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IMPROVING THE ACCURACY OF RAPID PROTOTYPING PROCEDURES BY GENETIC PROGRAMMING

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Abstract: *To achieve better quality of the PolyJet™ Rapid Prototyping procedure, which originally employs a method of size compensation by scale factors to reach a desired accuracy, we decided to improve the procedure's performance by adjusting scale factors for every part separately. The main accuracy problem of rapid prototyping procedures that are using polymers as a building material is shrinking of a finished layer in the phase of polymerization. To this purpose we used genetic programming that enabled us to acquire a formula for scale factor's determination based upon the geometry of the actual part. The method resulted in optimized scale factors and better overall performance of the PolyJet™ procedure compared to other rapid prototyping techniques used nowadays.*

Keywords: Rapid Prototyping, PolyJet™, Genetic programming

1. INTRODUCTION

1.1 PolyJet™ Rapid Prototyping procedure

In this study, the accuracy of PolyJet™ procedure was tested on the EDEN 330™ rapid prototyping machine. According to its functionality the PolyJet™ procedure can be grouped as one of the 3D printing procedures [1]. The core of the EDEN 330™ machines is a printing head, similar to those used in large industrial printers. But instead of paint EDEN 330™ printing head applies a liquid mixture of reactive photopolymers that polymerise into a solid object under the influence of UV lights. The three-dimensional model is build by layers. The thickness of individual layer is 0.016mm [2].

1.2 Scale factors

The main accuracy problem of the PolyJet technology is shrinking of the building material during the phase of polymerisation. Therefore the manufacturer of EDEN330™ machines has developed a method of compensating for material shrinkages by implementing a scale factor into the machine's software package (Figure 1).

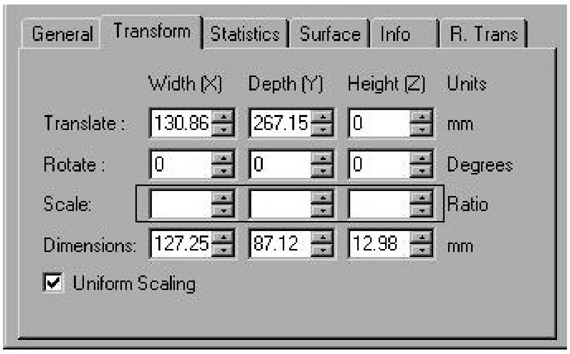

Fig. 1. Implementation of scale factors

The CAD models are scaled (enlarged) for the entered factor value in individual axes (according to the model's orientation in the machine's workspace) in order to compensate for the shrinkages during the polymerisation phase. According to the manufacturer, the recommended value of the scale factor is 0.23%.

1.3 Effects of the scale factors

In order to test the effects of the scale factors on the accuracy of the EDEN 330 machine, two series of 12 various objects were produced and measured. When building the first series of objects the scale factors were set at 0. Therefore the software package did not compensate for the shrinkages. In the second series the recommended value of the scale factor was used (0.23%).

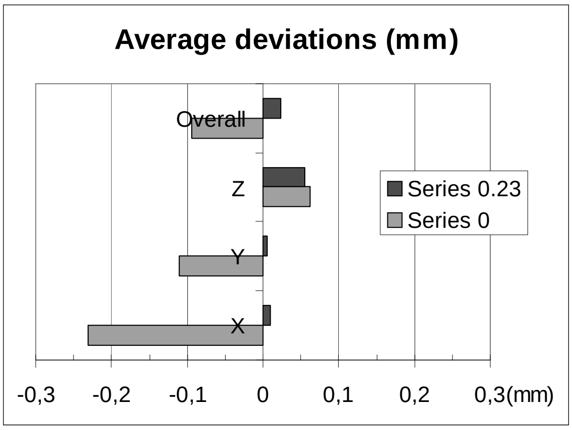

Fig. 2. Average deviations (in mm) of series 0 and 0.23

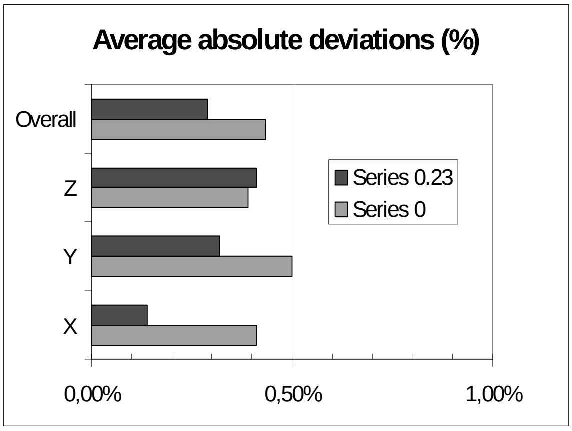

Fig. 3. Average absolute deviations (in percentage) of series 0 and 0.23

Observing the Figure 2 and 3 we can determine the effects of scale factors values on the accuracy of the EDEN 330 machine. The 0.23 series produced considerably better results in terms of accuracy than the 0 series. With the recommended value of the scale factor, the average absolute deviation was reduced from 0.44% to 0.29%. However we were interested if it is possible to optimise the process of compensation in order to achieve better overall accuracy than with series 0.23.

2. OPTIMIZING SCALE FACTOR VALUES WITH GENETIC PROGRAMMING

2.1 Genetic programming

Genetic programming was used to establish a mathematical relation between nominal measures of the object's CAD model in individual axes, scale factor value and final measures of finished objects. Then this mathematical model would be used to determine the optimal scale factor values regarding to the nominal measures of individual objects in each axis. The optimal value is determined in a case when the nominal and final measure (regarding to the mathematical model) are the same [3]. Genetic programming starts with a primal population of thousands of randomly created computer programs. This population of programs is progressively evolved over a series of generations. The evolutionary search uses the Darwinian principle of natural selection (survival of the fittest) and analogies of various naturally occurring operations, including crossover (sexual recombination), mutation, gene duplication, gene deletion [4]. I our case, each of this computer programs will represent a mathematical function, which will more ore less accurately define the final measure of an object (in individual axis) regarding to the nominal measures and the scale factor used. The final mathematical model will include the most accurate function (the fittest program) for each axis [5].

2.2 Using the genetic programming

Genetic programming was done in AutoLisp™ program language. Prior of running the genetic programming five preparatory steps must be completed. In the first step the set of terminals (independent variables and constants) must be defined. For our problem we defined the nominal measures in X, Y and Z axis and the scale factor value used as independent (input) variables (Figure 4).

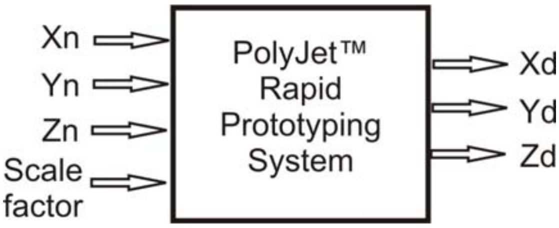

Fig. 4. Input and output variables of the rapid prototyping system

Secondly the set of primitive functions was defined. We choose the basic arithmetic operation of addition, subtraction and multiplication. We excluded the operation of dividing in order to prevent the ’divide by zero’ problem during the optimisation of the scale factor value process. In the third step the fitness measure must me defined. In our case the fitness measure was applied regarding to the difference between the functions value (F) and the measured final dimension of the manufactured object (output variable). The smaller is this difference the bigger genetical potential of that function will be.

In the forth step the control parameters of the genetic programming run are defined. Those include: population size, probability of performing certain genetic operation and the maximum size of individual programs. In the last step the termination criterion is defined. We can define the maximum number of generations ore some problem specific terminate condition. The most practical solution is to manually monitor and manually terminate the run when the values of fitness for numerous successive best-of-generation individuals appear to have reached a plateau.

2.3 Analysis of the genetic programming results

When the run for each axis was completed we have searched for the X, Y and Z axis function with the highest fitness measure (the most accurate one). Then we used those functions to determine the optimal scale factor (Figure 5) values regarding to the nominal measures (We calculated the scale factor values at which the nominal measure and the functions value (final measure) are the same (regarding to our established mathematical model) [6].

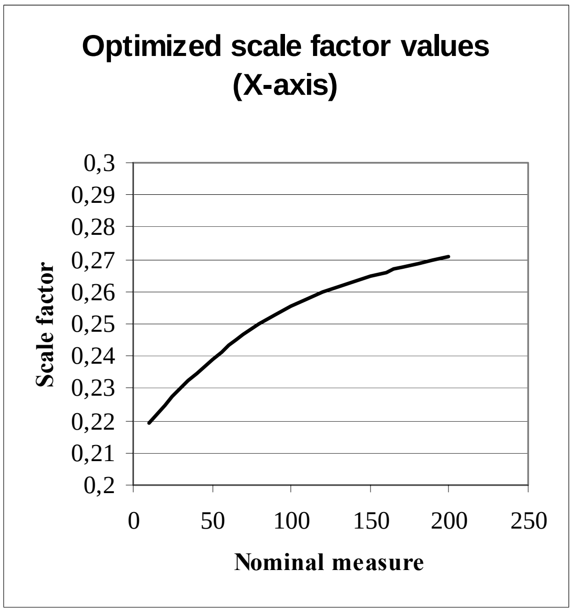

Fig. 5. Calculated optimal scale factor values regarding to the nominal measures in X-axis

3. TESTING OPTIMIZED SCALE FACTOR VALUES

In order to test the optimized scale factor values we have produced another series of test objects. This time we have calculated scale factor value for each test object for each individual axis separately according to the mathematical model. The results of the optimised series show additional improvement in accuracy of the PolyJet™ rapid prototyping procedure over previous series (Figure 6). The average absolute deviation was reduced from

0.44% of the series 0 to 0.13% of the optimised series. Especially large improvement has been achieved with the optimised values of scale factors in the X-axis of the machine (Figure 7). (0.41% of series 0 to 0.08% of the optimised series).

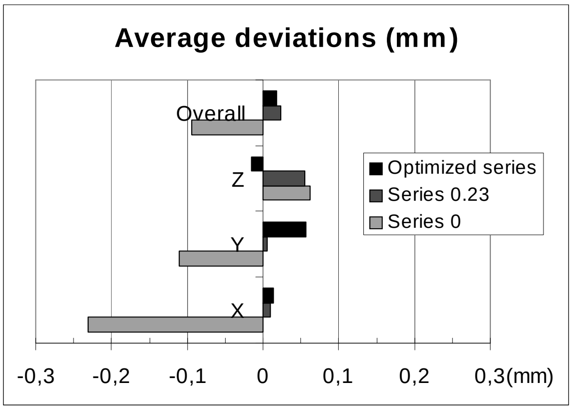

Fig.6. Average deviations (in mm) of the optimized series

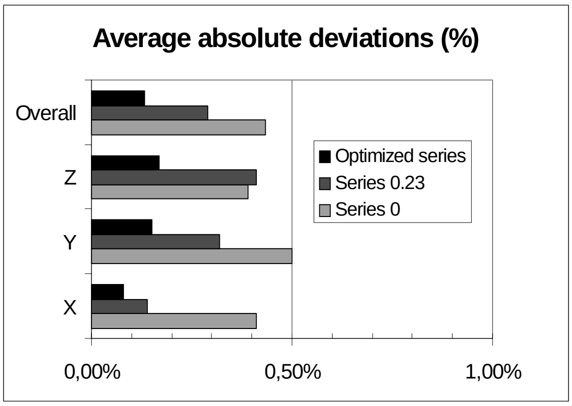

Fig.7. Average absolute deviations (in percentage) of the optimized series

4. CONCLUSION

The optimisation of the scaling process has definitely improved the accuracy of the PolyJet™ procedure. The problem of our method is that we are able to optimise scale value of a model based on only one dimension of a model in a particular axis. Because most “real-life” prototypes have many different dimensions in individual axes, choosing the optimal dimension on which to calculate the scale factor can be difficult. However, for the common usage of rapid prototyping the recommended value of scaling enables satisfactory results. Our optimisation method becomes useful, when we have to manufacture a prototype with one dimension that has very high accuracy demands. In that case, we can calculate the appropriate value of the scale factor for that particular dimension and than scale the whole prototype (correctly orientated in workspace) in appropriate axis by this factor value.

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