic CAD, the development process has focused on integrated tools based on three-dimensional modelling of the product and the human body that enable the use of ergonomic data originating from various sources, when performing ergonomic analysis of the product. This enables a designer to use a single analysis/simulation tool to evaluate and assess clearances, reach, visual requirements, and postural comfort at the earliest stages of design [5]. Moreover, it makes possible for a designer to incorporate the important features into designs, thus minimizing the risk of discomfort or even injuries way before a person ever physically encounters the product or working place that is subject of development.

Using an interactive interface, designers are able to manipulate both, the human form and the product design [6].

Two different approaches to developing such software tools have been taken [7]. One approach is oriented towards the development of so called stand-alone ergonomic CAD software with ergonomic assessment capabilities and a built-in tree-dimensional CAD module. The alternative approach leads to development of compatible ergonomic software based on special modules that enable ergonomic analysis within commercially available CAD systems, which are used to provide three-dimensional modelling and user interface.

Some of the best-known representatives of both groups of ergonomic CAD software are presented in the Table 1.

In continuation of this section more detail description emphasizing some application characteristics is given for each group in separate sub-section.

Table 1. Representatives of ergonomic CAD tools
Tablica 1. Predstavnici alata za ergonomski CAD

Stand-alone ergonomic CAD tools / Samostalni ergonomski CAD alati	Compatible ergonomic CAD tools / Kompatibilni ergonomski CAD alati
SAMMIE	SAFEWORK
APOLIN	MINTAC
TADAPS	ErgoSHAPE
Deneb/ERGO	HUMAN
ERGOMAN	RAMSIS
ErgoSPACE	ANYBODY

2.1. Stand-alone Ergonomic CAD Software

Stand-alone ergonomic software is applied independently of other CAD software used in product development processes. Thus, the user must learn terminology, command structures, and modelling techniques that are usually different from those in commercial CAD systems. Fortunately, many of these systems have the ability to import geometric models as modelled in other CAD tools, where the complexities of the models can be taken in consideration.

The working environment is composed of the product model and the model of a human that is assigned to perform virtual application of the product [8]. After modelling/import is finished, the parameters for various ergonomic analyses are set, and the analyses are carried out. The evaluation of the analyses results is the next step in the design process, where ergonomic satisfaction of the product needs to be evaluated. If remodelling of the product is needed, the whole cycle is repeated until the resulting model of the product does not satisfy ergonomic criteria. Even then, certain changes may still be necessary in order to improve other design requirements, as for example, aesthetics, manufacturability, etc.

2.2. Compatible Ergonomic CAD Software

Compatible ergonomic software has been designed for access within available commercial CAD systems, as for example [9] and [10]. These tools take the advantage of the designers' familiarity with the terminology, techniques, and command structures of commonly used CAD programs. The main advantage of these tools is the application of a single geometric model for all phases of the design process, which prevents many problems related to data transfer.

Similar to the application of stand-alone ergonomic CAD software, the development process starts with a concept design and usually an ergonomically-imperfect design candidate, which represent the starting point for compatible ergonomic CAD tool. The exact three-dimensional virtual model of the product is modelled using a geometric modeller of the commercial CAD software. When the model is finished, the ergonomic tool is run within the commercial CAD system, where the working environment and human model are prepared. The modelling is followed by assigning proper values to the ergonomic analyses parameters. It the next step, ergonomic analyses are carried out. Immediately after the results of the ergonomic analyses are evaluated, the product can be redesigned and remodelled in order to correct eventual ergonomic imperfection.

Alternatively, the process can be continued towards other analyses that need to be carried out for the model. The result of such multi-criteria analysis [11], conducted within single software environment is final design solution of the product that fulfils all ergonomic, mechanical, and other demands and conditions.

3. Intelligent support to ergonomic design process

Various advanced approaches have been investigated to improve product development process, such as those reported in [12], [13] and [14]. The need for integration of ergonomics into product design is evident for quite a long time now [15]. However, the need for knowledge-based decision support within ergonomic design process has been defined more recently. It is based on cognition that conventional ergonomic CAD tools do not meet the expectations of design engineers.

While they offer reasonable level of support in various ergonomic analyses [16], they fail to provide any kind of meaningful advice from engineering point of view in terms of design recommendations leading to better ergonomic value of the product, when appropriate.

In order to overcome this bottleneck and to round off a cognitive cycle [17] for continuous improvement of product's ergonomics, we are developing a prototype of an intelligent advisory system Oscar, based on expert design knowledge management.

Implementation of the intelligent support to the aesthetic and ergonomic design phase is presented in Figure 1. It is anticipated the product development cycle using intelligent advisory system would be very similar to the present conventional development cycle. The first main difference can be noticed in the concept design phase, where the intelligent advisory system should be used to improve the aesthetic and ergonomic value of the concept design solution.

The ergonomic analysis and aesthetic evaluation should be performed on the CAD model with more precise geometry definition. After that, the intelligent system could be used again to advice the user which redesign changes are possible to improve the ergonomic and/or aesthetic value of the product if applicable.

Possible logical frame of ergonomic knowledge management has been proposed by Du et al. at Computer-Aided Industrial Design & Conceptual Design conference in 2009 [18]. In the proposed frame the aesthetic appearance of the product is not considered as an influential parameter, which however is the case in

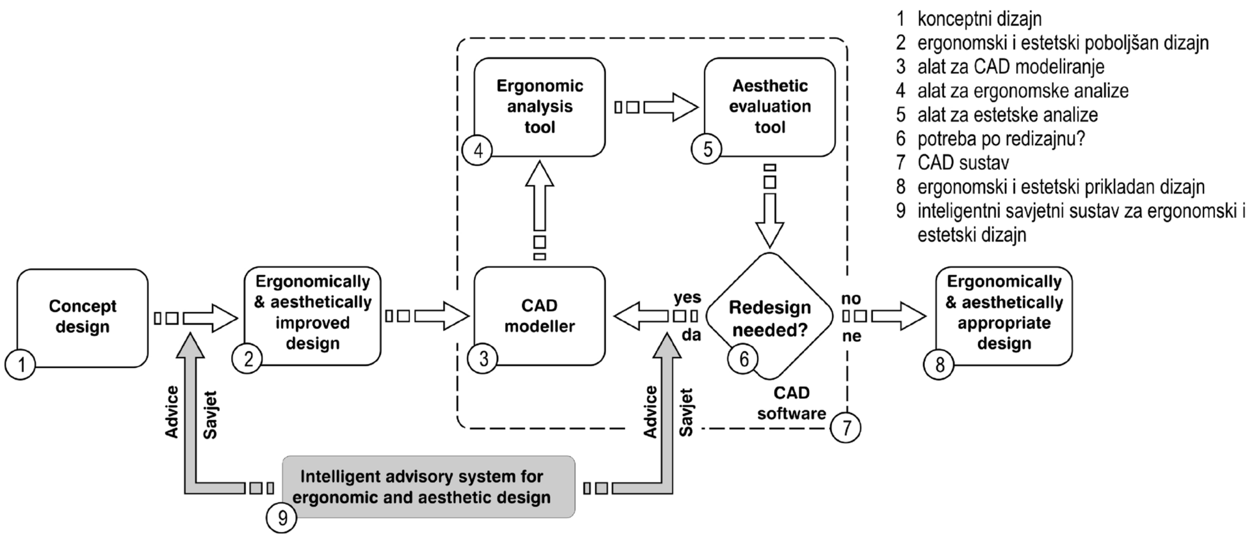


Figure 1. Implementation of intelligent support in design process

Slika 1. Implementacija inteligentne podrške u proces konstruiranja our system, as presented in Figure 2. Oscar is namely composed out of two sub-systems that can be applied in two different modes. We can use them independently from each other, or simultaneously and interdependent on the same design project. In the simultaneous mode, the task of the inference engine is not only to derive and propose recommendations for both, ergonomic and aesthetic design improvements, but also to synchronize and harmonize possible design solutions in order to find the optimal balance between the two aspects of the product being developed.

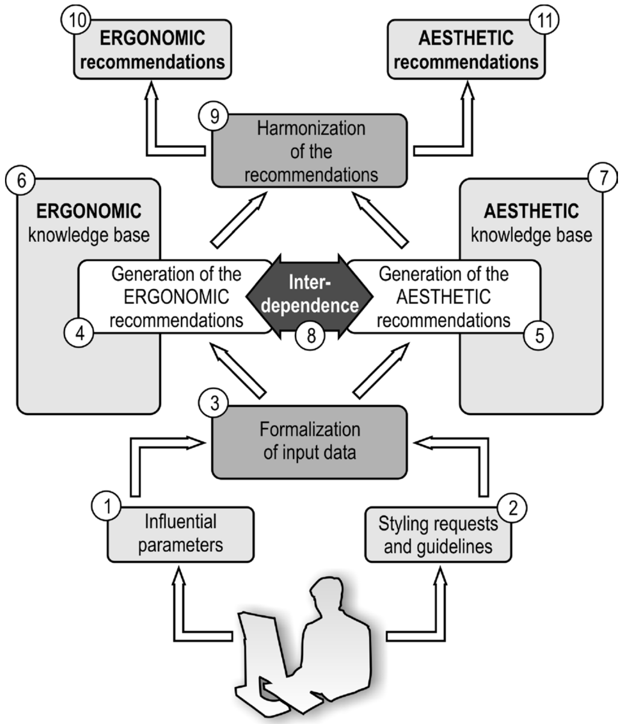
The intelligent decision support system Oscar is still a research prototype, and as such, a subject of intensive development, especially more subjective part of the system dealing with engineering aesthetics and aesthetic ergonomics [19]. On the other hand, the ergonomic part of the system, which is based on more objective ergonomic design knowledge built in the knowledge base of the system, is functional and thus, discussed in continuation of this paper in more detail.

4. Ergonomic design knowledge

The main focus of ergonomic design is compatibility of objects and environments with human factors. It seeks to harmonize functionality of the tasks with capabilities of humans performing them. Ergonomic design knowledge is extensive. It considers not only anthropometrics and biomechanics, but also cognitive issues. For this reason, we decided to limit our research on ergonomic design of hand tools [20].

Similarly to some other products that are manipulated with upper extremities, static and dynamic anthropometry, biomechanics and anatomy of the human hand needs to be taken into consideration [21].

Development of a knowledge base related to ergonomic design of hand tools has been carried out in three steps. First of all, all crucial ergonomic design goals were defined by studying literature and interviewing some human experts. In the next step, these goals have been associated with respective design recommendations that ensure a certain goal to be accomplished. Knowledge acquisition was again a combination of literature survey and transfer of human knowledge and experience. In the last step, the collected knowledge was organized and written in form of production rules to be used by the intelligent system. Exsys Corvid [22], a development environment for decision support systems, has been used to encode the knowledge into the knowledge base.



1 utjecajni parametari
2 zahtjevi i smjernice za stajling
3 formalizacija ulaznih podataka
4 generiranje ergonomskih preporuka
5 generiranje estetskihpreporuka
6 ergonomska baza znanja
7 estetska baza znanja
8 međuzavisnost
9 harmonizacija preporuka
10 ergonomske preporuke
11 estetske preporuke

Figure 2. Basic structure of the intelligent advisory system Oscar

Slika 2. Osnovna struktura inteligentnog savjetodavnog sustava Oscar

Different classes are interconnected with various attributes and their values in head of the rule in order to describe case specific situation, in which recommendations for product design that are listed in the body of the rule should be taken into consideration, as for example (a rule from Exsys Corvid):

```
IF:
    Define your Point of interest in this
    session: general ergonomics
AND:How old will the average user be: adult
AND:Define the tool to be considered: hand
    tool
AND:Estimated contact areas are: trigger(s)
THEN:
    Tissue compression has to be avoided.
       Confidence = 15
    Excessive forces have to be reduced.
    Confidence = 5
    Special care of Cognitive Ergonomics is
    needed.
       Confidence = 5
    [Ergo_Rec.ADD]
       Reduce resistance of tool activators.
    [Ergo_Rec.ADD]
       Consider anthropometry of the finger.
```

In the following sub-sections, the most important ergonomic design goals and respective design recommendations related to hand tools are presented. The rule shown here is an example how this knowledge is encoded in the system and refers to the case study discussed in the next section of this paper.

4.1. Dimensions and Configurations

In order to define appropriate dimensions and configurations to be respected in hand tools design, the anthropometrical data related to human hand are transformed into design recommendations (Table 2).

Table 2. Anthropometrical recommendations

Tablica 2. Antropometrijske preporuke

Attribute / Atribut	Value / Vrijednost
handle cross – section / presjek drške	round or oval / okruglo ili ovalno
handle diameter - power grip / premjer drške - snažni zahvat	min. Ø 32-45 mm
handle diameter - precision grip / premjer drške - precizni zahvat	min. Ø 7-15 mm
handle length / dužina drške	min. 100 mm
handle length - with gloves / dužina drške - s rukavicama	min. 114 mm
pistol grip handle angle / ugao drške kod pištoljskog zahvata	10° to 20° 10°do 20°
finger clearness / čistina za prste	min. 35 mm

Figure 3 shows in a graphic form the recommended dimensions for a handle that will be used in the next section as a case study.

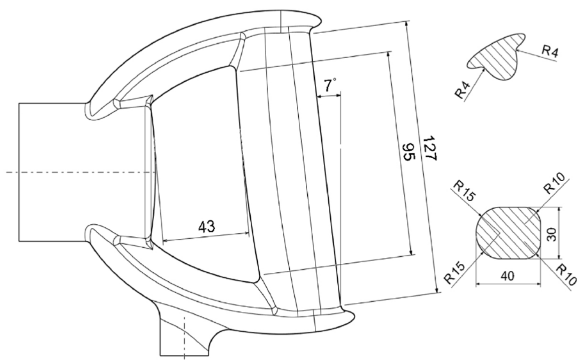


Figure 3. Recommended handle dimensions

Slika 3. Preporučene dimenzije ručke

4.2. Maintain Neutral Straight Wrist Position

All movements of the wrist, especially those cases in extremes of these movements, in connection with repetitive finger actions or prolonged forceful finger exertions, place extensive pressures upon the flexor tendons passing through the carpal tunnel. This may cause inflammation of tendon sheath and pressure upon median nerve and in consequence even serious injuries.

Bending the wrist, while performing the task, which requires repeated rotation or twisting of the forearm, can also stretch and pull the tendon connection at the elbow. Repeated stress at this connection can cause irritation and swelling, leading to so called tennis elbow. When the wrist is straight, tendons can slide easily through the sheath. It is thus very important to maintain the wrist in neutral straight position.

Recommendations:

- Use pistol grip for tools, which are used on vertical surfaces. The type of the grip used depends on the work piece height.
- Use inline cylindrical grip for tools, which are used on horizontal surfaces. Again, the type depends on the work piece height. For example, for the horizontal work piece in a femur level, the pistol grip is suitable.
- Use deviated handles, which maintain the straight wrist for tools for specific tasks.
- Provide adjustable handles for tools that will be used in several different positions.
- Use power tools instead of traditional tools for tasks that require highly repetitive manual motions.

4.3. Avoid Tissue Compression

Local pressure upon tissues of a palm or fingers may cause loss of circulation, damage nerves, leading to tingling of fingers; or damage tendons or muscles, leading to pain and difficult hand movement. This unsuitable pressure is caused by insufficient handle length (thickness) or hard surfaces on handles.

Recommendations (Figure 4)*:*

- Use handles of adequate length (thickness) that span the entire hand.
- Use contoured handles which spread the pressure over a large area (Figure 5).
- Use padding to soften the handle surface.

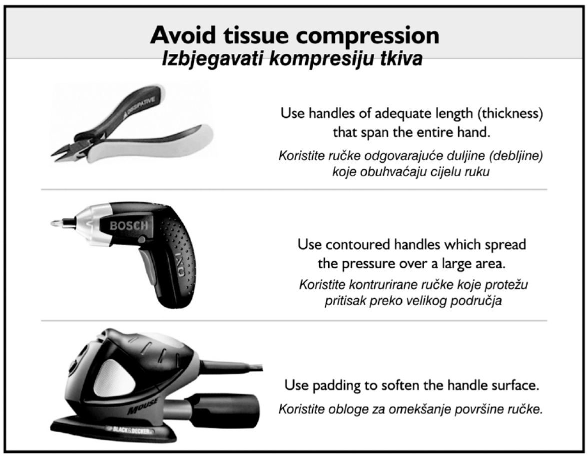


Figure 4. Systems' recommendations (screen shot)
Slika 4. Preporuke sustava (screen shot)

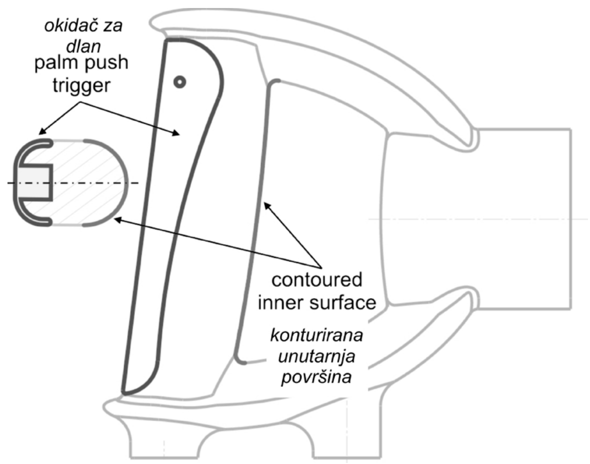


Figure 5. Design to prevent tissue compression
Slika 5. Oblik koji sprječava kompresiju tkiva

4.4. Reduce the Excessive Forces

Exertion of high finger forces, either prolonged or repetitive, can stretch and in turn fray tendons. This kind of damage can make it difficult for the tendon to slide through the tendon sheath, which can lead to further irritation and swelling. Irritation and swelling can lead to restriction of the tendon movement through the sheath, eventually causing so called trigger finger. Especially combination of both repetitive and prolonged motions can lead to permanent disorders, and carpal tunnel syndrome.

Excessive forces may also overload muscles and create fatigue and potential for injuries. Highly repetitive tasks which may not use so great force can also cause irritation. Contact with sharp edges of tools or bending the wrist greatly increases the hazard associated with the use of forceful finger exertions.

Recommendations:

- Use power grips (Figure 5) instead of forceful pinch grips with straight fingers. One can exert more force with the power grip than pinch grip.
- Use the appropriate grip size. To generate the most grasping force, design objects to a size that permits the thumb and forefinger to overlap slightly.
- Reduce resistance of tool activators (triggers, trigger lockers etc.).
- Use the alternative non-mechanical triggers (vacuum, optical etc.).
- Increase leverage within the tool. Add more fulcrums. Extend lever arm.
- Improve tool balance. Reduce tool length. Locate heavy masses such as motor, battery, etc. as close as possible to the wrist.
- Where relatively large force is needed to activate the tool (hydraulic or pneumatic power tools), use trigger levers for more fingers instead of single point trigger to spread the activating.
- Avoid sharp edges on triggers and handles.
- Add the second handle located near the front end of the tool to spread exertion between two hands. In this way the control of heavy tools and tools operating with large torque is also improved.
- Increase contact friction on handles by using slip resistant, nonporous and slightly compressible materials.
- Use a collar where the force is applied coaxially to the handle. It may reduce the grasping force.
- Use the expanding springs to prevent the constant need of opening handles.
- Use the power tools instead of traditional tools for tasks which require high excessive motion.

4.5. Ensure Proper Height for the Task

Working in position that implies the elbow raised and maintained above the shoulder height for prolonged periods can trap nerves and blood vessels under the bone and muscle, which leads to numbness and tingling in the hands, and can fatigue the muscles of the shoulder and upper arm. It is therefore required to design the tool in a way that ensures proper height of the task.

Recommendations:

- Design tool handles and other features to fit in the proper working height level.
- Reduce muscle exertion and improve control over the tool.
- For heavier manual work with the heavy power tools, design the tools for use at the hip level, with the tool

close to the body and the angle between the upper arm and forearm in range of 90°-120°.
- For precision work with lighter tools, design the tools for the use at the elbow level and higher.
- Use extended poles for work above the head.

4.6. Protect Against Vibrations, Heat, Noise

Local vibrations may cause circulation disorders, white fingers or other serious cumulative trauma disorders. Enhanced noise may increase fatigue and stress; and may cause problems of hearing. Hand may be affected by vibrations in range of 1,5-80 g and 8-500 Hz.

Recommendations:

- Improve the overall tool design taking into account the natural frequencies to decrease vibration distribution from the motor or other source of vibrations into other connected parts and handles.
- Use isolation mounts such as springs and rubber silent blocks between individual parts.
- Use damped tool handles.
- Use damping materials on a handle surface.
- Use heated handles where needed.
- Cover hot parts of the tool such as motors.
- Clean and adjust power tools periodically.

Remark: sound (noise) is a consequence of vibrations, actually vibrations transferred from the tool into an air and then into human ears; therefore same recommendations can be used analogously for decreasing the level of noise.

4.7. Reduce Static Load

Holding the same position for a period of time can cause pain and fatigue. The primary problem is duration. However, negative influence is additionally increased by high force or awkward posture.

Recommendations:

- Reduce the weight of the tool.
- Use tool supports.
- Improve tool balance. Reduce tool length. Locate heavy masses such as motor, battery, etc. as close as possible to the wrist.

4.8. Cognitive Ergonomics

Cognitive ergonomics deals with a mental interrelationship between the human and the product. The goal to be achieved by using design recommendations is to prevent mental overload and misunderstanding when using certain product – in our case the hand tool.

Recommendations:

- Use red colour for switch buttons or for warnings and dangers.
- Use vertical switches with the following meaning: up-ON, down-OFF.
- Turning a dial to the right increases the speed, torque or power.
- Use numbers: 1-slow....10-fast.
- Use the right hand to operate the trigger and other controls.

5. Case study

In order to demonstrate practical application of the ergonomic design knowledge built in the intelligent decision support system Oscar, a case study dealing with redesign of the pneumatic hammer handle has been carried out.

The goal of the project was redesign of the handle and new design of the casing for the pneumatic hammer presented on Figure 6. Basic edition of the existing pneumatic hammer was not equipped with body casing; simple rubber tubes were provided instead of body casing on customer request.

Pneumatic hammers are hand tools used for smashing and drilling hard materials. They are mostly used in field of civil engineering and mining industry. Pneumatic hammers belong to group of tools powered with compressed air and subgroup shock tools.

Figure 6. Existing pneumatic hammer handle
Slika 6. Postojeća ručka pneumatskog čekića

Pneumatic hammer is very useful tool for many purposes. Physical properties of air allow it to accumulate relatively big amount of energy, which in very important for the shock power of pneumatic hammer. Shock power is one of more important features of pneumatic hammer, as it is relatively high regarding to the weight of the tool itself [23].

The hammer that was chosen for the case study was underdeveloped from both, ergonomic and aesthetic point of view. The manufacturing company was aware of that, and took the opportunity using our innovative technologies to improve design of their product in order to increase their competitiveness [24].

One could argue that aesthetics is not important for such a tool. Yet, it has an important influence on user's cognitive comfort and emotional contentment. However, our primary goal for the case study, presented in this paper, was oriented into improvement of the ergonomic value of the tool with emphasize on the handle design.

Quality and usefulness of advice provided by the intelligent system depends on the quality of input parameters. This is why a lot of attention has to be dedicated to define them. Table 3 presents the most important influential parameters and their values as they were presented to the system.

Table 3. Most important input parameters

Tablica 3. Najznačajniji početni parametri

Parameter / Parametar	Value / Vrijednost
user information / info. o koristniku	male, 18-55 years old, average / muškarac, 18-55 godina, prosječan
place of use / mjesto upotrebe	constructing places, dust / gradilište, prašina
application direction / pravac uptrebe	mainly horizontal / uglavnom horizontalan
application technique / tehnika uptrebe	one or both handed, 1 operator / jedna ili dvo ručno, 1 operater
protective equipment / zaštitna oprema	gloves / rukavice
mech. characteristic / mehaničke karatweristike	solidness, stability, low weight / čvrstoća, stabilnost, mala težina
critical areas / kritična mjesta	rear handle, front hand support / zadnja drška, naslon prednje ruke
emotional contentment / emocionalno zadovoljstvo	solidness, reliability, power / čvrstoća, sigurnost, moč

In the next step, the knowledge base built in the system was applied to generate ergonomic design recommendations.

In the case study presented here, redesign recommendations proposed by the intelligent system Oscar can be summarized in three groups:

- change the shape and dimensions of the handle,
- change the cross-section of the handle,
- change the position of the handle.

Considering all recommendations based on the ergonomic knowledge built in the system and presented in previous section of this paper, including Figures 3 and 5, virtual model of the new pneumatic hammer handle was modeled (Figure 7). The form of the handle has been defined using parametrical values due to later adjustment assurance [25].

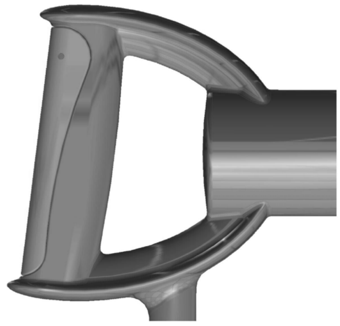


Figure 7. Virtual model of redesigned handle

Slika 7. Virtualni model novog oblika ručke

On the basis of the computer model of the handle, a prototype of the handle has been build using rapid prototyping technique 3D object printing. The prototype of the handle made in this way has been used for practical ergonomic evaluation by the users of the existing pneumatic hammers (Figure 8). Two connectors for the tube with compressed air were designed in order to find a better position in terms of tool balance when the tube is attached to it.

Figure 8. Evaluation using rapid prototyping

Slika 8. Evaluacija oblika pomoću modela brze izrade

The results of evaluation show, that the overall ergonomic value of the handle has been significantly improved by providing more space for fingers (also for a hand wearing a protective gloves), better wrist position, and better grip of the handle.

However, due to the prototype limitations, the evaluation of handle has not been performed during the work process itself (use of pneumatic hammer in practice). Future research work will also be oriented towards simulation techniques that will enable virtual evaluation of hand tool – user interaction, using principles of simulating nonlinear materials (i.e. human tissue) using cross-linked simulations [26-27].

6. Conclusions

Ergonomic design is a vital and complex part of product design process. In view of the complexity, multi-factors coupling and fuzziness of ergonomic knowledge, an intelligent support to ergonomic design in form of advisory decision support system is proposed.

In this context, the knowledge related to ergonomic design of hand tools has been collected, organised and encoded in form of production rules, which were found to be the most appropriate formalism due to their transparency and closeness with the human way of decision making process.

The knowledge built in the prototype of the intelligent system named Oscar is structured in form of different classes interconnected with various attributes and their values at the input side, while as the output of the system the user can expect (re)design recommendations leading to achievement of certain design goals that can improve the ergonomic value of the product (hand tool) being developed.

An industrial example was used as a case study to test the correctness, reliability and usefulness of the knowledge base. A rear handle of the pneumatic hammer was redesigned for this purpose using recommendations derived by the system. The redesigned handle demonstrates significant ergonomics improvements.

Upon these conclusions, it may be summarised that the intelligent decision support to ergonomic design process represent an added value to the existing ergonomic CAD tools that enable various ergonomic analyses, but fail to provide engineering advice on how to improve the ergonomic value of design candidate that is subject of ergonomic evaluation.

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