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Analysis of Faces' Accessibility for the Purpose of Modular Fixtures Design

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This paper describes the methodology for the identification of accessibility of faces of 3D model of the workpiece, for the purpose of its positioning and clamping, by use of developed software application. Software application is developed in SolidWorks environment with the purpose to design modular fixtures. Using the SolidWorks API, MS Excel, object-oriented programming language Visual Basic 6 and logic in the form of production rules and algorithms, the development of software application was executed. Identification of the accessibility of faces of 3D model of the workpiece is based on the identification of characteristic coefficients and generation of their values. The coefficient of accessibility of faces appears as a final result of conducted analysis of face`s accessibility of the 3D model workpiece. The results gained from this software application are used to generate points for the positioning and clamping in the process of modular fixtures design. Developed software application provides mathematical notation of the face`s accessibility for the adopted conditions and restrictions, which was verified on the particular workpiece.

Analiza pristupačnosti strana u svrhu projektiranja modularnih naprava

Izvornoznanstveni članak

Ovaj rad opisuje postupak za identificiranje pristupačnosti strana 3D modela radnog komada, u svrhu njegovog pozicioniranja i stezanja, korištenjem razvijene programske aplikacije. Programska aplikacija je razvijena u SolidWorks okružju u svrhu projektiranja modularnih naprava. Korištenjem SolidWorks API, MS Excel, objektno orijentiranog programskog jezika *Visual Basic 6* i logike u obliku produkcijskih pravila i algoritama, izvršen je razvoj programske aplikacije. Identifikacija pristupačnosti strana 3D modela radnog komada bazira se na identifikaciji karakterističnih koeficijenata i generiranja njihovih vrijednosti. Koeficijent pristupačnosti strane se pojavljuje kao krajnji rezultat provedene analize pristupačnosti strane 3D modela radnog komada. Rezultati iz ove programske aplikacije koriste se za generiranje točaka za pozicioniranje i stezanje u procesu projektiranja modularnih naprava. Razvijena programska aplikacija daje matematički zapis pristupačnosti strane za usvojene uvjete i ograničenja, što je verificirano na konkretnom radnom predmetu.

Keywords
Face accessibility
API - application program interface
Modular fixture
Accessibility coefficient
Functionality coefficient

Ključne riječi
Funkcionalnost strane
API - aplikativno programsko sučelje
Modularne naprave
Koeficijent prihvatljivosti
Koeficijent funkcionalnosti

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1. Introduction

Within the research [1], [2] methodology for assessing of workpiece faces` accessibility is defined, and it has been extended and improved in this paper. The basis of the improvement of the original idea is based on introduction of four characteristics steps during identification of workpiece face`s accessibility. The process of selection of optimum step has been developed during adoption of one of four generated solutions of workpiece face`s accessibility. A better insight of the of workpiece face`s accessibility status has been made by introduction of four steps in the process face`s accessibility identification for the purpose of possibility of positioning and clamping with components of modular fixtures.

Identification of face`s accessibility in one characteristic step (without introduction of variant coordinates) may generate the result which points to the fact that the positioning of the workpiece is not possible. Generated result can give a positive solution for the case of workpiece positioning by introducing variant coordinates. This significantly increases the possibility of realization of workpiece positioning and clamping process in relation to the original idea. The requirements

Symbols /Oznake

AC - accessibility coefficient,
- koeficijent pristupačnosti

AC_m - maximal accessibility coefficients ,
- maksimalni koeficijenti pristupačnosti

FC_u - face accessibility coefficient,
- koeficijent pristupačnosti strane

POV - value of test area, mm^2
- površina ispitne plohe

PST - coefficient of accessibility of neighboring points
- koeficijent pristupačnosti susjednih točaka

S_1 - coefficient of the position of the test area in relation to the selected face,
- koeficijent pozicije ispitne plohe u odnosu na izabranu stranu

S_2 - obstruction coefficient of the test area
- koeficijent opstrukcije ispitne plohe

S_3 - coefficient of matching test area with the selected face,
- koeficijent podudaranja ispitne plohe s izabranom stranom

T - side length of the test area,
- dužina stanice ispitne plohe,

for the possibilities research of automation of design process planning phase, which relate to the "choice and / or design of the fixtures" are evident [3], [4], [5], [6].

Automation of fixtures design is a very important link in the chain of complete automation of process planning design. Out of great number of fixtures types, modular or aggregate fixtures have an increasingly important role in the production process [7], [8]. Because of its modular structure and concept, this type of fixtures is suitable for design automation. Time analysis issue has a significant influence in the design of fixtures, because the design of fixtures can usually be started only after a complete definition of the process planning. It is estimated that out of the total time that the designer has available for designing of process planning, 25% on average goes for the design of fixtures [3], [4], [8].

The above facts indicate that automation of modular fixtures design significantly increases the level of automation of process planning design. Therefore, the requirements are expressed for the introduction of new technologies into the process of modular fixtures design, which aim to reduce time and cost of design and production.

To this end, informational technologies have been developed that led to the formation of completely new field in the area of automation of fixtures design called - computer aided design of fixtures (CAFD - Computer Aided Fixture Design) [1].

These technologies are based on the identification of CAD models of workpieces for which fixtures for positioning and clamping are to be designed. Therefore, it is significant to automate identification of faces of 3D model workpiece for the purpose of automation of workpiece positioning and clamping [2].

2. The structure of application for the analysis of faces' accessibility

Software application developed within SolidWorks [9] software system with the use of production rules [10], [11], programming language VB6 and MS Excel.

The basic structure of the developed application for the identification of faces' accessibility of the 3D model workpiece is shown in Figure 1, and the flowchart of the process development is shown in Figure 2 [12].

The developed application is used for identification of accessibility of the planar faces of CAD model or those that have a constant vector of the normal different than (0,0,0).

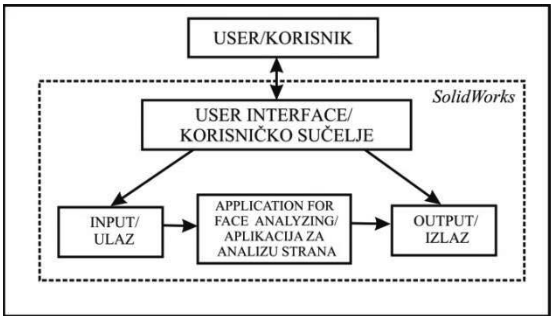


Figure 1. Basic structure of developed application

Slika 1. Osnovna struktura razvijene aplikacije

The basic idea that is implemented through the application for identification of faces' accessibility of the CAD model is based on examination of the face configuration from the standpoint of appearance of new openings or new contours on it.

The existence of such features (holes, bosses, fillets) prevents the setting up of modular fixtures components onto the observed face of the workpiece.

According to the flowchart of the process development within the developed application (Figure 2), CAD model is imported as a first step and then the user selects a face in an interactive manner. Developed application does the analyses whether the selected face has the normal vector. If so, the application continues with the analysis via calculations of face`s accessibility in an automated manner, if not, the application stops working. After the calculation of coefficient of face`s accessibility, the application generates results.

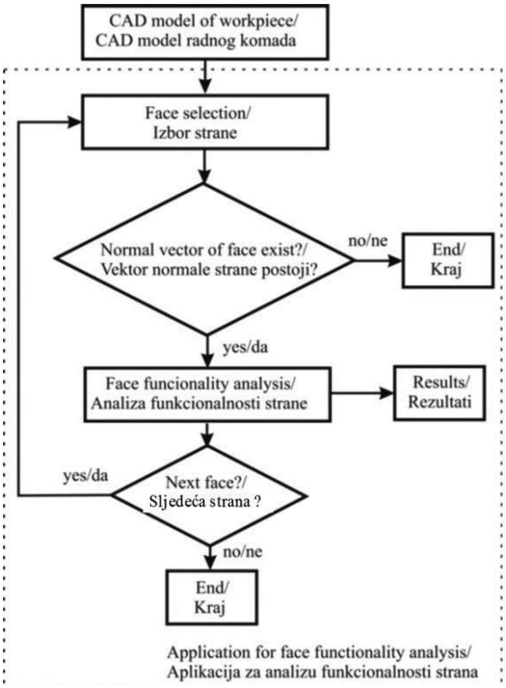


Figure 2. Flowchart of the process development within the developed application

Slika 2. Dijagram toka odvijanja procesa u okviru razvijene aplikacije

If it is necessary to identify the accessibility for another face, it is necessary to select a face and repeat the procedure described previously. After analyzing the face`s accessibility and generating results, the application finishes its work.

The mathematical apparatus on which application work of is based is presented in detail in [12] and the basic quantities that are necessary for understanding application functioning are presented in this paper.

The application for the analysis of planar faces` accessibility for workpiece positioning or clamping provides output in terms of accessibility indicators (AC - accessibility coefficient) of face`s corresponding segment in the form of numerical value between 0 and 2. Calculation of accessibility coefficient (AC) is based on the identification of four coefficients as follows [1]:

- The coefficient of the test area position in relation to the selected face - S_1;
- Coefficient of test area obstruction - S_2;
- Coefficient of matching test area in relation to the selected face in mm^2 - S_3;
- Coefficient of accessibility of neighboring points - PST;

Calculation of face`s accessibility coefficient is done on the basis of relation (1):

$$AC = S_3 + PST \tag{1}$$

S_1 coefficient, depending on the position of the test area in relation to the observed face of the workpiece CAD model generates values for three corresponding cases as shown in figure 3.

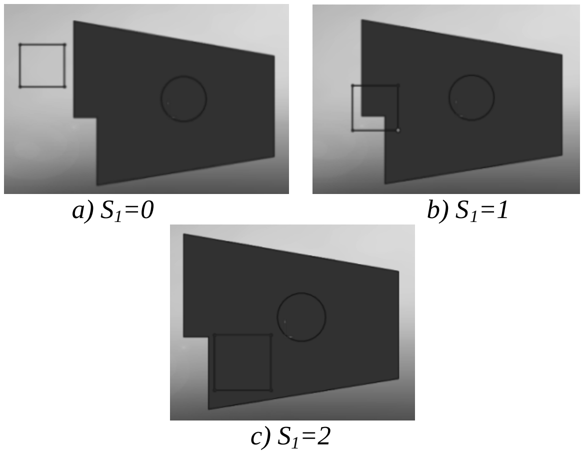


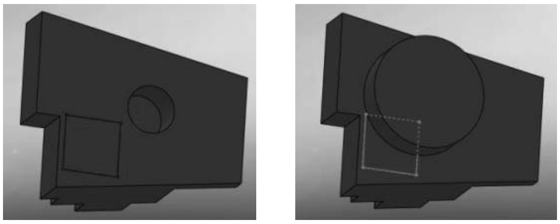
Figure 3. The positions of the test area and the values of the coefficient S_1

Slika 3. Pozicije ispitne plohe i vrijednosti koeficijenta S_1

The coefficient of the test area position in relation to the observed face generates value S_1=0 when the position of the test area contour falls outside the outer contour of the observed face (Figure 3.a). The value of S_1=1 is generated when the test area contour is cutting the contour of the observed face (Figure 3.b), while S1=2 is generated in case when the whole test area contour is in the contour of the observed face of workpiece CAD model (Figure 3.c).

The coefficient of obstruction of the test area S2 can take two cases. The first case (Figure 4.a) is defined by the condition when the test area is not obstructed by other faces or a solid model of the workpiece.

In that case, the coefficient of obstruction generates a value of S_2=0, otherwise when the test area is obstructed by the solid workpiece model, the coefficient of obstruction S_2=1 (Figure 4.b). Identification of the coefficient of test area obstruction is performed by use of SW tools: Extrude and Interface detection.



a) $S_2=0$ *b)* $S_2=1$

Figure 4. The positions of the test area and the values of the coefficient S_2

Slika 4. Pozicije ispitne plohe i vrijednosti koeficijenta S_2

S_3 coefficient depending on matching of the test area in relation to the observed face exists only in case when the coefficients S_1 and S_2 have values $S_1 \neq 0$ and $S_2=0$. In that case the calculation of the coefficient S_3 is performed on the basis of relation (2):

$$S_3 = \frac{POV}{T^2} \tag{2}$$

Where:
POV- is value of matching of test area in mm^2
T – is length of face of test area in mm

The case in which there is a coefficient of test area matching in relation to the observed face of the workpiece is shown in Figure 5 in the form of hatched surface.

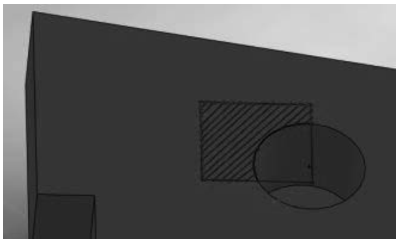


Figure 5. The case of the existence of the coefficient of S_3

Slika 5. Slučaj kada koeficijent S_3 postoji

In all other cases, the coefficient S_3 does not exist or is equal to 0, which results in the fact that the corresponding position of the test area in comparison to the observed face of the CAD model is unavailable for the positioning of components of modular fixtures.
Coefficient of accessibility of neighboring points (PST) indicates the accessibility of the segment at the point Pc taking into account the surrounding area of point of Pc (Figure 6). The space around the point Pc is space 3x3 of test area, which contains 8 points from P_1 to P_8. After the calculation of accessibility coefficients S_1, S_2 and S_3, the coefficient of the accessibility of adjacent points is calculated on the basis of relation (3):

$$PST(u,v) = \frac{1}{8}\sum_{i=1}^{8} S_{3,i} \tag{3}$$

Where:

$$S_{3,i} = \begin{cases} \dfrac{POV}{T^2}, S_{1,i} \neq 0 \wedge S_{2,i} = 0 \\ 0, S_{1,i} = 0 \vee S_{2,i} = 1 \end{cases}$$

P_4 o $(u-1, v+1)$	P_3 o $(u, v+1)$	P_2 o $(u+1, v+1)$
P_5 o $(u-1, v)$	P_c o (u, v)	P_1 o $(u+1, v)$
P_6 o $(u-1, v-1)$	P_7 o $(u, v-1)$	P_8 o $(u+1, v-1)$

Figure 6. Display of area 3x3 for the purpose of coefficient calculation PST

Slika 6. 3x3 oblast u svrhu proračuna koeficijenta PST

If the sum of the values of all accessibility coefficients is greater, the observed face for positioning and clamping is more suitable for the execution of automated process of positioning and clamping using components of modular fixtures.
Analysis of the face`s accessibility for positioning "from the bottom" is done using a standard test area of 50x50 mm. The reason for the use of this area lies in the fact that the contact area of components of modular fixtures for positioning in most cases can be inscribed into the chosen test area.
The process of face`s analysis for positioning "from the bottom" is done in four characteristic steps that are shown in Figure 7 [12].
In the first step of the analysis is done with the initial coordinates (0,0) which correspond to the initial position of the test area, which is used for testing of observed face. In the second step, the initial coordinates of the test are shifted to position (0,25), then in the third step (25,0) and in the last step to position (25,25). The reason for introducing the four steps of analysis lies in the fact that the application is developed for modular fixtures with standard distance of the holes on the plate (as well as on other components) measuring 50 mm. The developed tool can also be easily applied to arbitrary distances.
Obtaining the results for each of the four cases, the continuation of analysis is done in the form of the evaluation procedure of specific cases. The evaluation shows which of four cases generates the maximum value that is which of four cases provides better accessibility of the chosen surfaces, is based on the relation:

$$FC_u = \sum_{i=1}^{n} ACm_i \tag{4}$$

Where:

FC_u - is the accessibility coefficient of the whole face,
ACm_i – are accessibility coefficients whose value exceeds 50% of the maximum value of AC for each of the points on the observed surface.

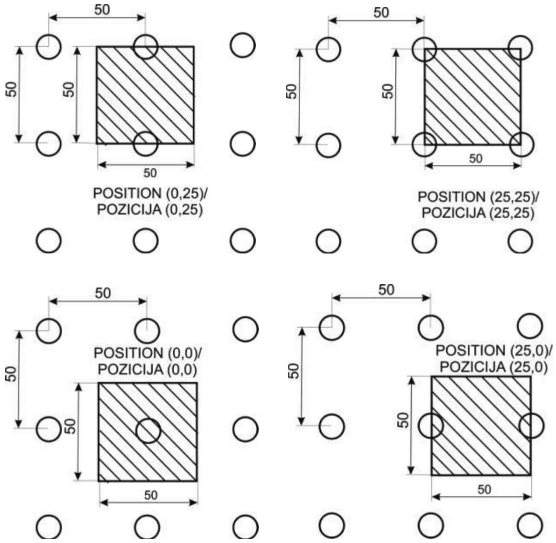


Figure 7. Typical cases in the analysis of the face

Slika 7. Karakteristični slučajevi pri analizi strane

The observed case whose value of FC_u is at maximum , is adopted as a case whose step moving coordinates, above mentioned, give the greatest chance for positioning of the components of modular fixtures to an analyzed face. In other words, the chosen case means that for the corresponding moving coordinates of the workpiece in relation to the initial position, the accessibility of the analyzed face has a maximum value. After the performed analysis of the faces' candidates for positioning "from the bottom ", as well as gained results from the analysis, using the algorithm for selection of the best case, the points on the observed face that become the points of contact with the modular component of positioning fixture are chosen.

The analysis of the accessibility face for positioning "from the side" as well as analysis of the face for clamping shall be made after the selection of points for positioning "from the bottom" and the fixing of the workpiece in relation to the base plate of the modular fixture.

Developed application for identification of planar faces' accessibility allows the user to configure and select required distance and dimensions of the test area by which the analysis (tests) of the selected face of the workpiece is done. A dialog window to set the tool for analysis of planar faces' accessibility is shown in Figure 8.

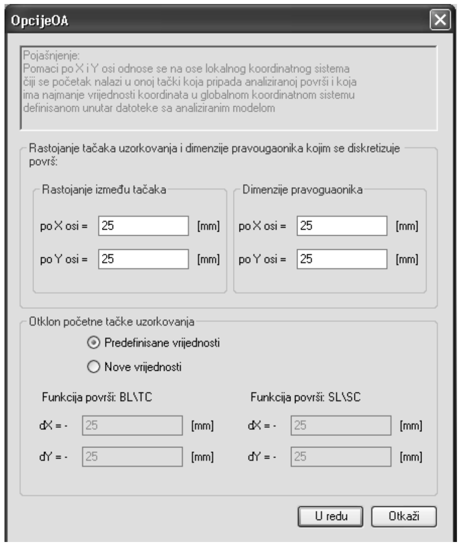


Figure 8. The dialog window for configuration of application parameters

Slika 8. Izbornik za podešavanje parametara u okviru aplikacije

3. Verification of the developed software application

Developed software application for analysis of the accessibility of selected planar faces of CAD model was verified on example of the workpiece shown in Figure 9.

Figure 9. The workpiece

Slika 9. Radni predmet

In this case the chosen face of the workpiece CAD model represents the face for "positioning from the bottom".

The analysis of the observed face`s accessibility is done by selecting and running the developed software application in an automated manner. A network of test points was generated, later followed by test area during the process of identification of observed face`s accessibility (Figure 10).

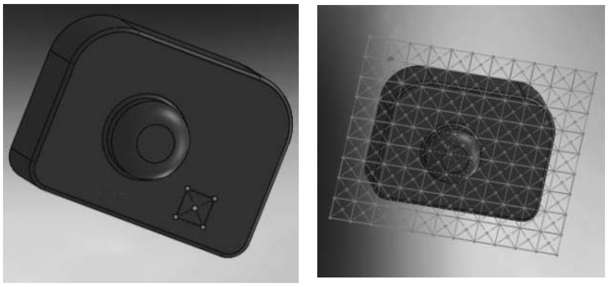


Figure 10. Details of the accessibility analysis process

Slika 10. Detalji procesa analize funkcionalnosti

Overall analysis procedure is repeated for the four cases defined above. Analysis of selected face`s accessibility selected case no. 3 with step moving coordinates (0,25), according to Table 1. For the chosen case the overall accessibility coefficient of the observed face has the greatest value.

Table 1. Typical cases and FC_u values for observed face

Tablica 1. Slučajevi i vrijednosti FC_u za promatranu stranu

Case number / Slučaj br.		Step moving coordinates / Koordinate koraka
1.	26,293	(0,0)
2.	24,342	(25,0)
3.	27,876	(0,25)
4.	21,470	(25,25)

Table 2 shows the values of the accessibility coefficients for "case 3" for each analyzed point on the observed face.

Table 2. The values of accessibility coefficients for the selected case 3

Tablica 2. Vrijednosti koeficijenta pristupačnosti za slučaj 3

PA	u										
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	0.000	0.000	0.256	0.525	0.582	0.583	0.583	0.566	0.363	0.000	0.000
	0.000	0.256	0.945	1.139	0.936	0.937	0.937	1.420	1.464	0.552	0.000
	0.000	0.525	0.743	0.722	0.250	0.250	0.750	1.245	1.789	1.025	0.000
v	0.000	0.582	0.790	0.250	0.000	0.000	0.250	1.250	1.836	1.082	0.000
	0.000	0.583	1.042	0.500	0.000	0.000	0.500	1.250	1.837	1.083	0.000
	0.000	0.510	1.310	0.446	0.446	0.446	0.446	1.587	1.688	0.788	0.000
	0.000	0.252	0.885	0.830	0.508	0.508	0.833	1.083	0.988	0.404	0.000
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

The values of the AC entering further analysis for selection of points on the workpiece that are in contact with modular components are emphasized. The choice of the number and arrangement of the contact points of modular components, and observed face of the workpiece depends on the typical pattern and model of positioning and clamping.

Gained results are automatically generated using MS Excel tool that is integrated into the developed software application in the form of Table 2 and the diagram shown in Figure 11.

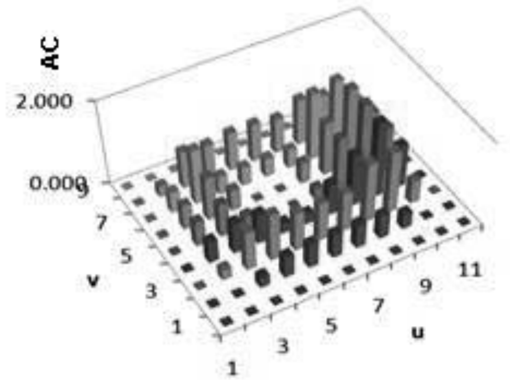


Figure 11. Histogram of the accessibility coefficient for the selected case 3

Slika 11. Histogram koeficijenata pristupačnosti za slučaj 3

4. Conclusion

This paper presents software application for identification of the accessibility of planar faces of the 3D model workpiece, during the design of modular fixtures. The result of the identification of faces` accessibility of the 3D model workpiece was implemented for the purpose of automation of positioning and clamping of the workpiece applying modular fixtures. Practical use of application for identification of faces` accessibility is possible in the process of positioning and clamping of the workpiece in CAPP/CAM systems for machining and welding processes. Additionally, it is possible to identify points for positioning and clamping of workpieces in other areas of application of CAD/CAPP/CAM technologies, such as rapid prototyping in medical applications, on a similar principle.

Developed software application for analysis of accessibility of selected planar faces of CAD model is verified on the example of the specific workpiece.

Gained results were automatically generated using MS Excel applications, and they provide values of accessibility coefficients, which indicate the points on the observed face of the workpiece into which it is possible to optimally set components of modular fixtures for positioning and clamping.

Developed software application, which is based on methodology for identification of faces` accessibility of 3D model workpiece with the purpose of its positioning and clamping, makes a contribution to the automation phase of design of process planning's, which refers to the "selection and / or design of fixtures".

The directions of future researches in this field may be routed to identification of faces` accessibility of other forms of faces of the workpiece (rounded, complex), integration with the system for optimization of selected contact points of fixtures` components and the workpiece (by system based on FEM analysis), tolerances analysis and positioning and clamping errors.

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