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ANALYSIS OF CONSTRUCTION OF LOCAL INTERPOLATION CUBIC SPLINES BASED ON DETAILED DATA AND ITS APPLICATION IN DIGITAL PROCESSING OF MEDICAL SIGNALS.

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Abstract. Currently, Spline functions play an important role in modern science and technology, especially in the digital processing of signals. Compared to classical interpolation methods, splines offer both higher approximation accuracy and simpler construction.

This study presents a local interpolation cubic spline model based on a linear combination of parabolas sharing two points. Its application to signal processing was analyzed through experimental data and numerical methods. The continuity of the constructed splines at node points was confirmed via graphs and numerical analysis.

The proposed method is effective in processing various geophysical and biomedical signals and is suitable for approximating integrals and solving corresponding integral equations. A one-dimensional medical signal was digitally processed, with results presented in tables and graphs.

1. INTRODUCTION

The classical interpolation polynomials are constructed in a cross section [a, b], while the spline functions are constructed in a single cross section [a, b], where the cross section is n pieces. The classical interpolation polynomials are approximated by constructing a single polynomial at the intersection [a, b]. The spline functions, on the other hand, allow [a, b] to intersect n segments and converge on each segment to allow the whole [a, b] interval to converge. The construction and implementation of spline functions is simpler than classical interpolation polynomials, and provides a quick approach to the object being recovered [1,2,4].

The local interpolation cubic spline function is one of the most important issues in the development of science and technology, especially in the application of practical problems. In particular, in geophysics, biomedicine, environmental processes and other fields, many results are being achieved in the field of signal recovery, processing and forecasting based on spline models [3,7].

In addition, good results are obtained in the approximate calculation of regular and singular integrals, as well as in the approximate solution of regular and singular integral equations using quadrature and cubature formulas based on the function of local interpolation cubic spline [6].

2. Construction of the local interpolation cubic spline function

Based on the linear combinations of the parabolic functions discussed above, we construct the local interpolation cubic spline function.

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Based on the linear combination of the above $Y_1(x)$, $Y_2(x)$, $Y_3(x)$, $Y_4(x)$, $Y_5(x)$, $Y_6(x)$, $Y_7(x)$, $Y_8(x)$ -parabolas (9), the 3-level $S3(x)$ local interpolation cubic-spline functions are formed. Now we draw the graphs of these parabolas in a single Cartesian coordinate system. Here each adjacent parabola will have two common points. This situation can also be seen from the graphs of the parabolas.

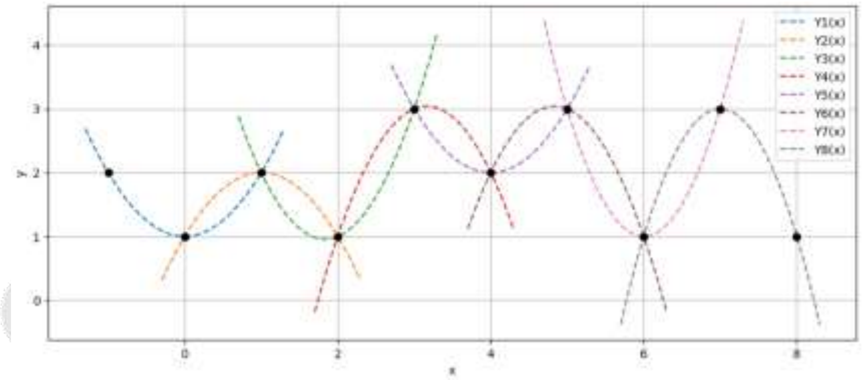

Figure 1. Graphic representation of parabolas with two points in common

Based on the linear combinations of the parabolic functions discussed above, we construct the local interpolation cubic spline function.

Based on the linear combination of the parabolas $Y_1(x)$ and $Y_2(x)$ constructed above, the local interpolation cubic spline function $S_{3(1)}(x)$, $x \in [0,\ 1]$ is constructed.

Here: $Y_1(x) = x^2 + 1$ and $Y_2(x) = -x^2 + 2x + 1$;

$$S_{3(i)}(t) = \left(\frac{5}{6} - t\right) Y_i(t) + \left(\frac{1}{6} + t\right) Y_{i+1}(t), \qquad t = \frac{(x - x_i)}{h}; \quad x \in [x_i, x_{i+1}].$$

Using what we know that $x_i = 0,\quad h = 1,\quad x \in [0,1].$, we create $t = \dfrac{x-0}{1} = x$, that is: $t = x$, and take it to (9).

As a result, the following expression is formed:

$$S_{3(1)}(x) = \left(\frac{5}{6} - x\right) Y_i(x) + \left(\frac{1}{6} + x\right) Y_{i+1}(x) = \left(\frac{5}{6} - x\right)(x^2 + 1) + \left(\frac{1}{6} + x\right)(-x^2 + 2x + 1)$$

$$= \frac{5}{6}x^2 + \frac{5}{6} - x^3 - x - \frac{1}{6}x^2 + \frac{1}{3}x + \frac{1}{6} - x^3 + 2x^2 + x = -2x^3 + \frac{8}{3}x^2 + \frac{1}{3}x + 1.$$

$$S_{3(1)}(x) = -2x^3 + \frac{8}{3}x^2 + \frac{1}{3}x + 1.$$

Based on the linear combination of parabolas $Y_2(x)$ and $Y_3(x)$, $Y_3(x)$ and $Y_4(x)$, $Y_4(x)$ and $Y_5(x)$, $Y_5(x)$ and $Y_6(x)$, $Y_6(x)$ and $Y_7(x)$, $Y_7(x)$ and $Y_8(x)$, structured as above, the local interpolation cubic spline functions $S_{3(2)}(x)$, $x \in [1,\ 2]$, $S_{3(3)}(x)$, $x \in [2,\ 3]$, $S_{3(4)}(x)$, $x \in [3,\ 4]$, $S_{3(5)}(x)$, $x \in [4,\ 5]$, $S_{3(6)}(x)$, $x \in [5,\ 6]$, $S_{3(7)}(x)$, $x \in [6,\ 7]$ were constructed.

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$$S_{3(2)}(x) = \frac{7}{3}x^3 - \frac{131}{18}x^2 + \frac{80}{9}x + \frac{7}{3}, \qquad S_{3(3)}(x) = -\frac{17}{6}x^3 + \frac{1503}{100}x^2 - \frac{233}{10}x + \frac{11}{2},$$

$$S_{3(4)}(x) = \frac{5}{2}x^3 - \frac{223}{12}x^2 + \frac{439}{12}x - 7, \qquad S_{3(5)}(x) = -\frac{5}{2}x^3 + \frac{277}{12}x^2 - \frac{651}{12}x + \frac{29}{3},$$

$$S_{3(6)}(x) = \frac{7}{2}x^3 - \frac{473}{12}x^2 + \frac{1357}{12}x - \frac{87}{6}, \ S_{3(7)}(x) = -4x^3 + \frac{160}{3}x^2 - 121x + 45.$$

3. Application of local interpolation cubic spline model to one-dimensional medical signals

In order to evaluate the capabilities of the initially constructed model and check its accuracy, we will consider the issue of interpolation of pre-selected single-variable complex functions and perform a comparative analysis on the graphs.

Now the spline model considered in the work was analyzed on the basis of its approximation to the given functions in the Matlab program and compared graphically.

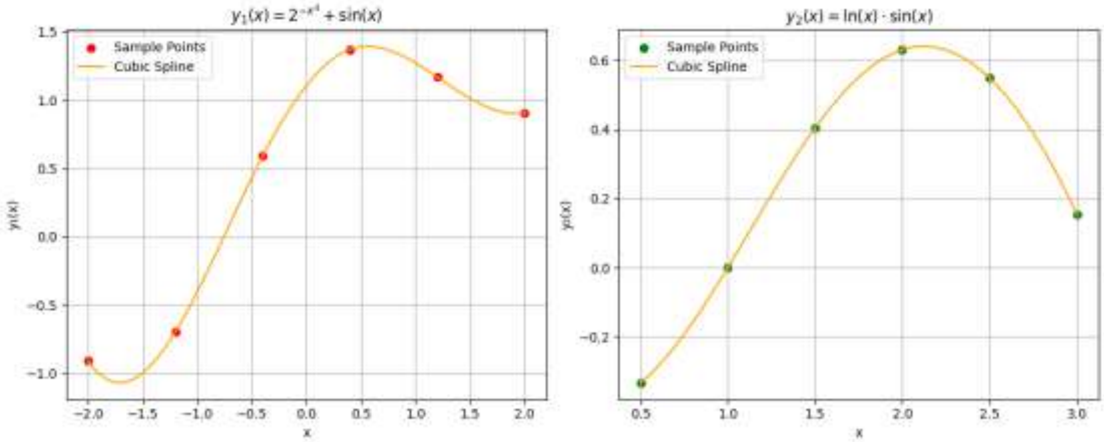

Figure 2. A graph of spline model recovery of complex functions given as an experiment

Graphical results of local interpolation cubic spline approximation of preselected functions f(x).

It can be seen from the figures 1, 2 that the local interpolation cubic spline function graph approximates the function graph well and can be applied to real objects [11,12].

Below we will consider the graphical analysis of medical signal processing using the Spline function. For this, we take the ECG signal obtained as an experiment. Its values are listed in Table 2 below.

Table 2. ECG signal values obtained as an experiment

№	Amplitude	№	Amplitude	№	Amplitude	№	Amplitude
1	-0.045	11	-0.075	21	-0.025	31	-0.195
2	-0.055	12	-0.09	22	0.01	32	-0.205
3	-0.055	13	-0.085	23	0.01	33	-0.19
4	-0.055	14	-0.105	24	0.1	34	-0.205
5	-0.055	15	-0.09	25	0.135	35	-0.22
6	-0.075	16	-0.11	26	0.075	36	0.145
7	-0.065	17	-0.095	27	0	37	1.025
8	-0.08	18	-0.11	28	-0.05	38	1.605
9	-0.065	19	-0.1	29	-0.045	39	0.24
10	-0.08	20	-0.085	30	-0.175	40	-0.625

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Using the values given above, we create a graphical representation of the spline model and analyze it.

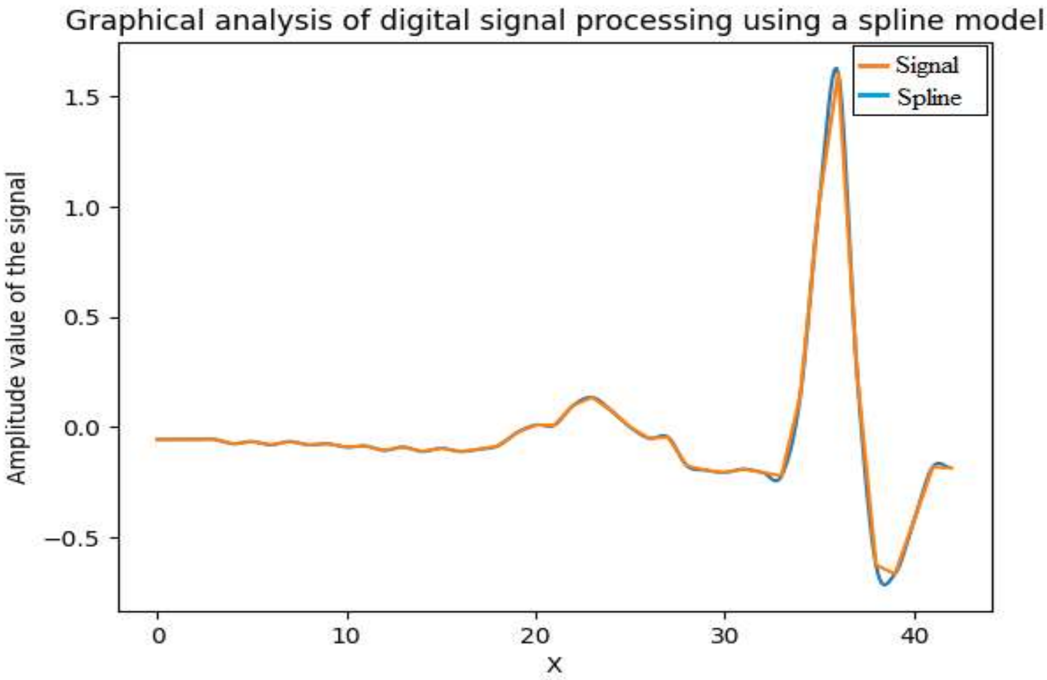

Figure 3. Graphical analysis of digital signal processing using a spline model

Table 3. Comparative analysis of experimentally obtained ECG signal values and values obtained based on the spline model

№	ECG signal	$S_3(x)$ Spline	$R=\lvert F(x)-S_3(x)\rvert$
1	1,605	1,605	0
2	1,546223	1,545023	0,0012
3	1,45018	1,44848	0,0017
4	1,325008	1,322708	0,0023
5	1,17714	1,17504	0,0021
6	1,014713	1,012813	0,0019
7	0,84426	0,84336	0,0009
8	0,675118	0,674018	0,0011
9	0,51362	0,51212	0,0015
10	0,365403	0,365003	0,0004
11	0,24	0,24	0
12	0,130238	0,129538	0,0007
13	0,0234	0,0218	0,0016
14	-0,07934	-0,08224	0,0029
15	-0,1786	-0,1816	0,003
16	-0,27171	-0,27531	0,0036
17	-0,3585	-0,3624	0,0039
18	-0,43779	-0,44189	0,0041
19	-0,5094	-0,5128	0,0034
20	-0,57206	-0,57416	0,0021

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21	-0,625	-0,625	0
		Max:	0,0041

The graph and table above show the results obtained from the digital processing of ECG signals. The maximum error in the values shown in Table 3 is 0.0041. We can see that the relative error is 0.936%. This fully satisfies us as a solution to the research problem, showing that the values of the recovered ECG signal are recovered with sufficient accuracy [6,9].

CONCLUSION

The results of this study show that the formation of the spline function in the interval [0, 7] was studied by constructing based on linear combinations of parabolas using four points connected in the interval 7 (having two common points). It was also verified that the spline functions constructed in the interval have a common value at the connecting node points (splines constructed between 2 nodes). It was found that the accuracy of the research results obtained by the mask model is high, and the process of application to real objects was also carried out. A graphical and tabular analysis of the result is also given. It is clear from the results of the analysis that the selected model is of particular importance due to its good approximation to the object and minimal error, as well as ease of use in EHM.

These results are used in educational processes, as well as in signal restoration and digital processing related to various fields.

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