

Comparison of interpolation methods based on real human motion data

Abstract. During a motion capture session markers may become occluded for brief periods of time. Resulting gaps in acquired data can be filled by means of interpolation methods. Additional data recorded alongside markers' trajectories frequently have a different sampling frequency. Thus, the need for a resampling method. This paper presents a comparison of Catmull-Rom Spline, modified Catmull-Rom Spline and Blended Parabolas interpolation algorithms. Real human motion data is used for the comparison in two respects: filling gaps and resampling captured data.

Streszczenie. Podczas sesji akwizycji ruchu niektóre marker mogą zostać chwilowo przesłonięte. Powstałe przerwy mogą zostać wypełnione z użyciem metod interpolacji. Dodatkowe dane zarejestrowane równocześnie z ruchem często próbkowane są z inną częstotliwością. Wynika stąd zapotrzebowanie na metodę resamplingu dla danych ruchu. Artykuł porównuje metody krzywych sklepanych Catmulla-Roma, zmodyfikowaną metodę Catmulla-Roma i krzywych przejściowych między parabolami. Do porównania w dwóch aspektach (wypełnianie przerw i resampling) wykorzystano rzeczywiste dane ruchu. (Porównanie metod interpolacji z wykorzystaniem rzeczywistych danych ruchu).

Keywords: motion capture data, interpolation, resampling

Słowa kluczowe: dane ruchu, interpolacja, resampling

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Introduction

Marker based mocap systems are one of the most prominent categories among motion capture systems [1,2]. Some markers may become occluded for brief periods of time during a motion capture session. As a result recorded motion contains gaps – that is, the trajectories of selected markers – are incomplete. By using an appropriate interpolation method we can fill in gaps in the captured data. Another reason for using interpolation methods comes from the fact that mocap data is frequently recorded together with so-called analog data such as ground reaction forces. Usually, the sampling frequency of the two data streams differs. Analog data is sampled at a different frequency than the frame rate of the motion capture data. Interpolation can be used to resample data in order to make these frequencies match. Resolution of either of the data streams may be both increased and decreased. This makes both combined analysis and presentation easier, and allows for generating a smoother animation [3]. There are many different interpolation algorithms [4,5,6]. Three interpolation methods are selected for inclusion in the comparison presented in this paper. These methods are: Catmull-Rom spline, modified Catmull-Rom spline and blended parabolas. Their performance is compared in two respects mentioned above: resampling captured data and filling in gaps in incomplete motion capture data. All tests performed for the purpose of this paper used a sample data file (Eb015pi.c3d) available on the 3D Biomechanics Data Standard site [7].

Selected interpolation methods

As stated above there are many algorithms that allow for numerical data interpolation [6]. Methods selected for comparison are described briefly below. Many interpolation methods can be presented in a matrix form (three matrices: U , M and B) which is easy to implement in software. This is the case for the selected methods. In general they can be expressed by:

$$(1) \quad \mathbf{P}(u) = \mathbf{U}^T \mathbf{M} \mathbf{B}; \quad \mathbf{U}^T = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix}$$

where: \mathbf{U} – a matrix containing interpolation parameters, \mathbf{M} – fixed coefficients, \mathbf{B} – vector containing geometrical information, u – interpolant (relative distance along the interpolated curve which belongs to the range of $[0;1]$ [6].

The following interpolation methods are chosen for comparison: Catmull-Rom Spline, its modified version and Blended Parabolas. These methods all are third-degree polynomial methods. Such methods are most frequently used in computer graphics.

The first method – the Catmull-Rom Spline (in the reminder of this paper also referred to as CM1/2) creates a cubic polynomial between two consecutive points in the data-set. The \mathbf{M} matrix used is identical to the one used for the Hermite method [6]. Tangents required for each interpolation node are generated automatically. The vectors are generated using points in the data-set with the help of the following equation [6]:

$$(2) \quad P'_i = \frac{1}{2}(P_{i+1} - P_{i-1})$$

where: P_i – i^{th} point in the dataset for which the tangent is computed.

The modified Catmull-Rom Spline (CMP) method is similar to CM1/2. The only difference is that it computes the required tangent vectors differently [6,8]:

$$(3) \quad P'_{i-1}(1) = \frac{|P_i - P_{i-1}|}{|P_{i+1} - P_{i-1}|} (P_{i+1} - P_{i-1})$$

$$(4) \quad P'_i(0) = \frac{|P_{i+1} - P_i|}{|P_{i+1} - P_{i-1}|} (P_{i+1} - P_{i-1})$$

where: P_i – i^{th} point in the dataset for which the tangent is computed.

As we can see, the left- and right-hand tangents of a point depend on the distances between the point and its predecessor and successor.

The Blended Parabolas method consists in constructing a blend of overlapping parabola segments [9, 6]. This method, although expressed differently in mathematical terms, gives results equivalent to the Catmull-Rom Spline method (CM1/2) [6]. For this reason it is not treated separately in the reminder of this paper.

Motion capture data resampling

A sample data file (eb015pi.c3d) [7] is used for the research presented in this paper. Trajectories of two markers are used in the experiment regarding data resampling. These markers are 'PV2' (2nd marker on the pelvis) and 'LFT1' (1st marker on left foot). In both cases the original data-set containing 450 samples is resampled to obtain 100, 300 and 800 points placed along the marker's trajectory. This is done using the following algorithm:

1) two points of the trajectory (the first and the last) remain unmodified,

2) $\Delta a = (n_o - 1) / (n_p - 1)$ is computed (where: n_o – original point count, n_d – desired point count),

3) $i = \lfloor \Delta a \cdot d \rfloor$ is computed (i – is the original sample's number and d – is the number of the sample that is currently being computed – the sample in resampled data-set),

4) the u interpolant, needed for building the U matrix, is computed as $u = \Delta a \cdot d - \lfloor \Delta a \cdot d \rfloor$,

5) the matrix U and the original points $P_{i-1}, P_i, P_{i+1}, P_{i+2}$ constitute the input of the interpolation method which is then used to compute a new sample of the resampled data-set,

6) after computing the d^{th} sample, the algorithm proceeds to computing the sample number $d+1$ and returns to step 3.

At the end of the experiment, in order to assess resampling results, the difference (error) between points in the original and interpolated datasets is computed. The following algorithm is used:

1) total error is set to 0,

2) for every point in the resampled data-set, the nearest point (with respect to Euclidean distance) from the original input dataset is found,

3) the computed distance squared is added to the total error.

Data resampling results are shown in the figures below. Figures 1 and 2 show how resampling a data-set from 450 to 100 samples affects the shape of the markers' trajectories. Three interpolation methods are compared. As can be seen, the shape of the trajectories is preserved very well despite a significant reduction in the number of samples.

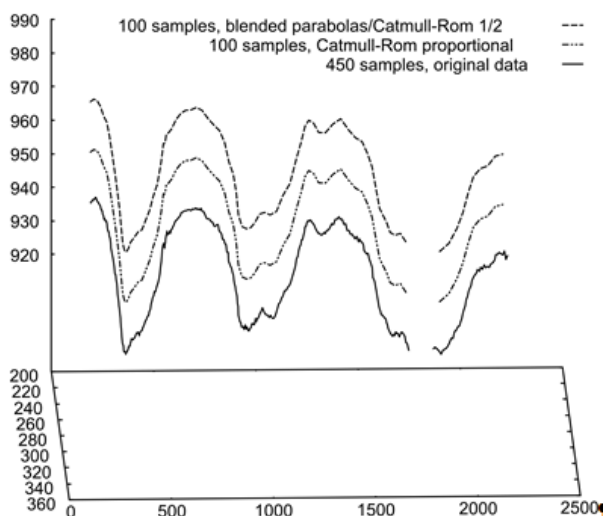


Fig. 1. Comparison of interpolation methods used for data resampling (marker PV2, the resampled markers' trajectories are offset relative to the original data in order to make visual examination easier)

Error values computed for different sample counts for both methods are listed in tables 1 and 2. Additionally the tables list differences of those error values. The differences between CMP1/2, BP and CMP methods in most cases are minor. Although generally CMP method notes higher error values the difference does usually does not exceed 1%. It is important to point out that for some sample counts the error of the CMP method is much higher and can even reach 54%

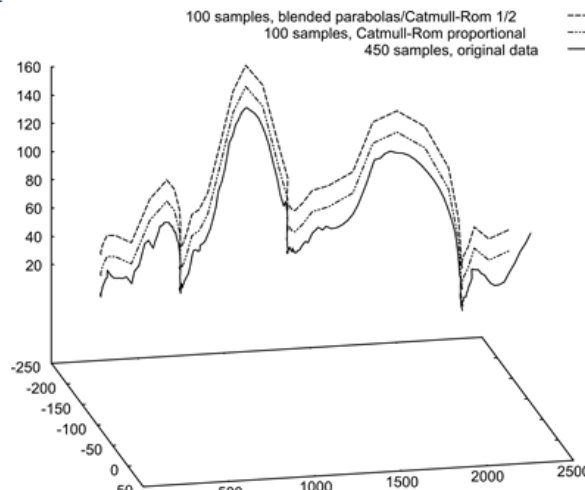


Fig. 2. Comparison of interpolation methods used for data resampling (marker LFT1, the resampled markers' trajectories are offset relative to the original data in order to make visual examination easier)

Figures 3 and 4 demonstrate how changing the number of samples affects the shape of a marker's trajectories. As an example, the Blended Parabolas method is selected (results for other methods are similar). As we can see, the overall shape of the marker trajectory is preserved well as the number of samples decreases. Fine movements are removed by resampling the data to a smaller number of points. Increasing the sample count, on the other hand, does not visibly affect the shape of the marker's trajectories. Errors computed for interpolated data are presented in tables 1 and 2.

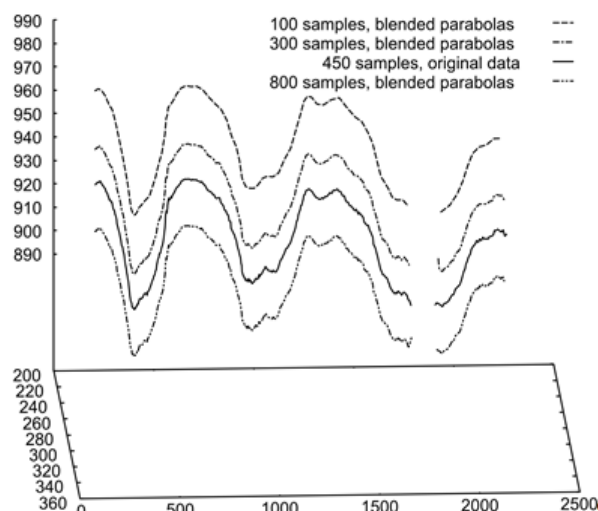


Fig. 3. Degradation of trajectory's shape depending on the final number of samples (marker PV2, the resampled markers' trajectories are offset relative to the original data in order to make visual examination easier).

Figures 5 and 6 show an assessment of the interpolation methods' accuracy for two resampled data-sets (markers 'PV2' and 'LFT1'). It is presented as a function of the number of samples in the final data-set. Error values for selected sizes of the final data-sets are also listed in tables 1 and 2. The CMP method tends to produce higher error values than the two other methods. Additionally CMP is the most complicated method (due to the need for tangent computation). The best results can be obtained with the both simpler methods, namely: Blended Parabolas and Catmull-Rom spline (CM1/2). As stated earlier they produce the same results; however, the first is easier and faster because it does not require tangent vectors computation (they are "built-in" into the \mathbf{M} matrix) [6]. There also exists an additional problem when using the CMP method with the motion capture data: on multiple occasions the tangent equation denominator (equations 3 and 4) is 0 – and thus, the tangents cannot be computed. This problem does not exist with BP and CM1/2 methods.

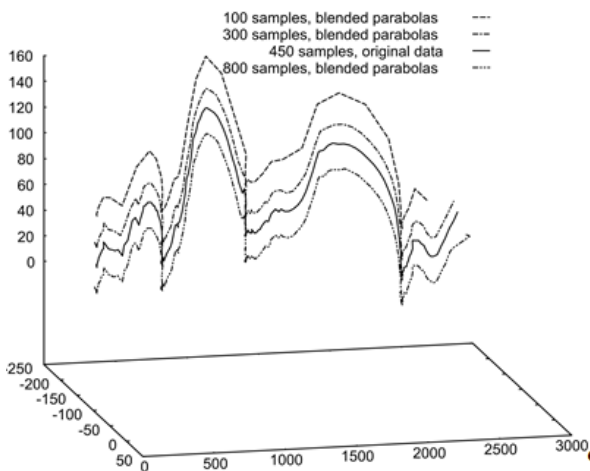


Fig. 4. Degradation of trajectory's shape depending on the final number of samples (marker LFT1, the resampled markers' trajectories are offset relative to the original data in order to make visual examination easier).

Table 1. Selected error values and their differences (marker PV2).

Number of samples	BP/CM12 error	CMP error	CMP – BP error difference
100	22363,1	22363,3	0,2
200	5859,4	5855,3	-4,1
300	2870,0	3310,7	440,7
400	1774,5	1777,0	2,5
500	1164,2	1165,9	1,7
600	759,8	765,2	5,4
700	764,2	829,2	65,0
800	615,1	688,3	73,2

Table 2. Selected error values and their differences (marker LFT1).

Number of samples	BP/CM12 error	CMP error	CMP – BP error difference
100	156987	157145	158
200	33881,2	33892,5	11,3
300	14838	14872,7	34,7
400	11569,8	11527,1	-42,7
500	6573,52	6557,62	-15,9
600	4386,63	4430,35	43,72
700	3156,55	4854,44	1697,89
800	3394,42	3369,12	-25,3

Filling gaps in motion capture data

As mentioned earlier, interpolation methods may also be used for filling in gaps (that are result of marker occlusion)

in the motion capture data. As in the above results, two markers from the sample file are used. These markers are also 'PV2' and 'LFT1'. The marker 'PV2' is selected because only its trajectory contains gaps. In the case of the 'LFT1' marker a gap is created artificially by removing samples numbered from 100 to 200. A situation in which the marker becomes occluded by some obstacle is recorded as zero values in the C3D file (these values are not plotted in figures to improve clarity). These zero values have to be replaced by results obtained from one of the interpolation algorithms.

The following procedure is used for generating missing values:

1) the gaps are detected – their beginning and ending; at least two non-zero values need to be present in the data-set in order to be taken into account as the beginning of a gap (zero values at the beginning and the end of the data-set are ignored),

2) two preceding points of the gap and two points following the gap are used as inputs for the interpolation methods,

3) using the selected method, the missing samples are computed. The number of samples that are computed is chosen to match exactly the original sampling frequency. Figures 7 and 8 show the results. For obvious reasons interpolation cannot recover the fine marker's movements. It is, however, able to provide good realistic results. The differences between the methods are best visible when the 3D trajectory is projected onto a plane such as the XY plane. Figures 9 and 10 show the projections.

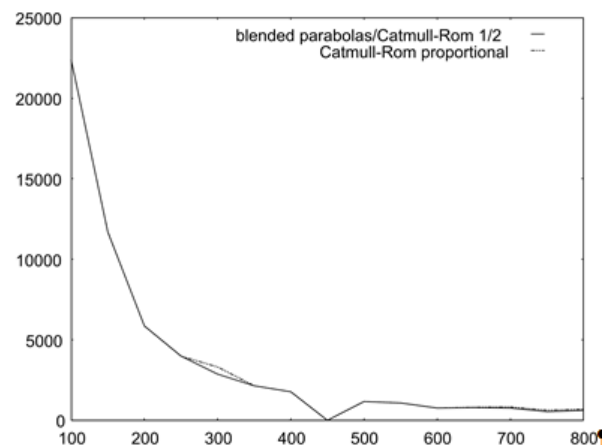


Fig. 5. The interpolation error as a function of the final samples count (marker PV2).

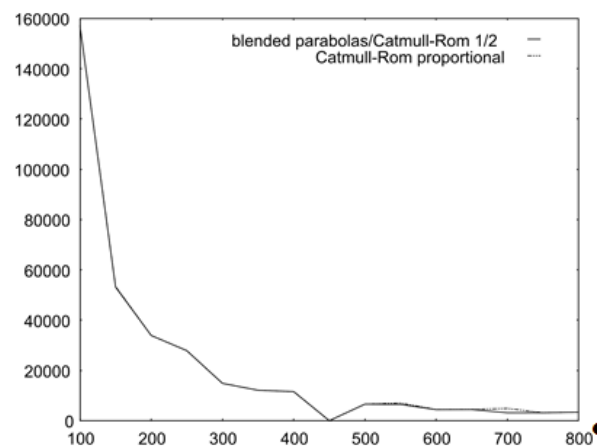


Fig. 6. The interpolation error as a function of the final samples count (marker LFT1).

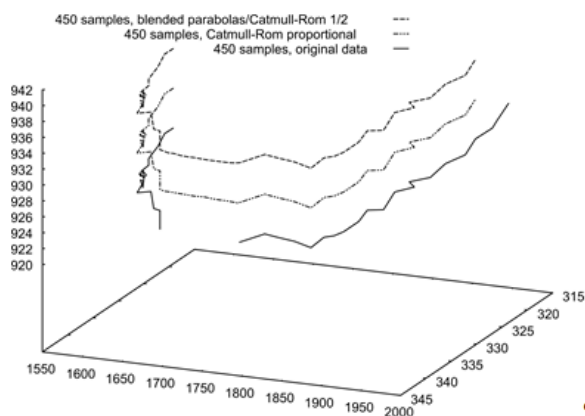


Fig. 7. Interpolation methods applied to filling the gaps (marker PV2, markers' trajectories with filled gaps are offset relative to the original data in order to make visual examination easier).

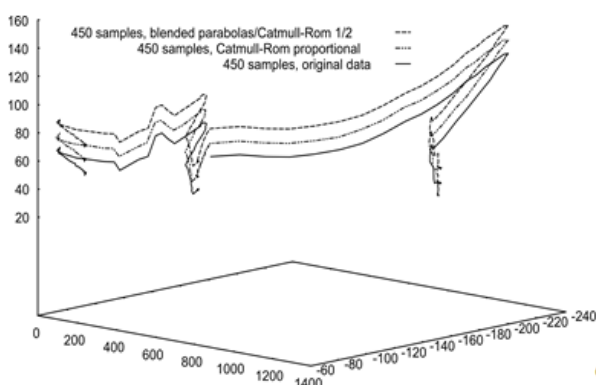


Fig. 8. Interpolation methods applied to filling the gaps (marker LFT1 markers' trajectories with filled gaps are offset relative to the original data in order to make visual examination easier).

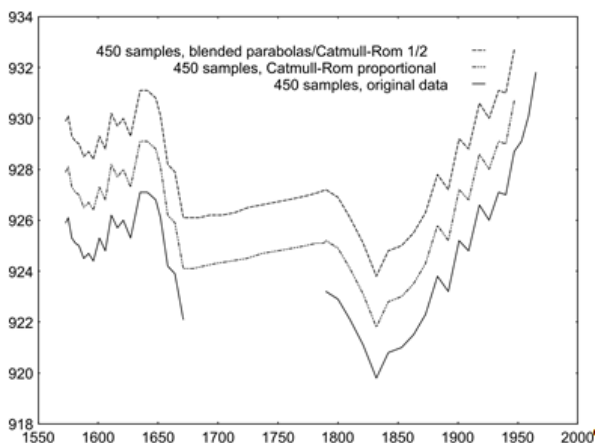


Fig. 9. Interpolation methods applied to filling in the gaps (projection onto XY plane, marker PV2, markers' trajectories with filled gaps are offset relative to the original data in order to make visual examination easier)

Conclusions

This paper presents two aspects of real motion capture data interpolation. The results presented above show that the best methods (when applied to gap filling and resampling) are the Blended Parabolas (BP) and the

Catmull-Rom Spline (CM1/2) methods. The BP method is especially worth mentioning. It produces the same results as CM1/2 but offers a shorter computation time and simpler implementation (tangent vectors are "built in" in the **M** matrix) [6, 10]. The modified Catmull-Rom Spline method causes problems with real motion capture data. Apart from being the most complicated method for motion capture data, the tangents cannot be computed in a significant number of points.

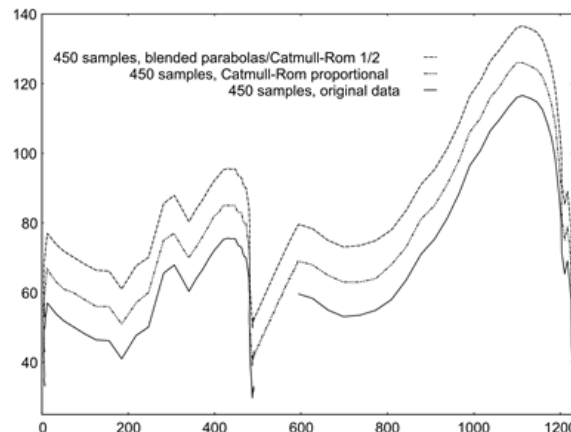


Fig. 10. Interpolation methods applied to filling in the gaps (projection onto XY plane, marker LFT1, markers' trajectories with filled gaps are offset relative to the original data in order to make visual examination easier)

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Authors: dr inż. Jakub Smółka, Politechnika Lubelska, Instytut Informatyki, ul. Nadbystrzycka 36B, 20-618 Lublin, Email: jakub.smolka@pollub.pl, dr inż. Maria Skublewska-Paszkowska, Politechnika Lubelska, Instytut Informatyki, ul. Nadbystrzycka 36B, 20-618 Lublin, Email: maria.paszkowska@pollub.pl
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