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Research Article

Customized Modeling and Manufacturing of Cranioplastic Implant using Rapid Prototyping

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Abstract

The most interesting and challenging applications of rapid prototyping technologies are in the field of medicine. Rapid Prototyping medical models have found application for planning treatment for complex surgery procedures, design and manufacturing of implants. This study explores and presents the procedure for making medical models using RPT, medical rapid prototyping technologies application in different fields of medicine. The selection of RP/RT technique is a central element of the life cycle of product development, effectiveness and success. RP/RT must be selected to satisfy the requirement of the job. A suitable selected technique contributes to the setup time, build speed, costs and quality in terms of surface finish, accuracy and strength. Fuzzy logic approach is one way for the optimum selection of RP/RT technique, since it translates subjective and qualitative evaluated criteria into numerical measures. Implement of fuzzy theory in the selection of the best rapid prototyping technique for a cranioplastic implant project.

Keywords: *Polyether ether ketone, RPT, Fuzzy logic, Fuzzy set, Fused deposition modeling*

1. Introduction

The possibility of exact preoperative, non-invasive visualization of the spatial relationships of anatomic and pathologic structures, including extremely fragile ones, size and extent of pathologic process, and of precisely predicting the course of surgical procedure, allows the surgeon to achieve considerable advantage in the preoperative examination of the patient and to reduce the risk of intraoperative complications, all this by use of virtual surgery (VS) or diagnosis per via 3D models. It could be done by using patient's images created for diagnostic purposes. By use of DICOM protocol, not only image recordings but all general data of the patient, that have previously been entered onto the diagnostic device console as well as all data on the device setting during patient's image production are transferred from the diagnostic device to computer systems (Pero Raos, et al, 2005).

Concerning the implants, medical models obtained by RP are normally used indirectly, as masters, to produce prosthesis in biocompatible conventional materials (e.g. Titanium, Cobalt- Chrome alloys, medical-grade Aluminium, medical-grade Silicone, PolyMethylMethAcrylate, PolyEtherEtherKetone etc.) mainly by casting and spray metal molding. However, RP technology has the ability to fabricate models with complex geometric forms, and so is very suitable to reproduce the intricate forms of human body. By using of RP models, visualization of intricate and hidden details of traumas by surgeon is enhanced.

The majority of the references found in literature on this subject are concerned with the production of medical models via Stereolitography (SLA). However, SL medical models, unfortunately, cannot be used inside the human body, as direct implants, due to the resin toxicity, which creates concerns about the long-term biocompatibility of SLA models. Nevertheless, the range of applications of those models is very large (Mandar M. Deoa, et al, 2013). Some recent researches aiming to improve the use of RP in the production of medical implants are directed toward producing implants of biocompatible materials directly in the RP process.

1.1 RPT in Medical Field

Rapid prototyping is the automatic construction of physical objects using solid freeform fabrication. The first technique for rapid prototyping became available in the late 1980s and was used to produce models and prototype parts. Rapid prototyping takes virtual designs from Computer Aided Design (CAD) or animation modeling software, transforms them into thin, virtual, horizontal cross-sections and then creates each cross-section in physical space, one after the next until the model is finished. Each rapid prototyping platform uses the same principles of slicing, layering and bonding to build parts (Ludmila, et al, 2012).

Several research institutions and commercial organizations have integrated Computer-aided Design (CAD) and Rapid Prototyping (RP) systems with medical

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imaging systems to fabricate medical devices or generate 3D hard copy of these objects for use in surgical rehearsal, custom implant design and casting. In biomedical applications, the objects normally already exist physically (Ian Gibson, et al). Prior to building, this highly complex data needs extensive pre-processing to provide a format that a CAD program can utilize, before transferring to an RP system.

1.2 Computed Tomography

A computed tomography (CT) image is a display of anatomy of a thin slice of body by acquiring and reconstructing the images from multiple X-ray absorption measurements mad around, the body's periphery. These CT images are free from superimposing tissues and are capable of much higher contrast due to elimination of scatter.

The fundamental concept is that internal structure of an object can be reconstructed from multiple projections. The purpose of CT scanning is to take a large number of data along a thin line of two dimensional transverse sections and reconstruct the structure within that slice (Text of Radiology).

Each pixel on CT image represent a small volume element called Voxel within imaginary slice of the body part examined. Therefore, 2D dimensional CT images corresponds to a 3D section of patient i.e. 3-dimension are compressed into two. The average linear attenuation coefficient of each voxel has been derived by computation from series of measurements collected by CT scanner. Each rays or data point therefore follows a basis equation.

$$\mathbf{I}_{(x)} = \mathbf{I}_0 e^{/\mu x} \text{ or } e^{/\mu x} = \frac{\mathbf{I}_0}{\mathbf{I}_{(x)}} \text{ or } \mu x = \log_e \frac{\mathbf{I}_0}{\mathbf{I}_{(x)}} \quad (1)$$

1.3 Fuzzy logic

Precision and certainty carry a cost. In soft computing, tolerance and impression are explored in decision making. The exploration of the tolerance for imprecision and uncertainty underlies the remarkable human ability to understand distorted speech, decipher sloppy handwriting, comprehend nuances of natural language, summarize text, and recognize and classify images. With FL, we can specify mapping rules in terms of words rather than numbers (Timothy 2010).

Computing with the words explores imprecision and tolerance. Another basic concept in FL is the fuzzy if–then rule. Although rule-based systems have a long history of use in artificial intelligence, what is missing in such systems is machinery for dealing with fuzzy consequents or fuzzy antecedents. In most applications, an FL solution is a translation of a human solution. Thirdly, FL can model nonlinear functions of arbitrary complexity to a desired degree of accuracy (Samir Khrais, et al, 2011). FL is a convenient way to map an input space to an output space. FL is one of the tools used to model a multi input, multi output system.

2. Process selection process

2.1 Fuzzy set and relations

Fuzzy set theory introduced by Zadeh (1965) has been implemented in many research areas. The theory states that if X is a collection of objects presented by x, a fuzzy set an in X is a set α of ordered pairs defined as follows:

$$\alpha=\{(x, \mu_\alpha(x)) | \; x \in X\} \quad (2)$$

where $\mu_\alpha(x)$ is the membership function of x in α, which maps $X \rightarrow \{0, 1\}$.

As the membership value of $\mu_\alpha(x)$ gets closer to unity, it will be more certain that x belongs to α.

Complementation:
α and β are complementary if $\mu_\alpha(x) = 1 - \mu_\beta(x)$ (3)

Equality
α is equal to β if $\mu_\alpha(x) = \mu_\beta(x)$ (4)

Intersection
$$\mu_{(\alpha\cap\beta)}(x)=\text{Min}\{ \mu_\alpha(x),\mu_\beta(x)\} =\mu_\alpha(x)\cap \mu_\beta(x) \quad (5)$$

Union
$$\mu_{(\alpha\cup\beta)}(x)=\text{Min} \{\mu_\alpha(x), \mu_\beta(x)\} =\mu_\alpha(x)\cup\mu_\beta(x) \quad (6)$$

Binary fuzzy relations:
$$R=\{((x,y),\mu_R(x, y))|(x. y)\in X\times Y \} \quad (7)$$

2.1 Product

Consider two fuzzy sets a and b from different universes X and Y. The Cartesian product (α × β), in the universe X ×Y, is defined by:
$$(\alpha \times \beta) (x,y)=\min\{ (\alpha(x),\beta(y))|(x,y)\leq X \times Y\} \quad (8)$$

2.2 Max-Min composition

Consider a fuzzy set a in the universe X and a relation R between X and Y universes. Then the max–min composition α R of a and R is a fuzzy subset of Y defined by:
$$(\alpha .R) (y) = \min \{\alpha(x), R(x, y)\} \text{ for all } y\epsilon Y \quad (9)$$

Therefore from the previous discussion we can obtain the following:

$$\alpha .(\alpha\times\beta)=\beta \quad (10)$$

$$\alpha (\alpha\times\beta)(y) = max_{\times\in X} \min \{ \alpha(x),\min\{\alpha(x), \beta(y)\}\} \quad (11)$$

2.3 Fuzzy if–then rules and Fuzzy reasoning

If–then rule are mathematical representation of human knowledge. Every ''if–then'' rule represents cause and effect where both cause and effect are fuzzy phrases. The level of uncertainty in the cause phrase is reflected in the evaluation of the cause in the IF–THEN statement. The fuzzy cause and effect phrase take the form:

If the variable X is α, THEN the variable Y is β.
If–then rule can be mathematically represented, as proposed by Mamdani and Assilian, by Cartesian product R of the fuzzy sets a and b, i.e., $R = \alpha \times \beta$.
If we have several IF–THEN rules R_i for i = 1, 2, . . , n between X and Y where each IF–THEN rule takes the form:

If X is a_i, then Y is β_i
Then, $R_i = a_i \times \beta_i$ assumes that all fuzzy values are complementary, such as function

$$\sum_{i=1}^{n} a_i = 1 \tag{12}$$

The set of rules could then be combined into one rule R

$$R = \bigcup_{i=1}^{n} Ri \tag{13}$$

The inference rule $\beta = \alpha$ R is then applied.

2.4 Linguistic variables

Linguistic variables may be introduced in many ways. Linguistic expressions of color could take many values such as red, yellow, green, blue, and could appear on the pressure dial as logical conditions. A predicate function that could have many interpretations, Color(y) could be used to represent the pressure value. For example, if y is the pressure value and y [0 psi–20 psi] then color(y) = green.

To make things discrete we assume that each fuzzy value is rated by a number in the set Y = {0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1}. In this paper the value ‘‘good’’ will be defined as the fuzzy set:

‘‘good’’ = [0 0 0 0 0 0 0 0 0 0 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

The value “poor” is defined by
“poor” = [1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0 0 0 0 0 0 0 0 0 0 0]

And the value “moderate” is defined as
“fair” = [0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1]

The combination of such typical fuzzy sets highlights the properties of Normality, Unimodality, Complementarily and Partition of Unity. We may notice that the potential different linguistic variables are almost infinite. For instance, the linguistic variable ‘‘not fair” means ‘‘poor” while ‘‘not good” may turn out to be ‘‘fair”. Similarly, ‘‘short”, ‘‘bad,” and ‘‘difficult” all may be streamed to the same values. It is left to the reader how linguistic compositions can be interpreted to typical forms. In addition, we may emphasize a set by taking the squared values of its elements if it was appended by the word ‘‘very good”.

‘‘very good”.= [0 0 0 0 0 0 0 0 0 0 0 0.01 0.04 0.09 0.16 0.25 0.36 0.49 0.64 0.81 1]

“Excellent” is taken by cube value of “good”. “Excellent” = [0 0 0 0 0 0 0 0 0 0 0 0.001 0.008 0.027 0.064 0.125 0.216 0.343 0.512 0.729 1]

2.5 Dynamic Factors

For each factor F listed in Table 1 with property value PV, linguistic evaluation value E, and rapid prototyping technique RP the following statement could be read by applying fuzzy rules as:

A (F, E, RP)(y): If factor F has value PV, then the rapid prototyping technique RP is E where A (F, E, RP)(y) represents the factor F with value (PVF) and the rapid prototyping technique (RP) with evaluation (E).

Where PV takes values ‘‘high’’, ‘‘moderate’’, ‘‘short’’, ‘‘long’’, ‘‘low’’ and so on. In addition, E takes the values of ‘‘poor’’, ‘‘moderate’’, ‘‘very good’’, etc.

The Cartesian product could be used to represent A (F, E, RP)(y) as follows:

$$A\ (F, E, RP)\ (y) = PV_F\ (x) \times E\ (F, PV, RP)\ (y) \tag{14}$$

where PV, and E are two different fuzzy sets living in the two different universes X, and Y. As a result, we have:

$$A\ (F, E, RP)\ (y) = PV_F\ (x) \times E\ (F, PV, RP)\ (y) = \min\ \{PV_F\ (x) \times E\ (F, PV, RP)\ (y)\} \tag{15}$$

Now, rule listed in previous section can combine the dynamic factor F, the rapid prototyping technology RP, and the rule A (F, E, RP) (y) into R F,RP as presented below:

$$R_{F,RP}\ (x, y) = U_{PV}\ A\ (F,E,RP)\ (x,y) = U_{PV}\ PVF\ (x) \times E\ (F,PV,RP)\ (y) \tag{16}$$

Using the combination rule, the evaluation for every rapid prototyping technique with respect to assigned dynamic factor could be calculated by the following equation:

$$E\ (F, PV, RP)\ (y) = = PV_F\ (x)\ R_{F, RP}\ (x, y) \tag{18}$$

2.6 Collective evaluation

In order to combine all evaluations based on each factor F in one overall evaluation, the following equation is used:

$$E\ (RP) = \cap_F\{(w(f)c\ \cup E\ (RP)\ \} \tag{19}$$

where w(f) is the experience evaluation weight for each factor F with values between 0 and 1. As w(f) becomes smaller the complement becomes larger, which decreases the effect of the fuzzy set on the combined evaluation E(RP). The best probable overall evaluation is determined by using the Centre-of-Gravity defuzzification method to calculate for every rapid prototyping technique its evaluation center EC (RP).

$$\text{Where, } EC\ (RP) = \frac{\sum_{x \in X} X.E\ (RP)(x)}{\sum_{x \in X} E\ (RP)(x)} \tag{20}$$

The rapid prototyping technique with the highest EC is then selected for the intended project.

Table 1 linguistic evaluation of alternatives

Criteria	Sub criteria	Lineament	Stereolithography	PolyJet	Selective Laser Sintering	Fused Deposition Modelling	3D Printing	Electron Beam Melting
F1. Attributes	Surface finish	High	Fair	Fair	Poor	Fair	Poor	Good
		Medium	Good	Fair	Fair	Good	Fair	Good
		Low	Excellent	Good	Good	Good	Good	Excellent
	Layer thickness	Medium	Good	Good	Fair	Fair	Poor	Excellent
	Accuracy	High	Fair	Good	Poor	Fair	Poor	Very Good
		Medium	Good	Very Good	Fair	Good	Good	Excellent
		Low	Good	Excellent	Good	Good	Good	Excellent
	Max part size	Small	Good	Very Good	Good	Fair	Poor	Moderate
		Medium	Moderate	Good	Fair	Good	Fair	Good
		Large	Moderate	Poor	Fair	Very Good	Good	Good
	Min feature size	Medium	Good	Fair	Good	Good	Poor	Very Good
F2. System usage	Build up Speed	Fast	Fair	Fair	Fair	Fair	Fair	Good
		Medium	Good	Good	Fair	Fair	Good	Very Good
		Slow	Very Good	Good	Good	Good	Good	Excellent
	Post Processing	Advanced	Poor	Poor	Poor	Fair	Fair	Fair
		Medium	Fair	Fair	Fair	Fair	Good	Good
		Easy	Good	Good	Good	Good	Good	Good
	Materials Supported	Static	Fair	Fair	Poor	Good	Very Good	Very Good
F3. Office Condition	Maintenance	Static	Poor	Fair	Poor	Good	Very Good	Poor
	Reliability	Static	Very Good	Fair	Good	Good	Poor	Very Good
	Hazardous	Static	Poor	Poor	Fair	Good	Good	Good
	Office friendly	Static	Fair	Poor	Poor	Fair	Fair	Fair
F4. Process Cost	Material Cost	Static	Expensive	Moderate	Expensive	Moderate	Moderate	Very Expensive
	Operating Cost	Static	Expensive	Moderate	Expensive	Moderate	Moderate	Very Expensive
	Setup Cost	Static	Expensive	Moderate	Expensive	Moderate	Moderate	Very Expensive
	Materials Supported	Static	Fair	Fair	Poor	Good	Very Good	Very Good

Table 2 Evaluation Value

	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
0.15	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.1	0	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4
0.25	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5	0.5
0.3	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.6	0.6	0.6	0.6
0.35	0.7	0.7	0.7	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.7
0.4	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.8
0.45	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9
0.5	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
0.55	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9
0.6	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.8
0.65	0.7	0.7	0.7	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.7
0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6
0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.8	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.4	0.4	0.4	0.4	0.4
0.85	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.3
0.9	0.2	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.2
0.95	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1
1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0

3. Solution

3.1 Stereolithography

To explain this equation, the solution of the rule

R $_{\text{Surface finish Stereolithography}}$:

= A ('F1a', 'High', 'Stereolithography)(x, y) ∪ A ('F1a', 'Medium', 'Stereolithography)(x, y) ∪ A ('F1a', 'High', 'Stereolithography)(x, y)

= ∪ 'High ‘ x E('F1a', 'High', 'Stereolithography') ∪'Medium' x E('F1a', 'Medium', 'Stereolithography') ∪'Low' x E('F1a', 'Low', 'Stereolithography')

= (' High' x 'Fair') ∪ (' Medium' x 'Good') ∪(' Low' x 'Excellent')

= (' High (x)' Δ 'Fair(y) ') ∇ (' Medium(x)' Δ 'Good(y)') ∇ (' Low (x) ' Δ 'Excellent (y)')

R $_{\text{Surface finish Stereolithography}}$: (1, 0.3)

= (' High (1)' Δ 'Fair(0.3) ') ∇ (' Medium(1)' Δ 'Good(0.3)') ∇ (' Low (1) ' Δ 'Excellent (0.3)')

= max {min {High (1), Fair(0.3) }, min{ Medium(1), Good(0.3)}, min {Low (1), Excellent (0.3)}

= max {min {0.2, 0.6}, min {0.4, 0}, min {0,0}

=max {0.2, 0, 0}=0.2

3.2 PolyJeT

R $_{\text{Surface finish Polyjet}}$
= A ('F1a', 'High', 'PolyJet)(x, y) ∪ A ('F1a', 'Medium', 'PolyJet)(x, y) ∪ A ('F1a', 'High', 'PolyJet)(x, y)
= ∪'High ‘ x E('F1a', 'High', 'PolyJet') ∪'Medium’ x E('F1a', 'Medium', 'PolyJet') ∪'Low’ x E('F1a', 'Low', 'PolyJet')
= (' High' x 'Fair') ∪(' Medium' x 'Fair') ∪(' Low' x 'Good')

3.3 Selective Laser Sintering

R $_{\text{Surface finish Selective Laser Sintering}}$
= A ('F1a', 'High', 'Selective Laser Sintering)(x, y) ∪ A ('F1a', 'Medium', 'Selective Laser Sintering)(x, y) ∪ A ('F1a', 'High', 'Selective Laser Sintering)(x, y)"
= ∪'High ‘ x E('F1a', 'High', 'Selective Laser Sintering') ∪'Medium’ x E('F1a', 'Medium', 'Selective Laser Sintering') ∪'Low’ x E('F1a', 'Low', 'Selective Laser Sintering')"
= (' High' x 'Poor') ∪(' Medium' x 'Fair') ∪(' Low' x 'Good')

3.4 Fused Deposition Modeling

R $_{\text{Surface finish Fused Deposition Modelling}}$
= A ('F1a', 'High', ' Fused Deposition Modelling)(x, y) ∪ A ('F1a', 'Medium', ' Fused Deposition Modelling)(x, y) ∪ A ('F1a', 'High', ' Fused Deposition Modelling)(x, y)"
= ∪'High ‘ x E('F1a', 'High', ' Fused Deposition Modelling') ∪'Medium’ x E ('F1a', 'Medium', ' Fused Deposition Modelling') ∪'Low’ x E('F1a', 'Low', ' Fused Deposition Modelling')"
= (' High' x 'Fair') ∪(' Medium' x 'Good') ∪(' Low' x 'Good')

3.5 3D-Printing

R $_{\text{Surface finish 3D-Printing}}$
= A ('F1a', 'High', '3D-Printing)(x, y) ∪ A ('F1a', 'Medium', '3D-Printing)(x, y) ∪ A ('F1a', 'High', '3D-Printing)(x, y)"
= ∪'High ‘ x E('F1a', 'High', '3D-Printing') ∪'Medium’ x E('F1a', 'Medium', '3D-Printing') ∪'Low’ x E('F1a', 'Low', '3D-Printing')"
= (' High' x 'Poor') ∪ (' Medium' x 'Fair') ∪(' Low' x 'Good')

3.6 Electron Beam Melting

R $_{\text{Surface finish Electron Beam Melting}}$
= A ('F1a', 'High', 'Electron Beam Melting)(x, y) ∪ A ('F1a', 'Medium', 'Electron Beam Melting)(x, y) ∪ A ('F1a', 'High', 'Electron Beam Melting)(x, y)"
= ∪'High ‘ x E('F1a', 'High', 'Electron Beam Melting') ∪'Medium’ x E('F1a', 'Medium', 'Electron Beam Melting') ∪'Low’ x E('F1a', 'Low', 'Electron Beam Melting')"
= (' High' x 'Good') ∪ (' Medium' x 'Good') ∪(' Low' x 'Excellent')

Table 3 Factor weight

F1a	0.53
F1b	0.91
F1c	0.31
F1d	0.46
F2a	0.63
F2b	0.57
F2c	0.22
F3a	0.19
F3b	0.21
F3c	0.15
F3d	0.19
F4a	0.47
F4b	0.39
F4c	0.28

Table 4 Overall combined evaluation vector for the 6 RPT

	Stereolithography	PolyJet	Selective Laser Sintering	Fused Deposition Modeling	3D Printing	Electron Beam Melting
1	0.2	0.1	0.2	0.36	0.1	0.2
2	0.37	0.1	0.1	0.36	0.1	0.37
3	0.4	0.1	0.2	0.37	0.1	0.36
4	0.5	0.1	0.36	0.16	0.1	0.3
5	0.4	0.1	0.1	0.2	0.1	0.1
6	0.3	0.1	0.1	0.09	0.1	0.3
7	0.2	0.1	0.37	0.37	0.1	0.36
8	0.16	0.1	0.1	0.09	0.2	0.4
9	0.3	0.2	0.2	0.3	0.3	0.36
10	0.4	0.36	0.3	0.4	0.36	0.4
11	0.3	0.5	0.5	0.2	0.36	0.5
12	0.2	0.4	0.4	0.36	0.36	0.4
13	0.36	0.4	0.4	0.09	0.3	0.3
14	0.2	0.4	0.4	0.2	0.3	0.2
15	0.16	0.09	0.37	0.2	0.16	0.2

Table 5 Evaluation center EC(RP) for the four rapid prototyping techniques

Stereolithography	PolyJet	Selective Laser Sintering	Fused Deposition Modeling	3D Printing	Electron Beam Melting
0.30	0.22	0.21	0.28	0.20	0.25

Table 6 Overall combined evaluation vector for the 6 RPT with effect of weight factor

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stereolithography	0.17	0.20	0.36	0.16	0.18	0.19	0.11	0.04	0.06	0.08	0.05	0.04	0.17	0.08	0.04
PolyJet	0.08	0.05	0.09	0.03	0.05	0.06	0.06	0.02	0.04	0.08	0.08	0.08	0.19	0.16	0.03
Selective Laser Sintering	0.17	0.05	0.18	0.11	0.05	0.06	0.21	0.02	0.04	0.06	0.08	0.08	0.19	0.16	0.10
Fused Deposition Modeling	0.30	0.19	0.34	0.05	0.09	0.06	0.21	0.02	0.06	0.08	0.03	0.07	0.04	0.08	0.06
3D Printing	0.08	0.05	0.09	0.03	0.05	0.06	0.06	0.04	0.06	0.08	0.05	0.07	0.14	0.12	0.04
Electron Beam Melting	0.17	0.20	0.33	0.09	0.05	0.19	0.21	0.09	0.07	0.08	0.08	0.08	0.14	0.08	0.06

Result and Discussion

A multi-criteria decision making model was presented in this study to aid in selecting the best rapid prototyping technology for cranioplastic implants. Six alternative technologies were considered in the decision analysis. Fuzzy reasoning is used to model the experts' comprehension and uncertainty in the factors used in the decision criteria. The study includes fifteen factors that have been collected through surveys from different manufacturers. The factors were rated according to each alternative technology using linguistic statements. The model splits the factors into two categories: static and dynamic where different fuzzy rules can be drawn from each category. The fuzzy rules are then used as an input to the model to calculate the competencies between the alternatives. The alternative with the highest competency score represents the best choice.

Although they cost more than the other two alternatives, it was found that the Stereolithography technology scores are the highest. The study shows that the competency Stereolithography and Fused Deposition Modeling (FDM), the FDM is most preferable for the reason of the material cost of FDM is lower than the Stereolithography material. The Photosensitive material used for the Stereolithography having the preserving problem with limited period. The results of the analysis indicate that human-related mistakes are one of the main causes that negatively affect the rank of the rapid prototyping technologies**.** Therefore, makers should reduce human-related mistakes through the inheritance and documentation of experience to promote the manufacturing process yield.

Multi-criteria decision making technique using fuzzy reasoning can merge quantitative and qualitative factors to handle different groups opinions of experts. The proposed fuzzy model significantly contributes to the improvement of manufacturing quality in prototyping. Specifically, the model can assist prototyping manufacturers in solving similar multi-criteria problems by offering an objective and systematic method of selecting the optimal performing machine.

Conclusions

Many diseases, Traumatisms and impact caused by the accident can end up damaging the cranium. Cranium is a protection covering over the vital organs of head and any serious damage to the cranium can only be treated with reconstructive surgery. In order to perform the surgery a model of cranium must be created well in advance before treating the patient. Medical practitioners mostly rely on rapid prototyping for this task, as rapid prototyping is the primary choice for the cranioplasty. There are six technologies available for completing the rapid prototyping model and they are Stereolithography, PolyJet, Selective Laser Sintering, Fused Deposition Modeling, 3D printing, and Electron Beam Melting

Following results have been inferred from the works done in project

1) After applying the multi-criteria decision making model of fuzzy it is clear that stereolithography and fusion deposition are able to provide a optimistic results
2) Upon the implication of linguistic and membership function for the decision making process we can figure out that fused deposition has a low material cost and more suitable for the application that we are concerned.
3) After the correction is done with the modeling software the 3D model is ready for the production through the Fused Deposition Method (FDM). The parameters have been analyzed for FDM for the proper production of the 3D model in to product.

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