USING INFRA-RED MOTION CAPTURE DATA TO MEASURE THE BOW PRESSING FORCE IN BOWED STRING INSTRUMENTS

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Abstract: A method for estimation of bow pressing force is proposed. Infra-red motion capture data are processed and some descriptors are computed; tilt angle, bow transversal position, bow deformation and hair ribbon deflection. Using the descriptors, machine learning and the force data observe, a model is obtained and trained in order to estimate the bow pressing force. Several processes were followed to get the highest correlation and a lower error. The best results were obtained using a classification process of the data into "force" and "no force" existing, followed by a regression process. The models obtained were used with data of real performance but the result wasn't good. The movement of the bow during calibration process and real performance data is different, and the calibration bow movement was done by non-musician, so it could be possible that the calibration data doesn't cover all the possible behave of the bow as in a real performance.

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Chapter 1
Introduction

A score is only a piece of paper without a performer. The performer has de power to bring to live the music writes in this paper.

The score has the composer's indications and the performer has to interpret them. The aim of some indications are expression, like dynamic, *piano*, *forte*, etc., and other indications are for gestures, like *staccato*, *legato*, *pizzicato*, etc. All the musicians know the meaning of each indication, but each performer plays them in different way. The composition could have different meanings depending on how it's performed.

The quality of a performer depends on the way of play a musical composition and how the musician transmits emotions with his/her performance.

1.1 Motivation

Music performance has been always in the point of view of research to try to understand how the physical action applied by the performer affects to the sound and the instrument behavior. Thus computational performance approaches appears.

Within computational performance modeling, four main tasks can be differentiated: measuring, analysis, modeling and synthesis. Measuring deals with acquiring data from real performance, i.e. note onset times, blowing pressure, pitch or blow velocity. Two main methods exist for acquiring data, direct or indirect acquisition. For example, to know what the position of a finger is when you are playing the guitar, it can do it

directly using a camera or a capacitive sensor, or indirectly using the pitch from the audio.

The following step is to analyze the data in order to find some similarity with reality. Then a model could be generating to predict patterns or behaviors of the instruments. And finally it can be generate a synthetic performance from the model.

Bowed string instruments are one of the most difficult instrument to play, to measure and to synthesize because the complexity of how it is performance. The most difficult parameter to measure in bowed string instrument is the force.

This project is focused on measuring and analysis force during violin performance.

1.2 Goals

Obtain a method to estimate the bowing pressing force, depending on the bow deformation, bow position, tilt and pseudo force applied.

This aims are related to a sort of secondary goals:

1. State of the art review of bowing force and fingering force.
2. Bowing force:
    a. Analysis and identification of motion capture data from calibration process.
    b. Extraction of descriptors from motion captures data to calculate the bow deformation, position and tilt.
    c. Develop of a regression model using machine learning to obtain force estimation from real performance.

1.3 Structure of the thesis

1. Introduction: Motivations and goal.
2. State of the art: relevant existing research about force estimation in bowing.
3. Methodology.
4. Results.
5. Conclusions and future work.
6. Appendix.
7. Bibliography.

Chapter 2
State of the art

2.1 Violin

The violin is a bowed string instrument, so it is played using a bow to control the sound level, timbre and articulation. Using the left hand, the violinist selects the pitch and gives expressivity to the performance using, for instance, the vibrato.

The training of a violinist consists basically in get knowledge and control over the instrument. In the beginning, the student has the challenge of control the finger, wrist, and elbow movement among others. This movements are tiny and imperceptibles but with importance in the sound. The violin technique is complex and it covers the position of the body, the hands, the body movements, the bow position and movement, etc.

The base of a good violin technique is to control a high variety of bow strokes, which gives variety and richness in musical dynamic of the performance. The bow strokes has a huge important in the sound and helps to express the violinist personality. Each bow strokes requires a certain force, a particular position and velocity to have the right execution. Measure this parameters is a difficult task due the complexity of measure without any intrusiveness system.

Depend of the position of the bow, frog, middle or tip a different force has to be applied. Choosing a bow position close to the frog the musician gets a maximum force. Normally it’s used to forte notes, to start playing with energy or culminate a crescendo. Choosing a bow position close to the tip it obtains soft notes, figure 1.

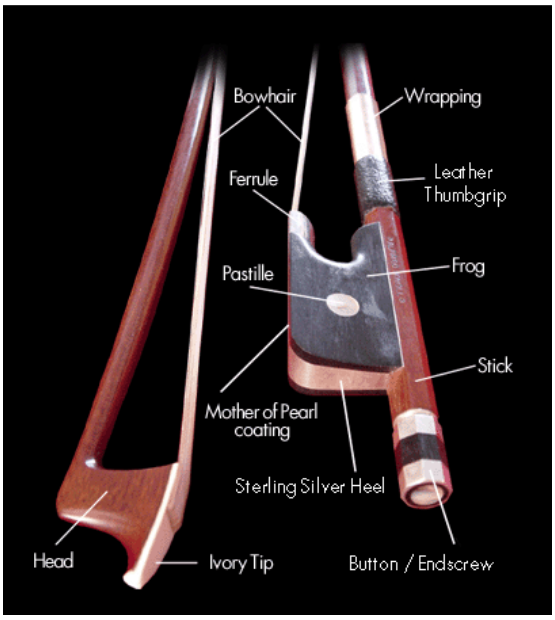


Figure 1 Part of a bow

In relation with finger force, the left hand finger press the string against the fingerboard of the string instrument to control pitch. It's necessary a force to press the string down so it barely touches the fingerboard.

The interest of measuring control parameters in playing could help in the study of musical instruments by physical modeling, the control parameters of the model become the same as for the real instrument.

2.2 Bowing force

Bowing force has been studied since 1986 with Askenfelt, who was the first one to start studying of measure the bow motion in string instrument (1) [Askenfelt 1986]. The measure the bow position using a thin resistance wire inserted amongst the bow hairs. Bow velocity was calculated from the slope of the both position curve in parts of interest. Bow force was measured using four strain gauges glued to the bow hair in frog and the tip and connected to a Wheatstone bridge, figure 2.

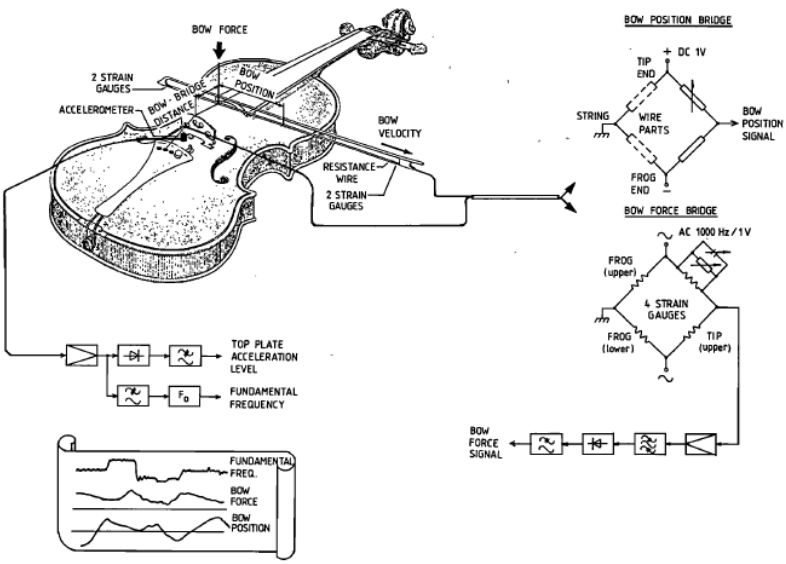


Figure 2 Equipment used for registration of bow motion

Paradiso propose a new method to measure the bow position using wireless (2) [Paradiso 1997]. He built two drivers in the bow and used the antenna in the bridge of the violin as a receiver. The bow pressing force is measured using a force-sensitive resistor below the forefinger. The main problem of these systems is the intrusiveness that affects to the player.

Young measured the bow pressure with strain gages and the bow position was measured in a similar way as in Askenfelt. The strain gages are the midpoint of the bow stick, the force data is sent via a wireless to a computer (3) (4) [Young 2002 and Young 2003].

Rasamimanana used accelerometers attached to the bow and force sensitive resistors (FSRs) to measure of bow pressure, obtaining the strain of the bow hair. This system can be attached to any bow, so it is a big advantage (5) [Rasamimanana 2003]

Demoucron proposed to use two strain gages, one at the frog and other on the tip, to detect the bow pressing force in function of the hair ribbons deformation and the bow position (6)[Demoucron 2006].

Guaus worked in a system to measure the pressing force that a violinist applies to the string through the bow using two string gages attached one to the frog and the other to the tip. The deformation of the hair ribbons modify the behavior off an electronic circuit

which was connected to a microcontroller to converts the data to MIDI format (7)[Guaus 2007].

In Guaus 2009 they improved the worked done to obtain real force values in Newton for long recordings using Polhemus Liberty system (6DOF) to obtain the localization and orientation of the violin body and the bow, electromagnetic field (EMF), figure 4, and strain gage attached to the frog of the bow , figure 3.

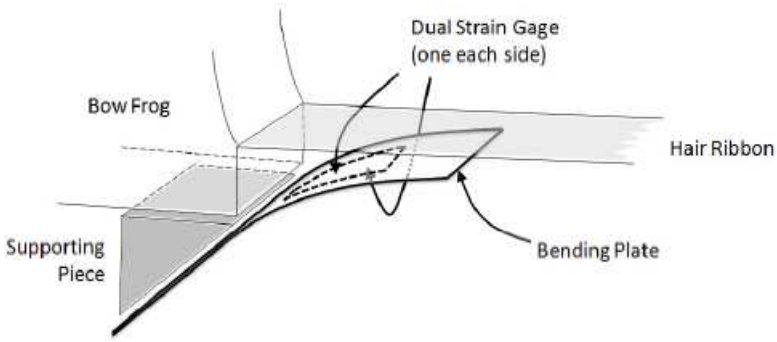


Figure 3 Strain gage at frog of the bow

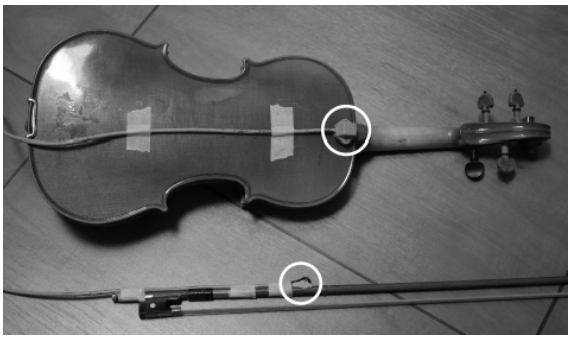
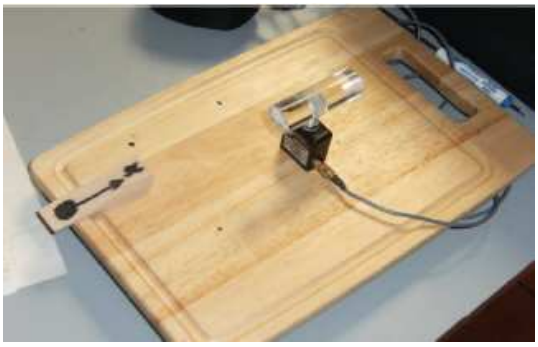


Figure 4 EMF violin and bow

In the process of calibration they used a load cell, figure 5, to obtain the real force in Newton; the cylindrical piece is a virtual string so the bow is played using this virtual string as a normal string.



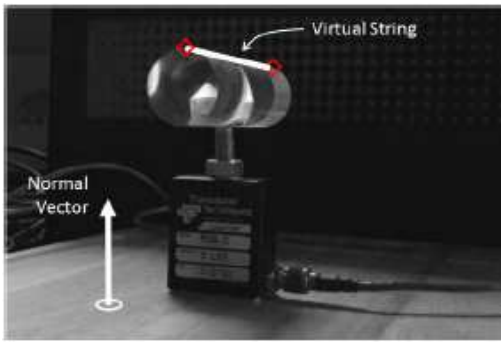


Figure 5 Load cell

The problem of this system was the intrusiveness to the player and making difficult a prolonged use of the stage (8)[Guaus et.al. 2009].

Marchini worked on a novel methodology for the estimation of bow pressing force. The technique was based on using a physical model of the hair ribbon deflection. This model used the position and orientation measurements of the violin and the bow coordinates. The acquisition of the instrumental gesture parameters was done using the Polhemus Liberty system, a 6DOF tracking system based on EMF and done in real time. Real force data was acquired using a load cell and the physical model was calibrated and evaluated using this data. The methodology reduced the intrusiveness, obtaining high accuracy. (9) [Marchini et.al. 2011]

The goal of this project is based in [Guaus 2009] and [Marchini 2001]. The aim is find a method to estimate the bowing force using the motion capture calibration data obtained using a load cell.

Chapter 3

Methodology

3.1 Data Processing

To develop this work, we had infra-red motion capture data and load cell calibration data provided by MTG from SIEMPRE project (Social Interaction and Entrainment using Music Performance Experimentation) in collaboration with McGill.

The data base consists in recording of violin I's bow, violin II's bow, viola's bow and violoncello's bow of three different days during force calibration process. Each recording has duration of 1:30 minutes approx. and the sample rate is 300Hz.

Were recorded using infrared cameras (IR) and each bow had markers which were captured by the IR with 3DOF. Each bow had six markers, three on the frog and three on the tip, as it's shown in the figure 6. The frog markers are considering a rigid body, as the tip markers.

Figure 6 Bow markers

The marker position is known for each frame. We used Qualisys to identify and label the information of each point, figure 7.

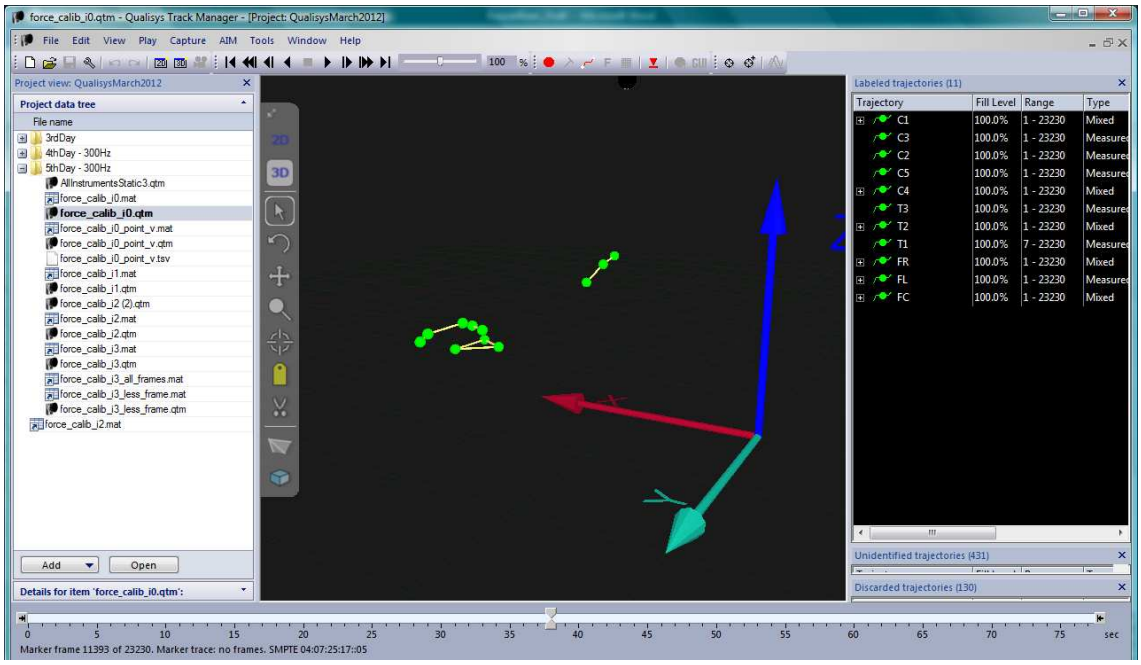


Figure 7 Qualisys

3.1.2 Data force

In order to design and evaluate our system, the force data were measure using a NI DAQ load cell during the calibration process at sample rate of 24000Hz, as in [Guaus 2009] and [Marchini 2001]. The cell has a cylinder to simulate a virtual string, figure 5. As well, some markers were added to the cylinder at the base of the load cell and they were recorded during the calibration process.

The output of the load cell is a voltage, which is processed to match the corresponding value in Newton using $y = qx + s$, where q is the voltage gain and s is the voltage offset.

3.1.3 Data synchronization

Once all the data are identify with Qualisys, the data is export to Matlab. At this point, it's necessary do a resample of the data due the motion capture and the load cell data has different sample rate. As well, a synchronization of Qualisys data and NI DAQ data is needed to know the data force for each instant of Qualisys.

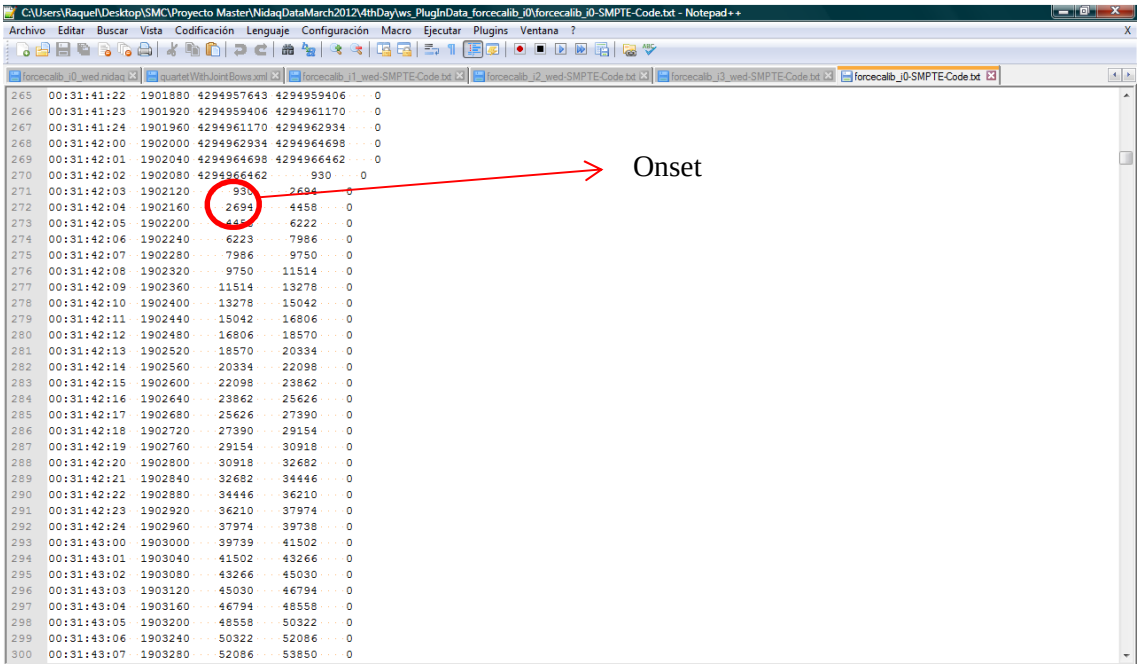
To synchronize the data, we have the Qualisys information (which gives data about the start and end frames and subframes), the NI DAQ force information and SMPTE time code information:

- The SMPTE time code at 44100Hz gives the onset information of each frame.
- It's necessary to know in what frame starts Qualisys data and see from what instant we have information of force, for that we used SMPTE time code.
- We go to the same frame of SMPTE than Qualisys, and then we check the onset audio frame, figure 8. In order to know what data force corresponds with the onset we apply the following process:

$$nidaq\ sample = \frac{SMPTE\ onset}{fmSMPTE}\ x\ fmnidaq \quad (1)$$

Where fmSMPTE is 44100Hz and fmnidaq is 44100 Hz.

- With this process we know the data force for each frame/subframe of Qualisys data



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266	00:31:41:23	1901920	4294959406	4294961170	0
267	00:31:41:24	1901960	4294961170	4294962934	0
268	00:31:42:00	1902000	4294962934	4294964698	0
269	00:31:42:01	1902040	4294964698	4294966462	0
270	00:31:42:02	1902080	4294966462	930	0
271	00:31:42:03	1902120	930	2694	0
272	00:31:42:04	1902160	2694	4458	0
273	00:31:42:05	1902200	4458	6222	0
274	00:31:42:06	1902240	6223	7986	0
275	00:31:42:07	1902280	7986	9750	0
276	00:31:42:08	1902320	9750	11514	0
277	00:31:42:09	1902360	11514	13278	0
278	00:31:42:10	1902400	13278	15042	0
279	00:31:42:11	1902440	15042	16806	0
280	00:31:42:12	1902480	16806	18570	0
281	00:31:42:13	1902520	18570	20334	0
282	00:31:42:14	1902560	20334	22098	0
283	00:31:42:15	1902600	22098	23862	0
284	00:31:42:16	1902640	23862	25626	0
285	00:31:42:17	1902680	25626	27390	0
286	00:31:42:18	1902720	27390	29154	0
287	00:31:42:19	1902760	29154	30918	0
288	00:31:42:20	1902800	30918	32682	0
289	00:31:42:21	1902840	32682	34446	0
290	00:31:42:22	1902880	34446	36210	0
291	00:31:42:23	1902920	36210	37974	0
292	00:31:42:24	1902960	37974	39738	0
293	00:31:43:00	1903000	39739	41502	0
294	00:31:43:01	1903040	41502	43266	0
295	00:31:43:02	1903080	43266	45030	0
296	00:31:43:03	1903120	45030	46794	0
297	00:31:43:04	1903160	46794	48558	0
298	00:31:43:05	1903200	48558	50322	0
299	00:31:43:06	1903240	50322	52086	0
300	00:31:43:07	1903280	52086	53850	0

Figure 8 SMPTE time code information

After synchronized the data force and the Qualisys data, we can start to compute descriptors.

3.1.4 Virtual hair ribbon end points

The initially position of all markers is known, figure 9. Also, the information about the position of hair ribbon ends in the coordinate system of their respective rigid body, frog and tip, which weren't recorded.

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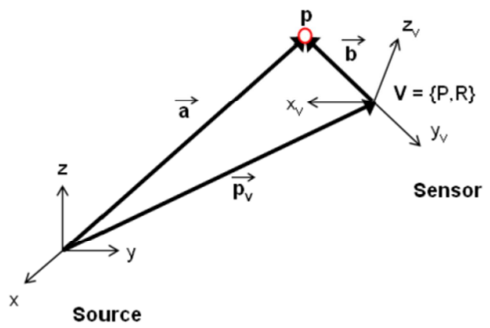
Figure 9 initially position of markers

The virtual hair ribbon points are useful to compute the bow descriptors, so we compute the position of this points end using a 3D translation / rotation. Two different coordinate system are defined, one by the information of the figure 9, initially position, and the other in the Qualysis system.



<u>Coordinate system of initial information:</u>

- For each rigid body, frog and tip, it's computed an orthogonal basis using some vectors defined by the frog points and tip points.
- It's computed the distance between the virtual point and one of the points of the frog and tip. In the case of the frog, it is define the middle point of the three markers. So the distance is between by the virtual point and the middle point frog.

$$d = virtual_{point} - p \quad (2)$$

Where d is the distance between the virtual point and the rigid body, the $virtual_{point}$ is the virtual point's coordinates and p is the coordinate of one of the point on the frog or tip, it depends of in with rigid body is the calculation.

- The coordinates of the virtual point in the local coordinate system is done by:

$$point_{ini} = \frac{Base_{local}}{d} \quad (3)$$

Where $point_{ini}$ is the local position of the virtual point in the orthogonal local base, $Base_{local}$ and d is the distance defined previously.

- The aim is to define the $point_{inil}$ in the Qualisys coordinate system of each rigid body.

<u>Qualisys coordinate system:</u>

- The orthogonal base of each rigid body is computed, $Base_q$ and the local position of the virtual point is defined using:

$$point_q = p_q + Base_q * point_{ini} \quad (4)$$

Where $point_q$ is the position of the virtual point in the Qualisys coordinate system, p_q is the selected point to calculate the distance of the virtual point to the rigid body, same point as in the initial coordinate system but express in the actual system, $base_q$ is the orthogonal base of the rigid body and $point_{ini}$ is the localization of the virtual point in the initial coordinate system.

We follow this process to compute the virtual hair ribbons point of the frog and the tip in the Qualisys coordinate system. Finally the descriptors are computed using all the information of Qualisys data and virtual hair ribbons end points.

3.1.5 Bow descriptors

Bow descriptors were computed using the infra-red motion capture data and the virtual hair ribbon points. The descriptor gives the information about tilt angle, bow transversal position, bow stick deformation and hair ribbon deflection.

Tilt angle

The tilt is defined by the angle between the string vector and the normal of the frog plane form by the three points on the frog, figure 8.

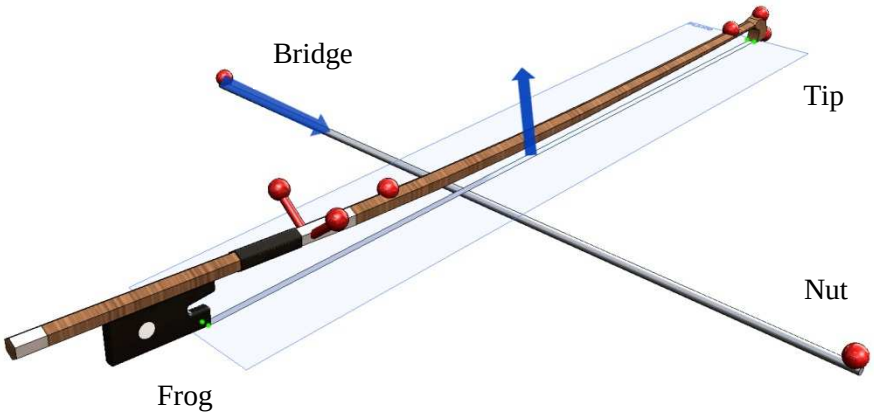


Figure 8 Tilt vectors

The figure 9 tell us that the bow tilt were changing during the calibration process, that the reason because the angle tilt increase and decrease.

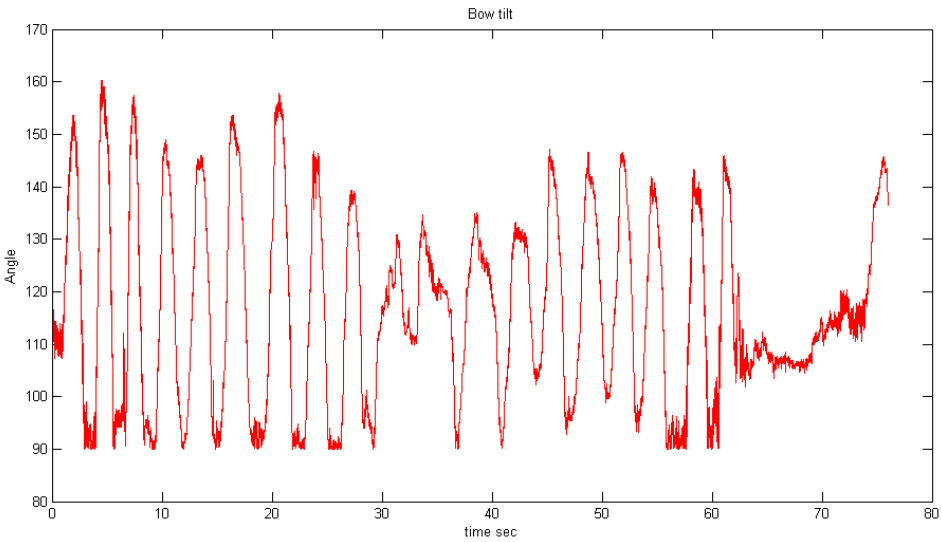


Figure 9 Tilt angle Violin 1, 5th day

Bow stick deformation

Bow deformation is defined by the angle between two vectors, one from the frog and other from the tip. The frog vector is composed by middle point of the triangle defined by the three frog point, and the central point on the stick. It's shown in the figure 10.

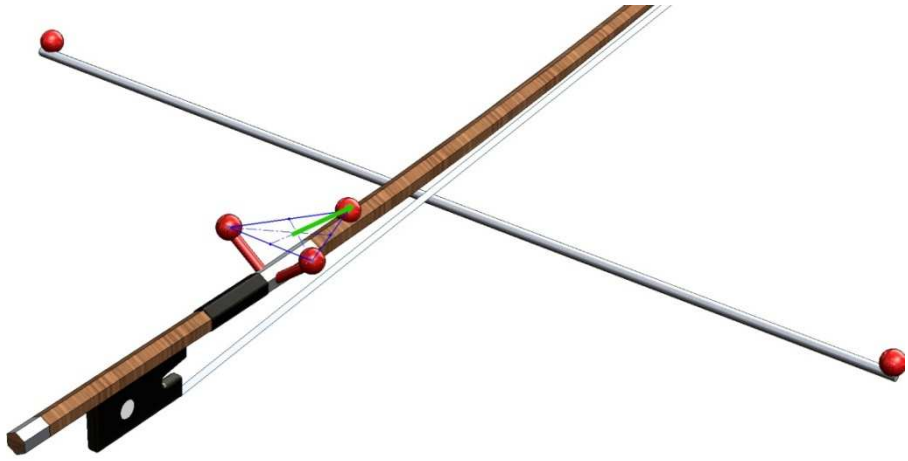


Figure 10 Frog vector

The vector in the tip is composed by two of the point on of the tip, figure 11. The deformation is the angle between these two vectors.

Figure 11 Tip vector

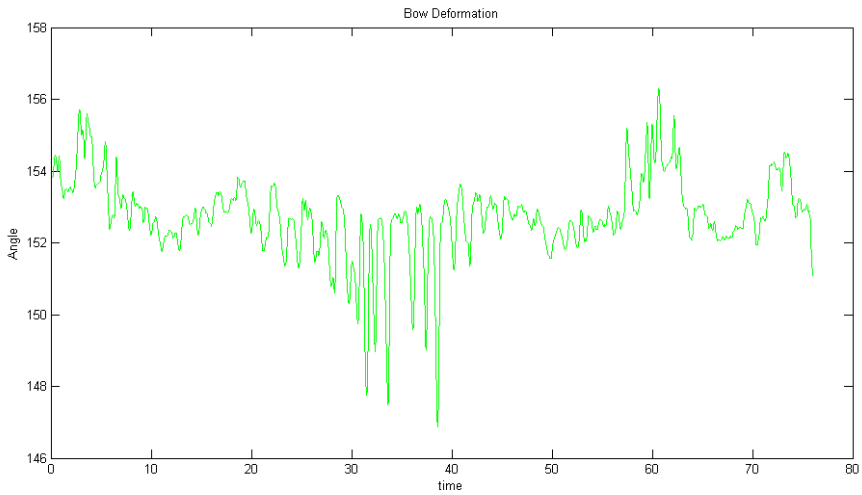


Figure 12 Bow deformation Violin 1, 5th day

Bow transversal position

It gives us the information of where is the bow respect the string. To measure the distance we calculated the intersection between the string and the hair ribbon.

For that, some segments are defined. In the figure 13 is show the segment between the virtual point of the hair ribbon.

Figure 13 Virtual hair ribbons

Another segment is delimited with the two points of the string. The intersection of the string segment and the hair ribbon segment is the points shown in the figure 14.

Figure 14 Intersection points

The bow position is the distance between the virtual hair ribbon point on the frog and the intersection point, the blue line in the figure 15.

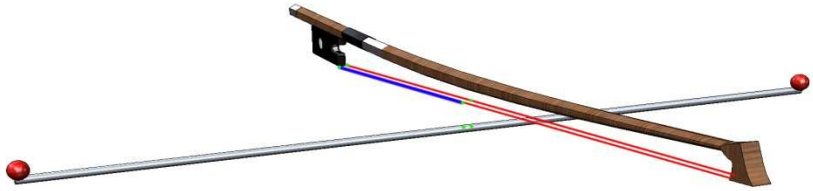


Figure 15 Bow position

The graphic, figure 16, shows the distance of the frog respect the string during the calibration process

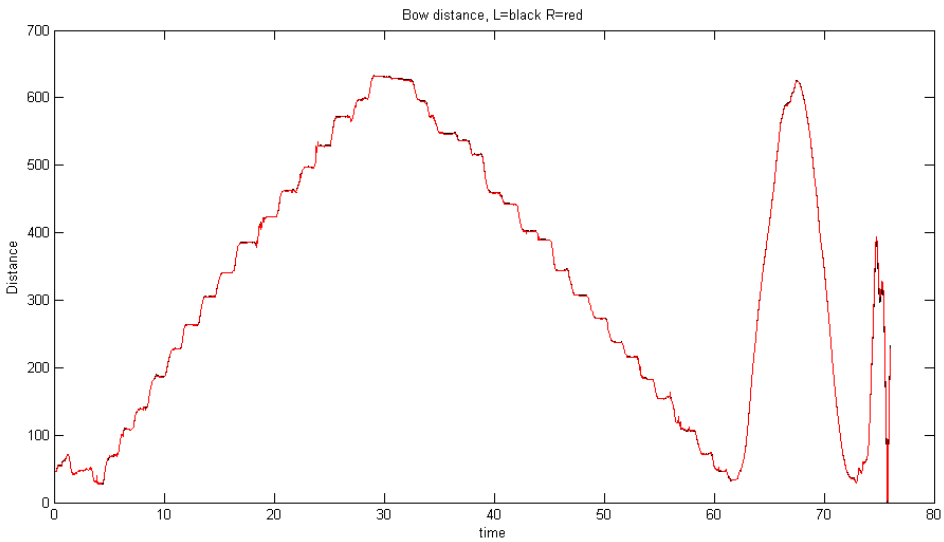


Figure 16 Bow position Violin 1, 5th day

Hair ribbon deflection

It's defined by the distance between the intersection points of the hair ribbon segment and the string segment, figure17.

Figure 17 Negative pseudo force R/L. Not Playing

It defined a vector between the intersection points, the direction of the vector will point out in different direction depends of if a force is applied or not. In our case, if the vector point out to down that means the bow is over the string, so it's not playing, figure 18.

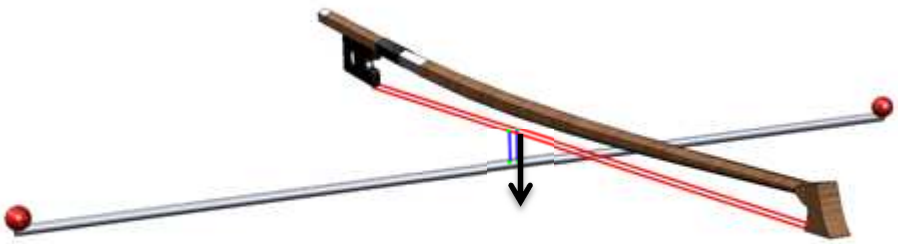


Figure 18 Bow over the string

When a force is applied, the hair ribbon suffers a deflection, figure 19, because the virtual string has more tension that the hair ribbon, so it's consider rigid.

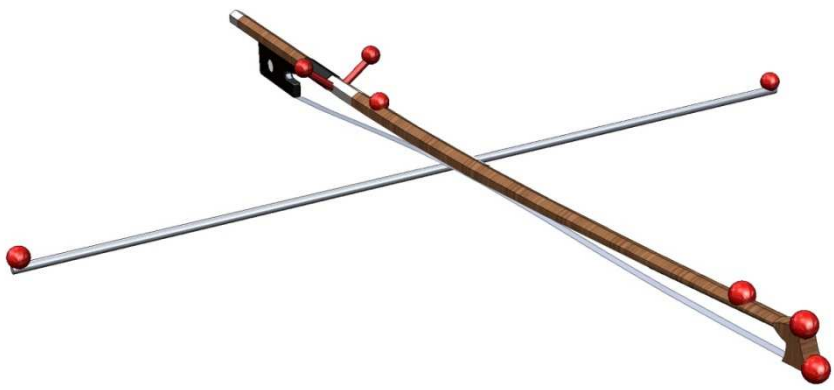


Figure 19 Hair ribbon deflection

In this situation, the virtual segment between the hair ribbon points is below the string, figure 20, and the vector point out up.

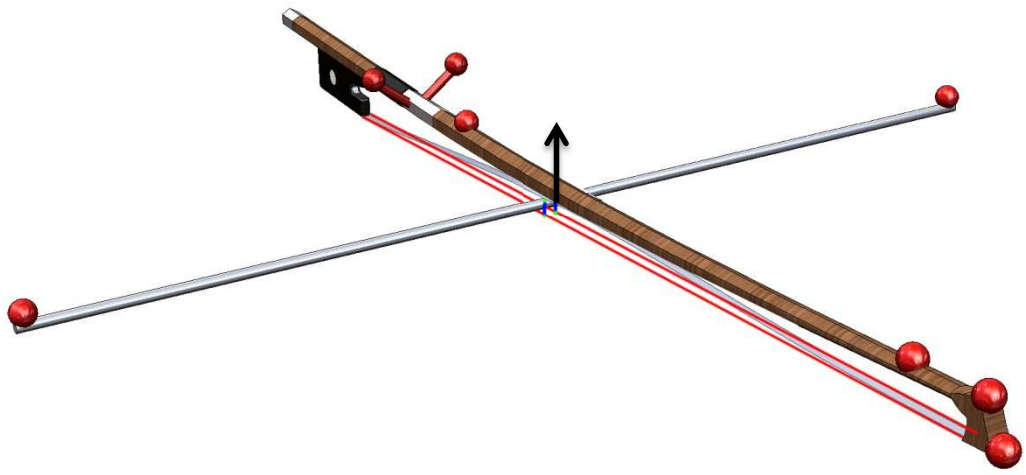


Figure 20 Playing

In the figure 21, it can be seen that when a force exists, the hair ribbon deflection is positive, and when a force doesn't exist, is negative.

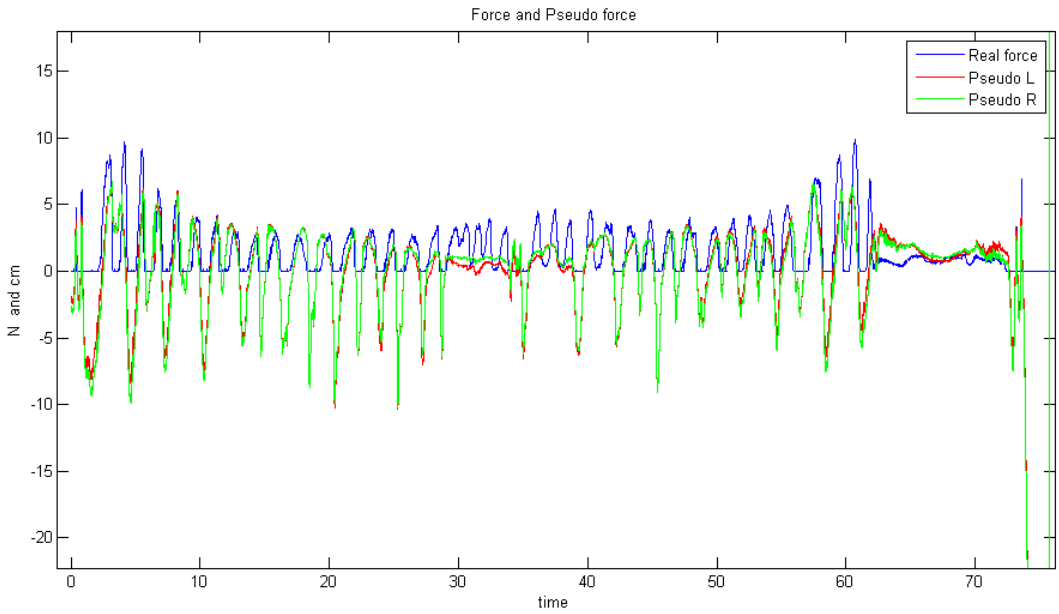


Figure 21 Hair ribbon deflection R/L Violin 1, 5th day

Depends of the tilt angle, the hair ribbon deflection will be different respect left and right. In the figure 22, when it exist a high tilt angle, the hair ribbon deflection L is different than the deflection R, that means it's is applied more force in the right side of the bow.

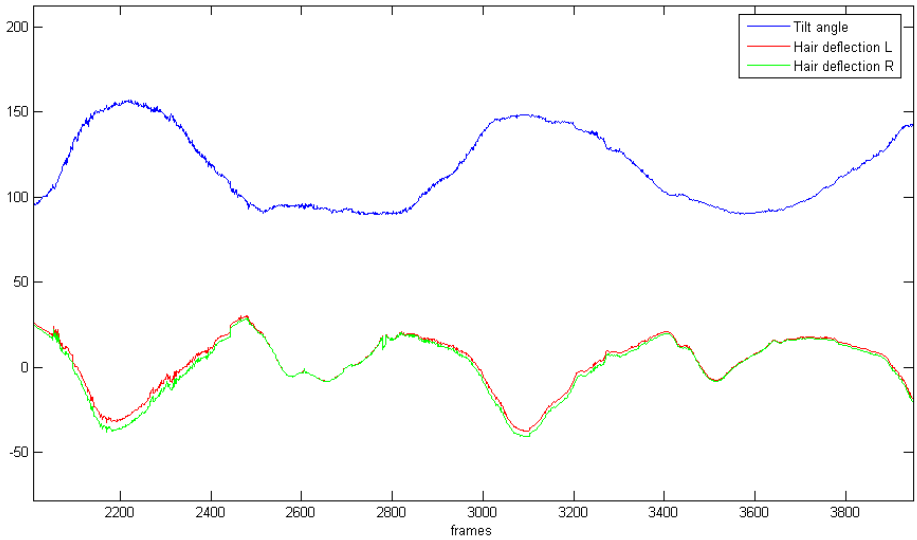


Figure 22 Tilt and Hair ribbon deflection

3.2 Bow force estimation

A regression model was compute using the descriptor data in order to estimate the bow pressing force.

To achieve the best results, we followed different process. First, the regression model was computed and tested. After that, we made a classification process to classify between "force" and "no force", and finally we combined both process. It was used support vector machine (Libsvm) with a radial Kernel:

$$exp(-gamma * |u - v|\text{^}2) \quad (5)$$

We played around with the parameter gamma, and using a value of 0.1 we obtained high correlation.

3.2.1 Regression model

To train and test the regression model, 10 cross- fold validation was used. This technique does a partition of the data into a training set, to train and obtain a model, and test set, to validating the model. For each fold, it is done different partition and the validation results are the averaged over the 10 rounds. Also, the root mean square error (RMSE) and correlation were calculated. RMSE is used to measure the differences between the values predicted by the regression model and the force values observed. Figure 23 represents the process.

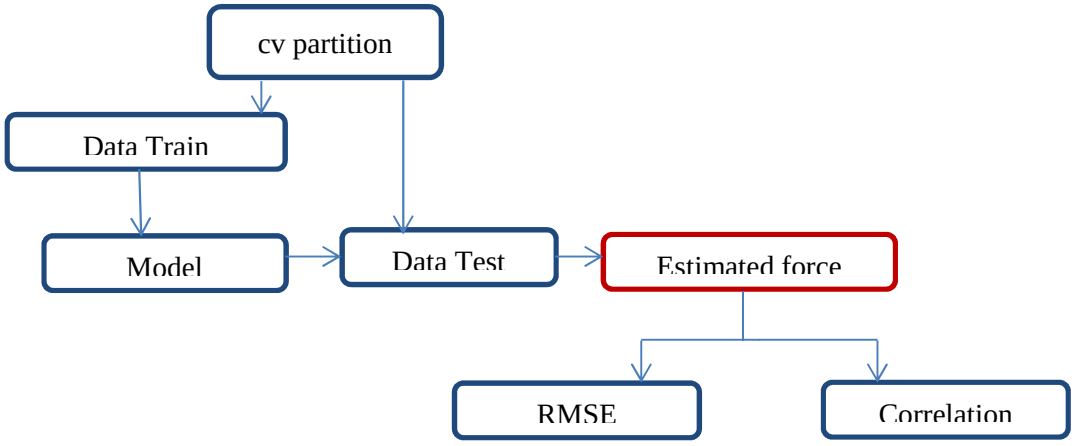


Figure 23 Regression process

	RMSE	Correlation
Violin	0.3960	0.9565
Viola	0.3755	0.9492
Violoncello	0.3755	0.9492

Table 1 Regression

In the figure 24 represent the violin force estimated using regression; an “onset” can be appreciated when the real force is close to cero (red-estimated force, blue-force obseved).

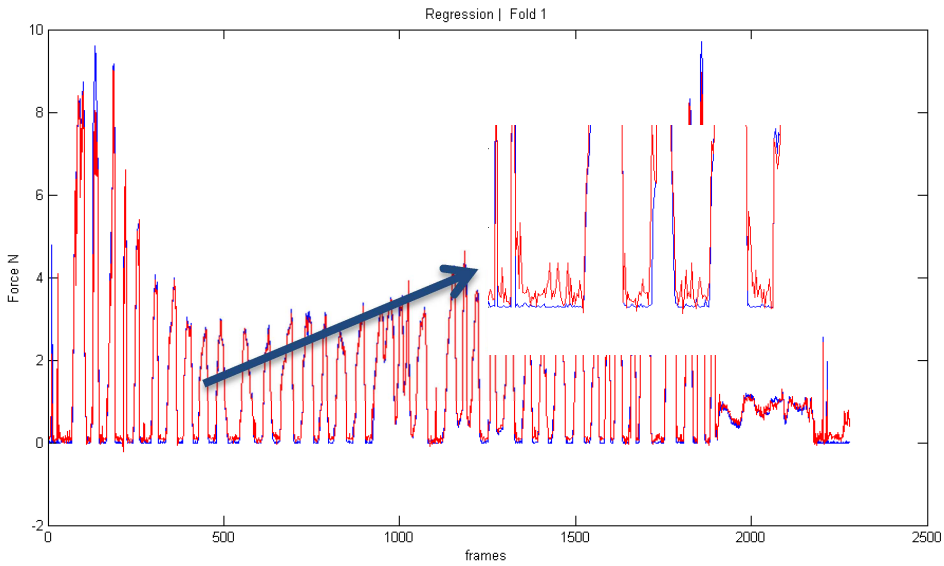


Figure 24 Regression force

In order to avoid this onset around cero, the force data was labeled by hand as “force” and “no force”. The regression model was calculated using only the “force” frames. The table 2 shows the results for each instrument.

Instrument	Mean RMSE (N)	Correlation
Violin	0.3929	0.9581
Viola	0.3945	0.9450
Violoncello	0.4073	0.9779

Table 2 Results by instrument

We could label the data as “force” and “no force” because we had the information of the real force measured, but what happed in the case of not have the force data? Thus a classification process was done.

3.2.2 Classification model

The aim is to classify the data as “force” and “no force”. The process is the same than in regression; 10 cross fold validation were used to train and test the model, process in figure 25.

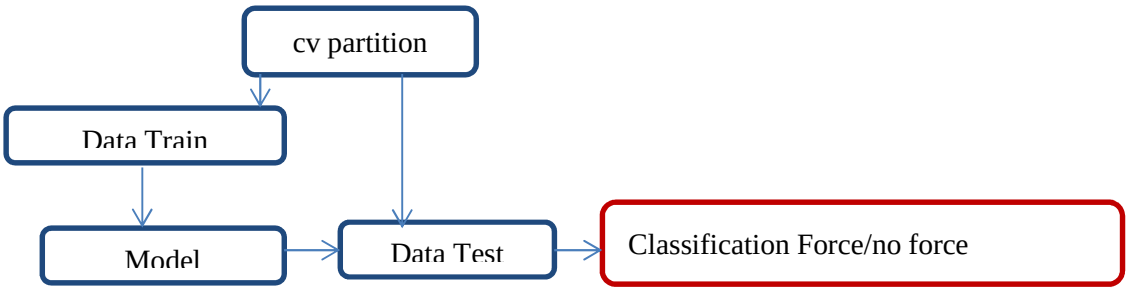


Figure 25 Classification process

Violin

	0	1
0	783	8
1	4	1483

Viola

	0	1
0	589	9
1	7	1193

Violoncello

	0	1
0	973	12
1	5	754

Table 3 Classification result

We combined the classification model and the regression model to improve the process of estimation pressing force

3.2.3 Classification and regression

To evaluate the method of classification + regression, we used as well 10 cross fold validation. Alter that, the classification model was applied to classify the data as “force” and “no force”. The regression model was applied only for “force” frames to obtain the estimated force. For that frames classified as “no force”, the estimated force was consider 0.

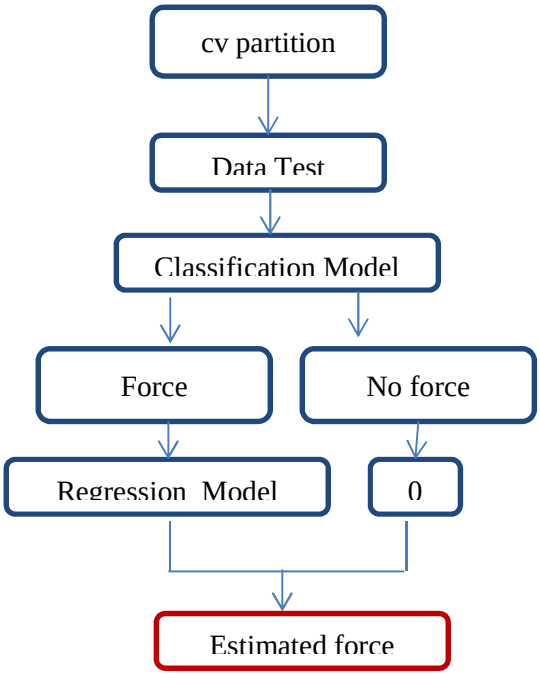


Figure 26 Classification + Regression process

The evaluation of the process is shown in the table 4 for each instrument. It can be appreciated a better result respect the only regression process.

Instrument	Mean RMSE (N)	Mean RMSE (Regress)
Violin	0.2791	0.3929
Viola	0.3431	0.3945
Violoncello	0.3145	0.4073

Table 4 Classification + Regression result

In the figure 27 is shown the real force, blue, the estimated force by regression, green, and the force estimated by classification + regression, red. We observe that the class + regress have better result than only regression

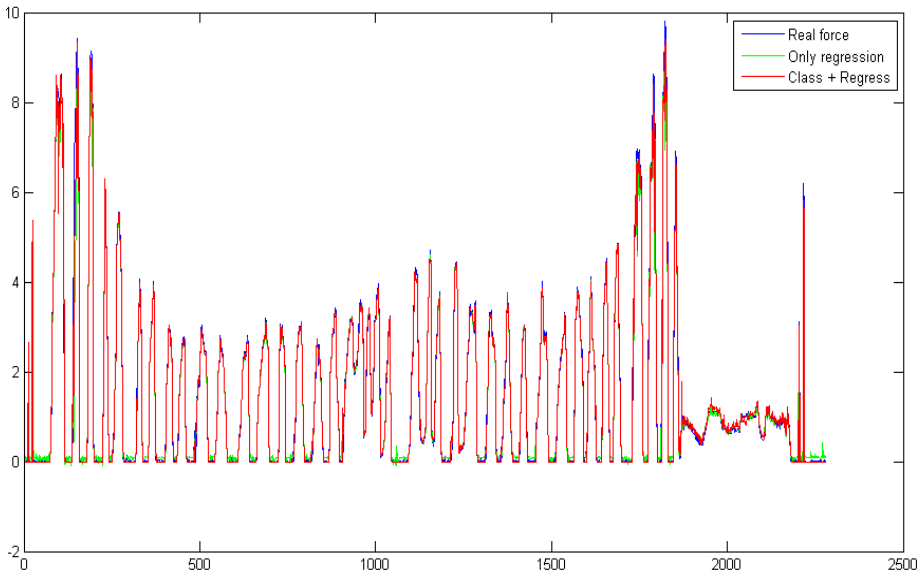


Figure 27 all result

If we zoom in the plot, which is the force estimated by regression (green) has the onset and the force estimated using classification and regression (red) doesn't have this onset, it looks like the real data force.

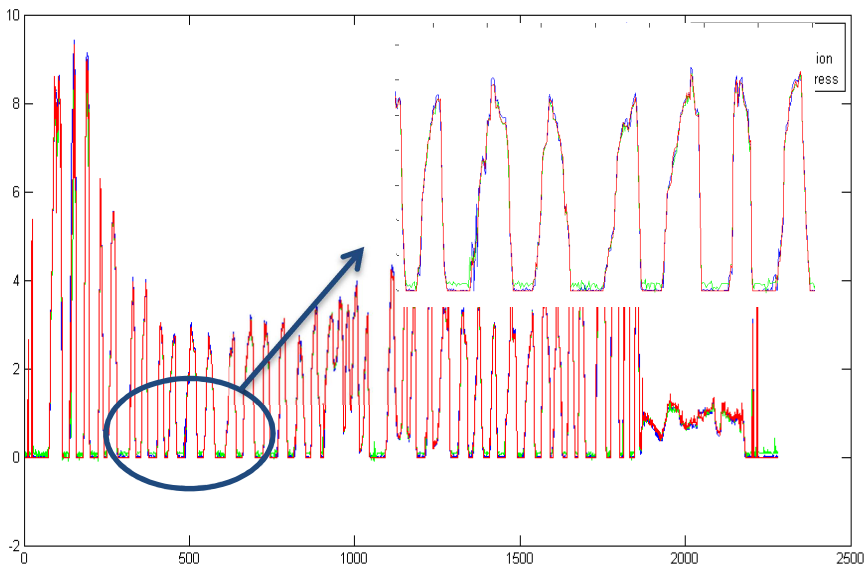


Figure 28 Zoom

Chapter 4

Results

4.1 Bow descriptors

The descriptors for violin, viola and violoncello were computed. The results showed in this chapter corresponds with the recordings of the 5th day of the database, approx. 1:30 min each one. Thanks to the descriptors we have the information of the movement and the behavior of the bow during the recordings.

4.1.1 Violin

In the figure 29, it can be appreciate all the descriptors for violin; bow tilt, bow deformation, bow transversal position and the hair ribbon deflection R and L (pseudo force).

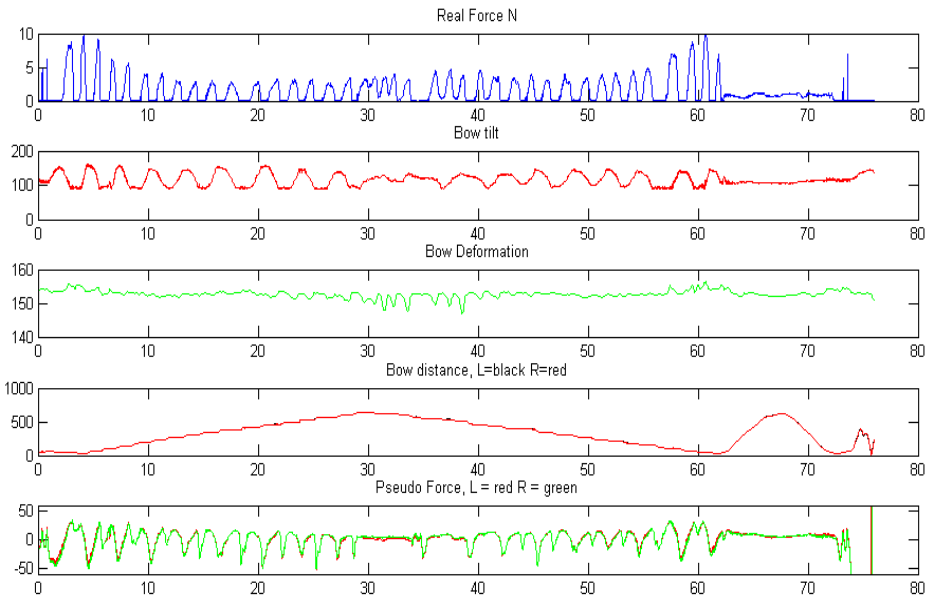


Figure 29 Violin's descriptors

During all the calibration process, the tilt is changing, we can see this in the descriptor, which increases and decreases.

The bow transversal position indicates the position of the frog respects the string, so with the plot, we can figure out the movement of the bow during the calibration process (it starts in frog-tip – frog – tip - frog).

The bow deformation has different behavior in the frog and the tip, figure 30, which it has sense because the bow has different behavior depended on the area.

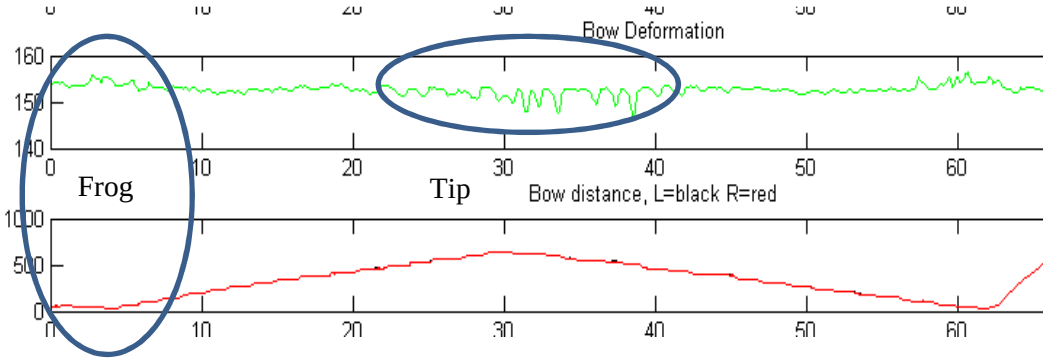


Figure 30 Zoom Deformation-bow distance

4.1.2 Viola

The viola's descriptor has more or less the same aspect than the violin's descriptors. The tilt is changing until the 40 sec and then it's constant, figure 31.

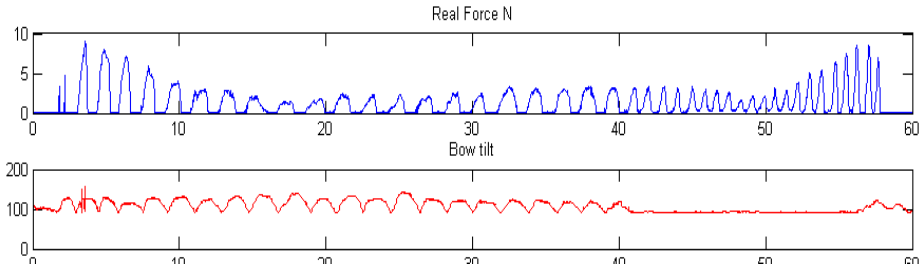


Figure 31 Viola's tilt

The deformation is different in the frog and the tip, the bow positions is different because the movement is and finally the hair ribbon deflection depends on the force and the tilt, figure 32.

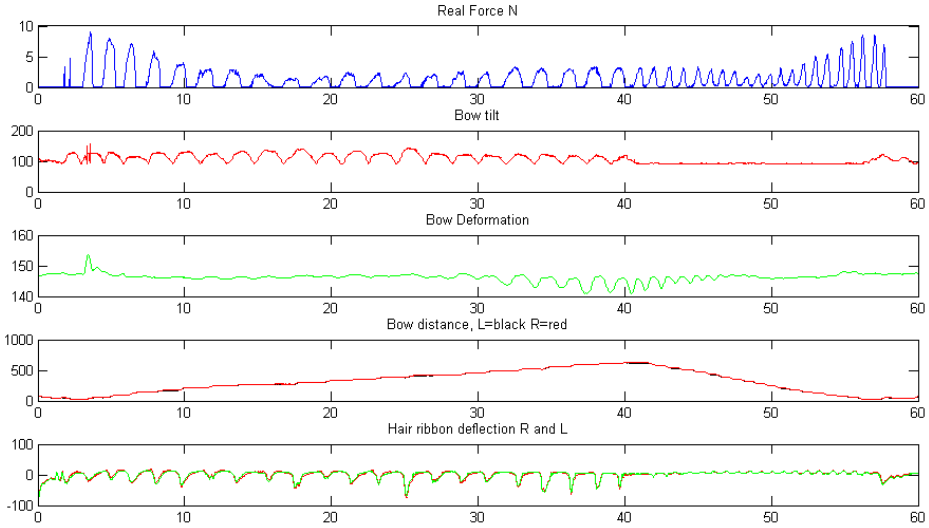


Figure 32 Viola's descriptors

4.1.3 Violoncello

In the violoncello's descriptors we see that the deformation is more flat than the viola's and violin's deformation. The bow is different, is bigger and the force applied by the performed is different as well, figure 33.

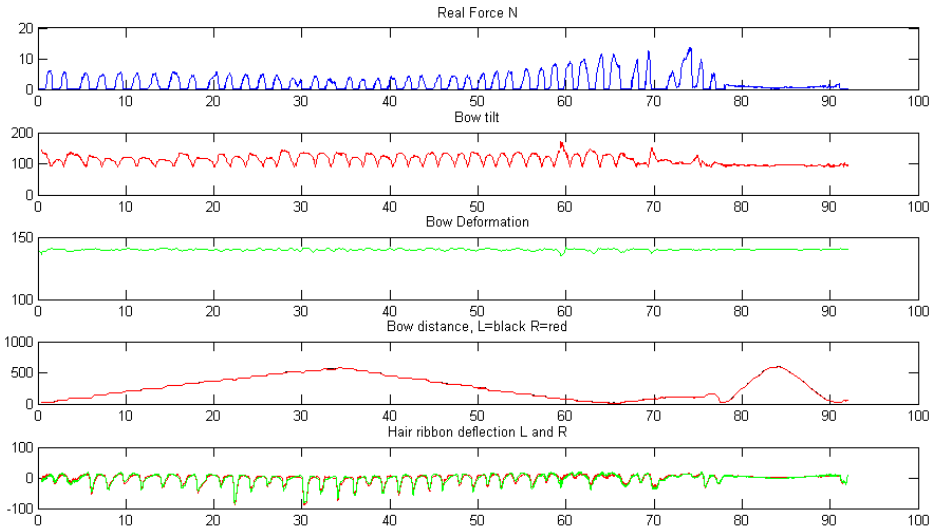


Figure 33 Violoncello's descriptors

4.2 Pressing force estimated

In chapter 3 was explained the process to estimate the pressing bow force. Regression process and classification plus regression process was compared. To improve the results of the estimated force, different process to select the best parameters to train and test models were followed.

1. **Windowed data**

   In this process are selected the frames labeled as "force". In order to do a different partition of the data, a window of 30 frames is defined. The procedure followed is:

   - Separation of the data in to windows.
   - Cross fold partition with the windows.
   - The windows selected for train are concatenate to create a training matrix, also with the windows for testing.
   - The same process of regression, figure 23, is followed.

   The aim of this process is to train the model with different part of the data, to avoid the similarity. The results obtained, table 5, are worse than the regression with the "normal" data because of that, but they give us a better idea of the estimated force now that, we are testing the regression model with data which hasn't similarity with the training data.

Instrument	Mean RMSE (N) (Window)	Correlation (window)	Mean RMSE(N) (normal)
Violin	1.0186	0.7163	0.3929
Viola	1.2183	0.4859	0.3945
Violoncello	1.43123	0.7332	0.4073

Table 5 Windowed data

Some of the result of the estimated pressing force for each instrument is shown in the following figures 34, 35 and 36 (red-estimated force, and blue- real force observed)

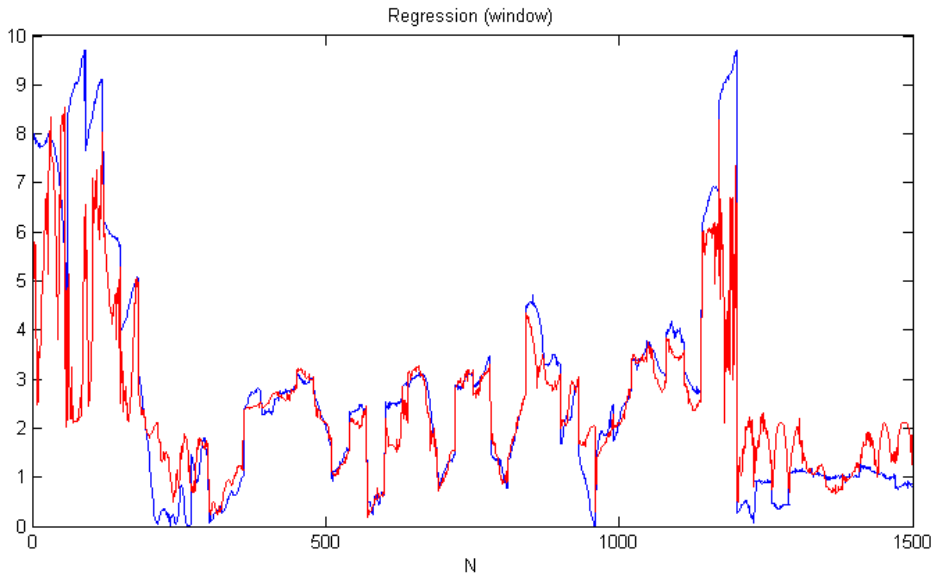


Figure 34 Regression (window), Violin

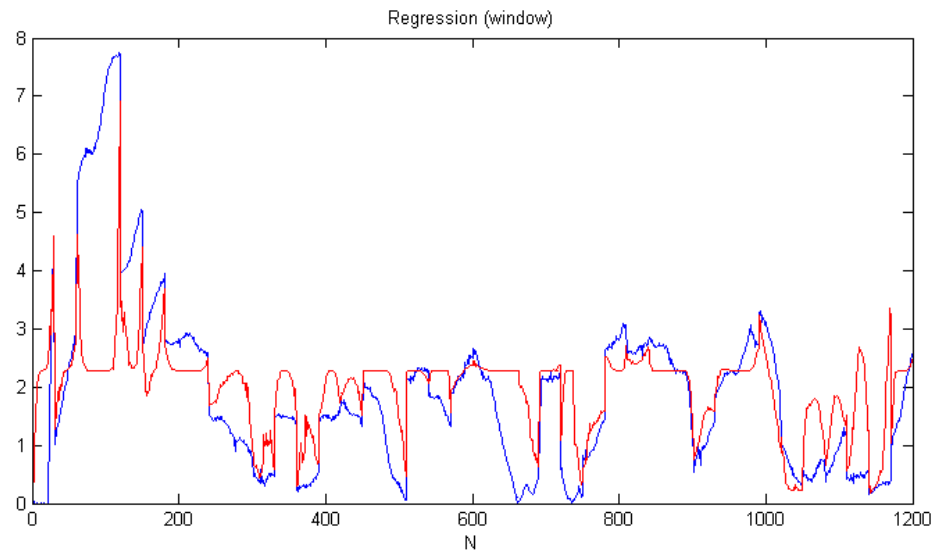


Figure 35 Regression (window), Viola

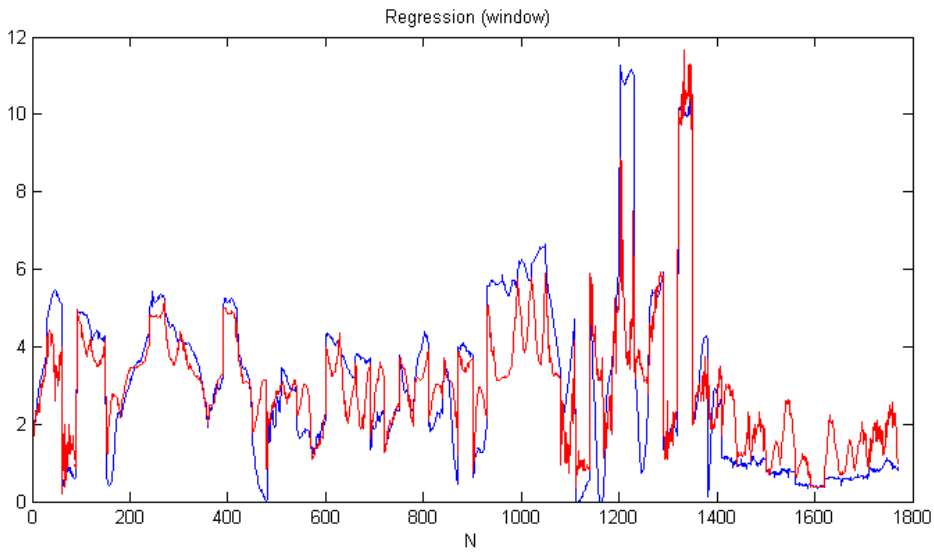


Figure 36 Regression (window), Violoncello

2. Smooth data

A smooth of 100 was applied to the data in order to compare the result obtained with the data without smooth in the process of regression. The result with smooth is much better than without, table 6.

Instrument	Mean RMSE (N) (Smooth)	Mean RMSE(N) (normal)
Violin	0.1729	0.3929
Viola	0.1947	0.394
Violoncello	0.2643	0.4073

Table 6 Regression smooth data

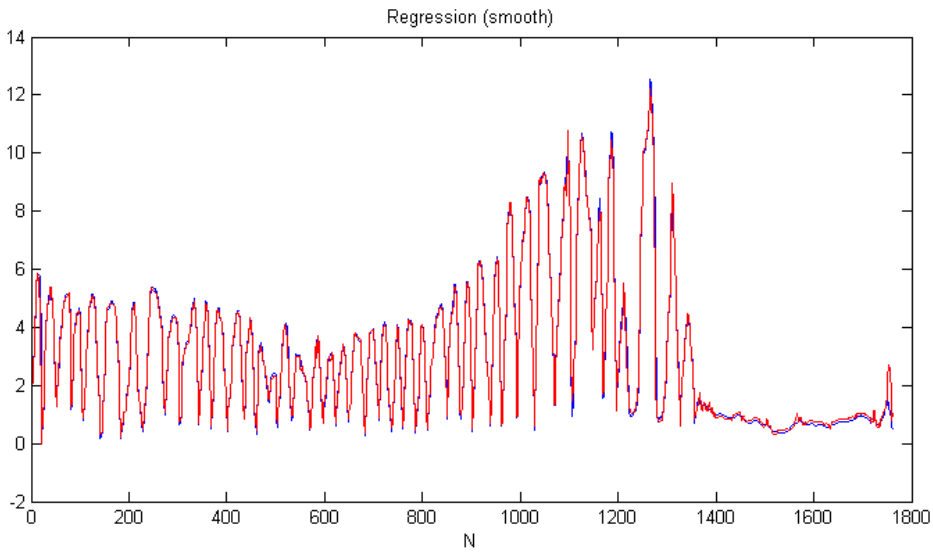


Figure 37 Regression smooth data, violoncello

3. Resample of the data

In this part with use a resampling of the data in order to avoid high concentration of sample in the parameters' area. The range of each parameter is divided in to smaller range, after that, this new range represents a block in the space. The algorithm keeps a maximum of N samples per block, if it has fewer samples than N, the function takes all the samples.

Also, with this method, the size of the data decreases so the time to compute a test the model is smaller.

Violin

Using this method, we obtain the same conclusion; the best result is using a gamma of 0.1, table 7.

Violin	RMSE	Correlation
5	0.9708	0.6126
0.1	**0.2193**	**0.9708**
0.01	0.2527	0.9582

Table 7 Regression Violin

The following plot shows the estimated force for gamma of 5 and 0.1; using a gamma 0f 5 the estimation has noise and don't estimate properly the low and high values, figure. In other hand with the gamma of 0.1 it obtains estimation very similar to the original force, figure.

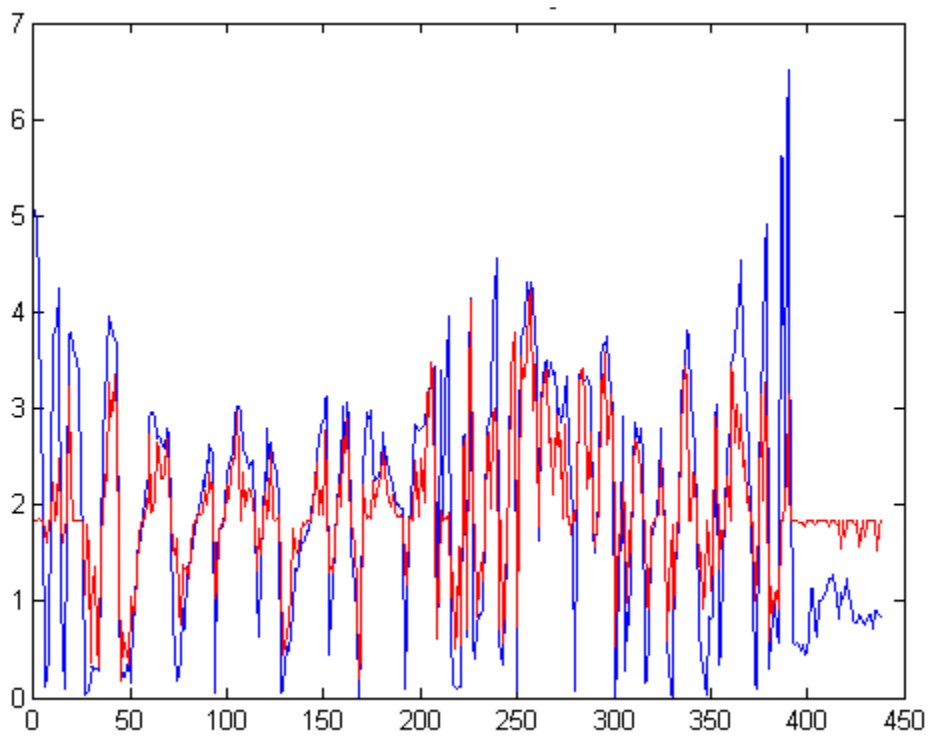


Figure 38 Regression (resample) gamma 5, violin

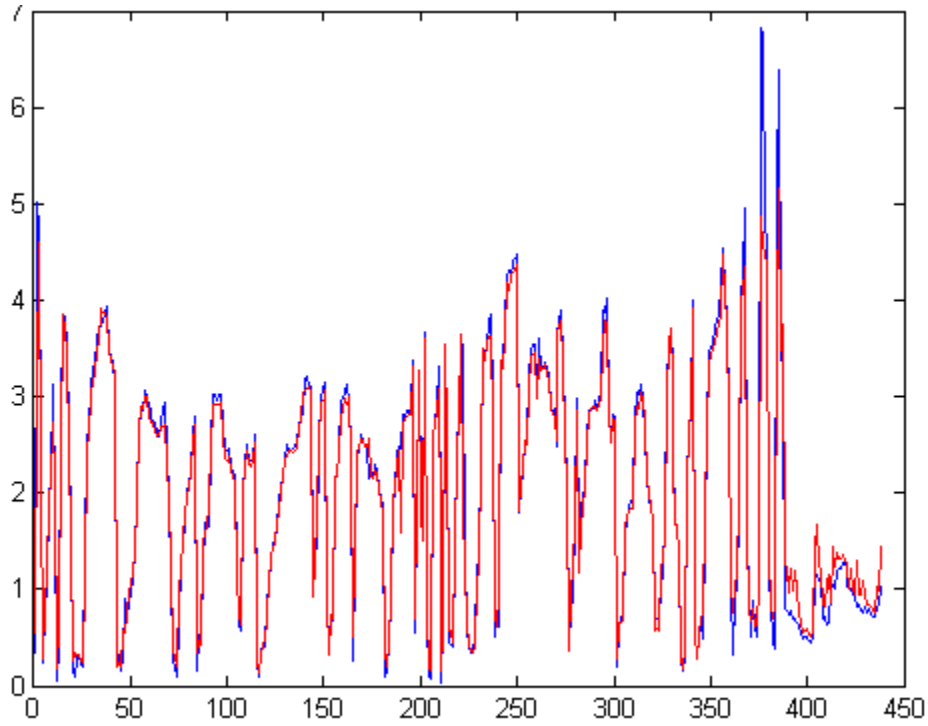


Figure 39 Regression (resample) gamma 0.1, violin

The same result are observed for viola and violoncello; the high correlation and less error is obtained using a gamma of 0.1 and radial Kernel.

Viola

Viola	RMSE	Correlation
5	1.3432	0.4409
0.1	**0.3634**	**0.9502**
0.01	0.4428	0.9252

Table 8 Regression viola

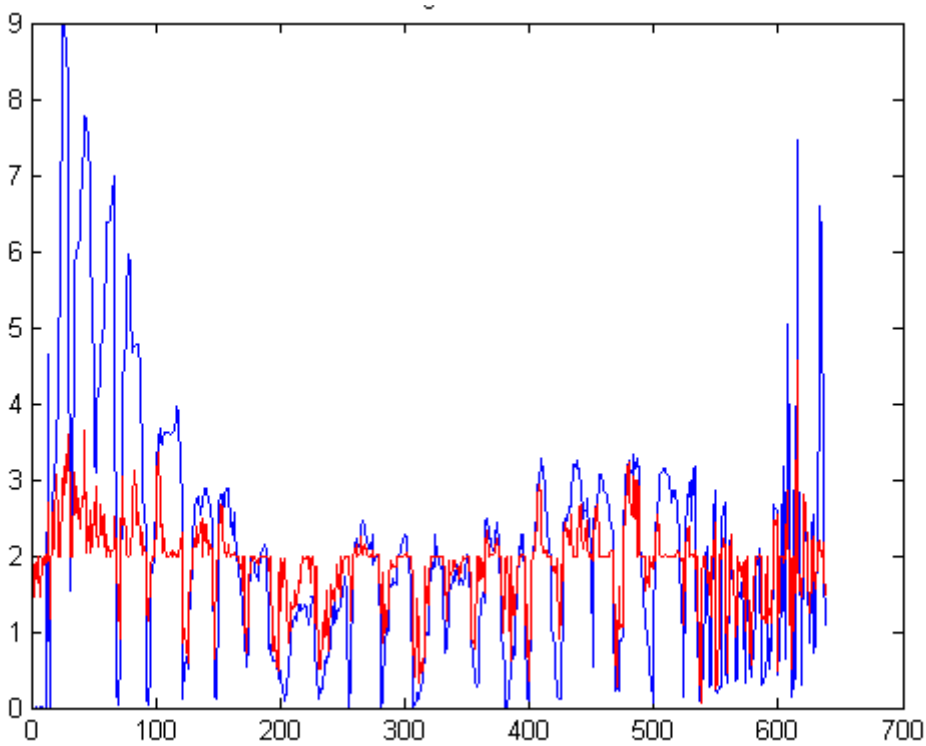


Figure 40 Regression (resample) gamma 5 viola

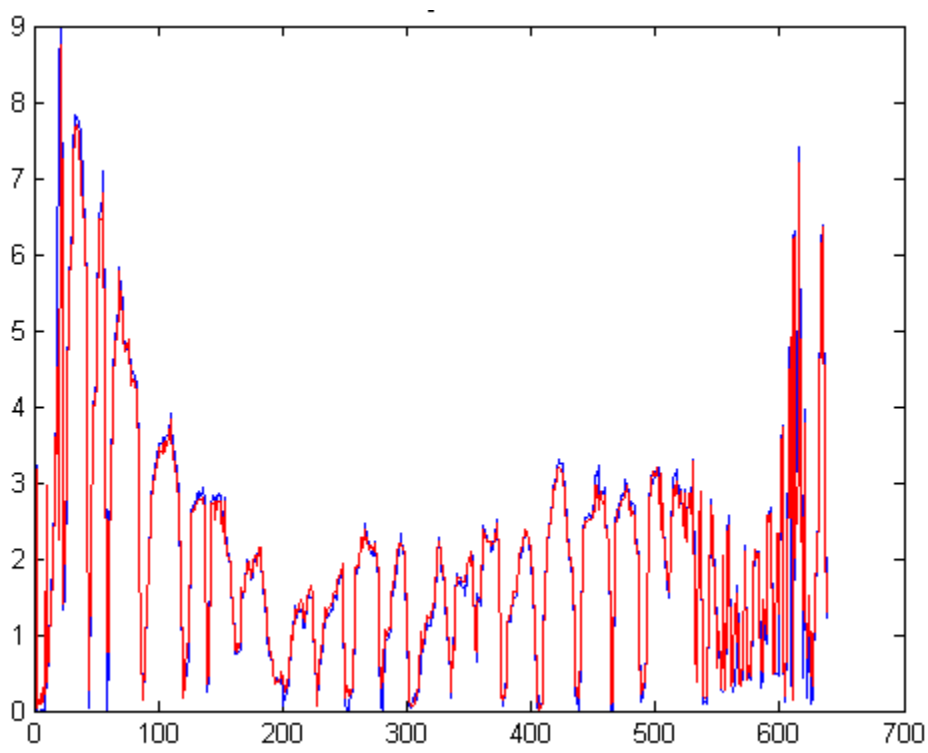


Figure 41 Regression (resample) gamma 0.1 viola

Violoncello

Violoncello	RMSE	Correlation
5	2.0034	0.4464
0.1	**0.5057**	**0.9611**
0.01	0.5672	0.9482

Table 9 Regression violoncello

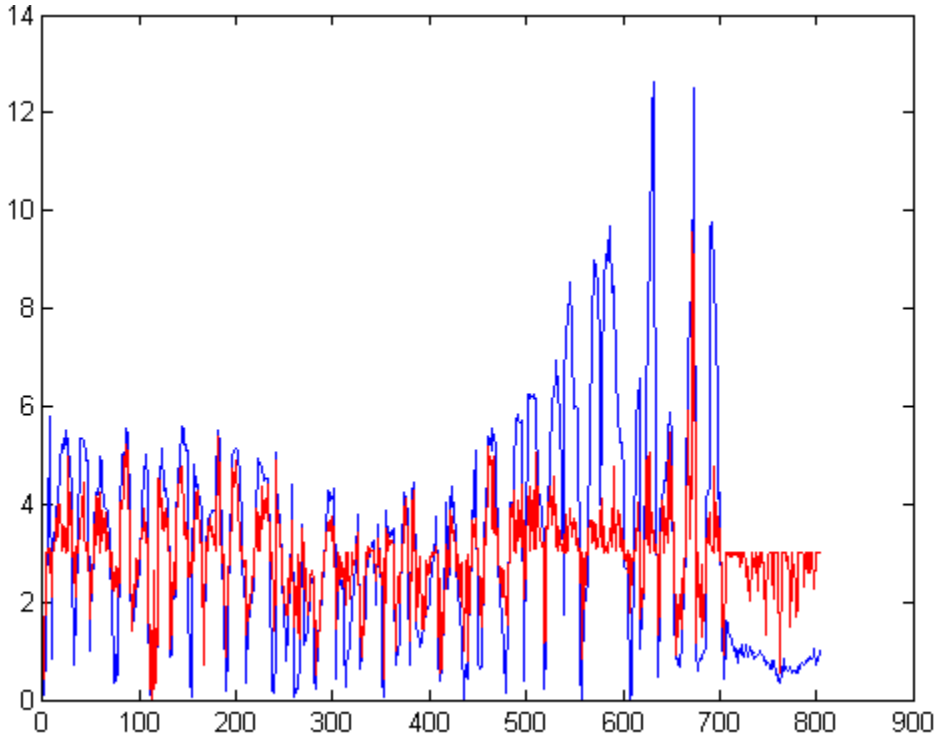


Figure 42 Regression (resample) gamma 5 violoncello

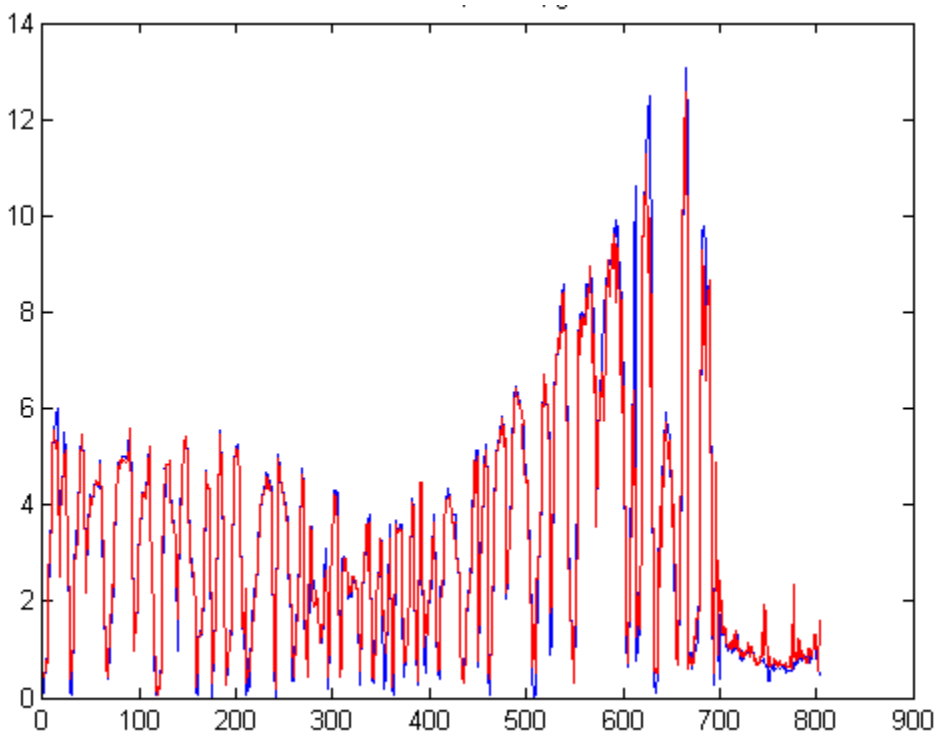


Figure 43 Regression (resample) gamma 0.1 violoncello

Linear Kernel

Using the resample data, the time to compute the models are faster, so we compute the models using linear kernel. The results are worse than using radial kernel. These are the results:

Instrument	Mean RMSE (N)	Correlation
Violin	0.7256	0.6764
Viola	1.6166	0.0707
Violoncello	1.84	0.5062

Table 10 Regression with linear kernel

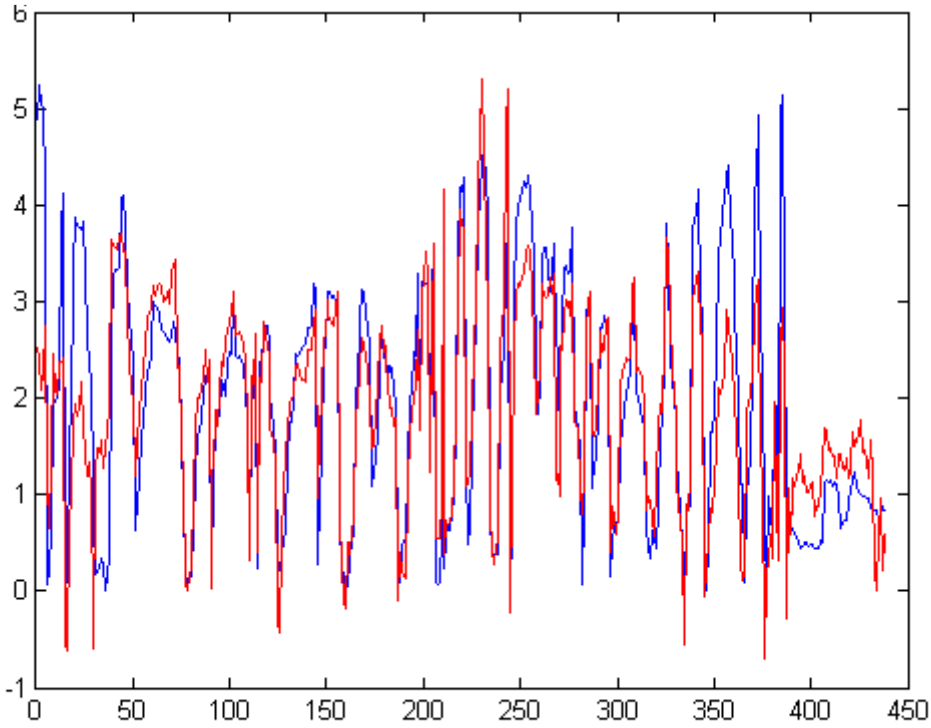


Figure 44 Regression (resample) linear kernel violin

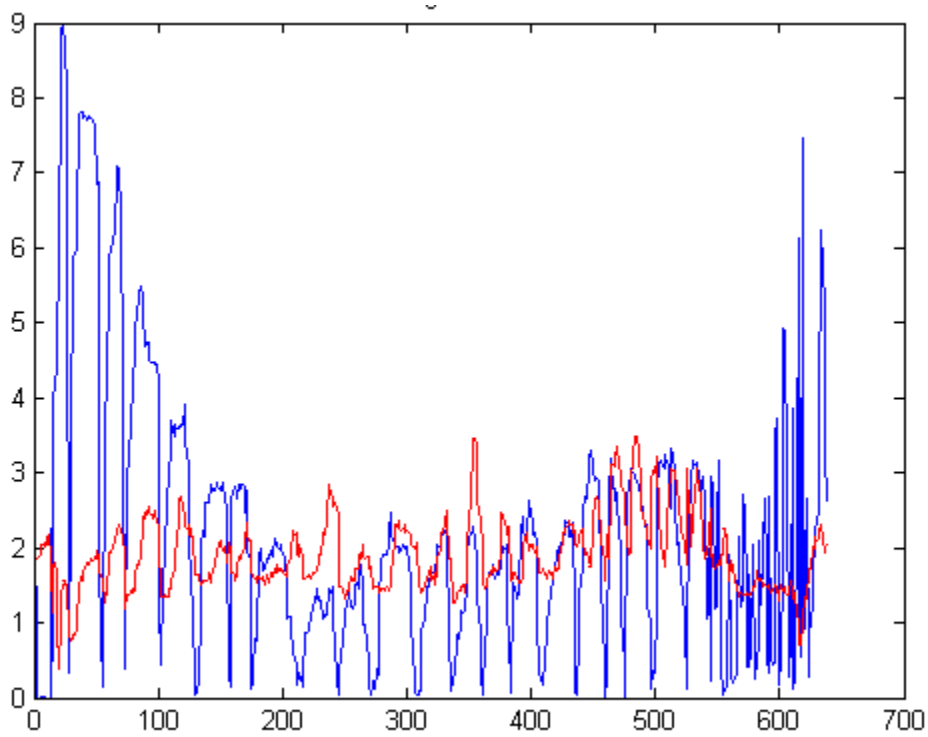


Figure 45 Regression (resample) linear kernel viola

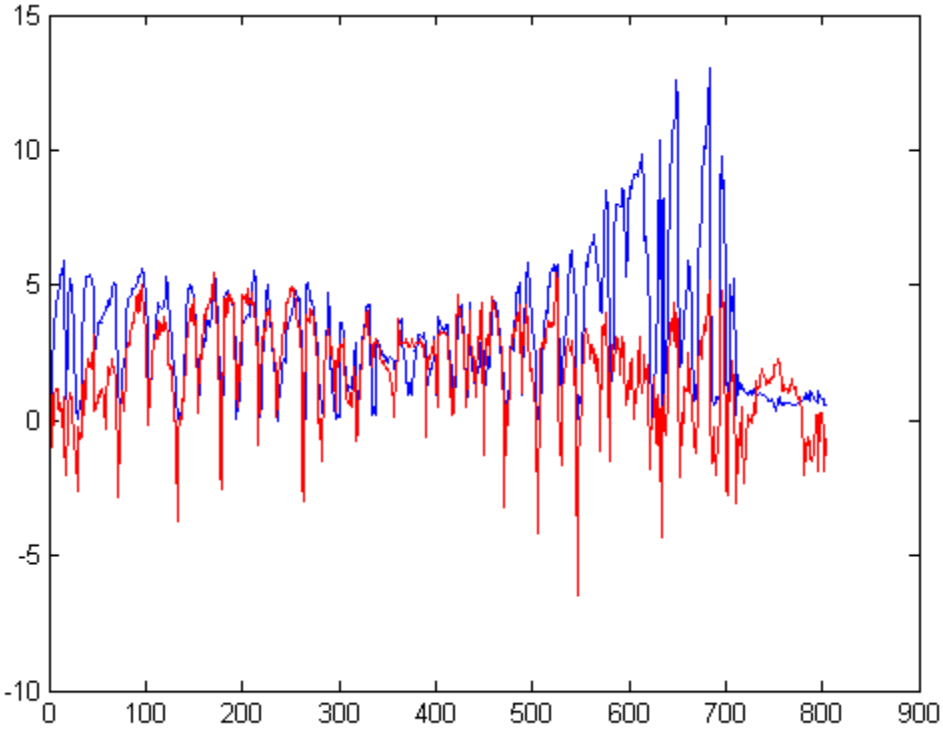


Figure 46 Regression (resample) linear kernel violoncello

4. Result of using data of real performance

The best result obtained for estimate the force during the training and testing process was using a radial Kernel with a gamma of 0.1. Models for classification and regression were built using the data of violin, viola and violoncello (without cross fold).

Each model was used by our college Jie Chen in order to estimate the pressing force for data of real performance for his thesis. The result is not what we expect; the estimated force has no sense.

The database used by Jie is the data of SIEMPRE project (Social Interaction and Entrainment using Music Performance Experimentation) in collaboration with McGill. In the data used, the performance consists of a détaché first piano, then mezzo force and finally forte. The difference between three "intensity" of force has to be estimated.

Estimated force of viola real performance:

The figure 47 shows the result of apply the classification model, and for the samples classify as "force", it is applied the regression model. The estimated force has no sense; it has an onset around 2 N, and in order hand, it can be appreciating "three part" of force, it could be the different dynamics.

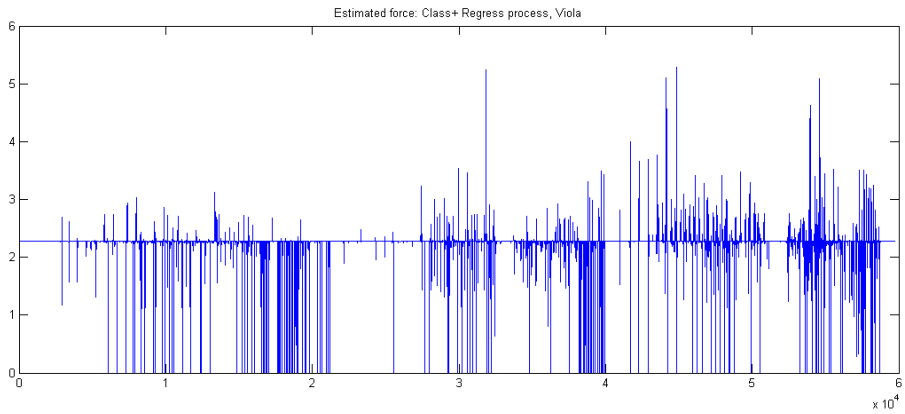


Figure 47 Estimated force of viola real performance (classification and regression)

Figure 48 shows the estimated force using regression model, without classification. It is quite similar to previous.

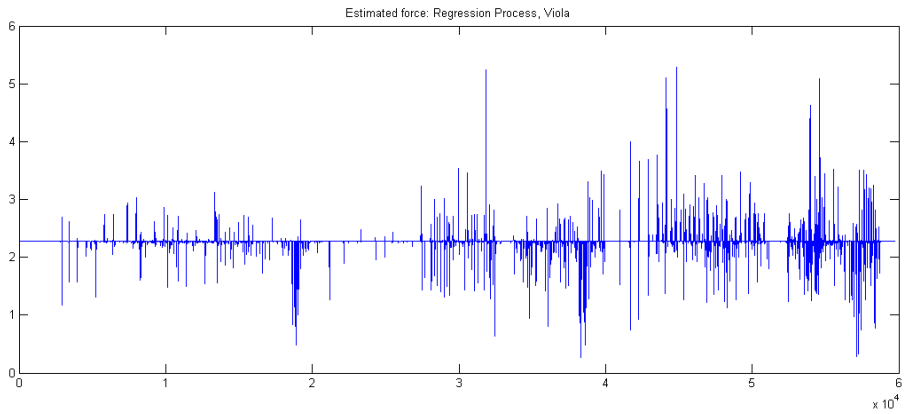


Figure 48 Estimated force of viola real performance (Regression model)

Estimated force of violin real performance:

In the case of the violin, the estimated force using classification plus regression is similar for each dynamic. In the figure 50 is shown the force using only regression.

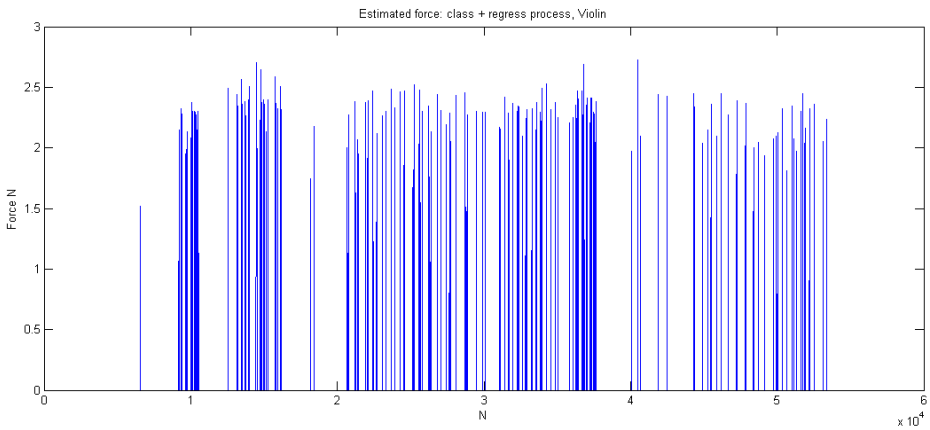


Figure 49 Estimated force of violin real performance (classification and regression)

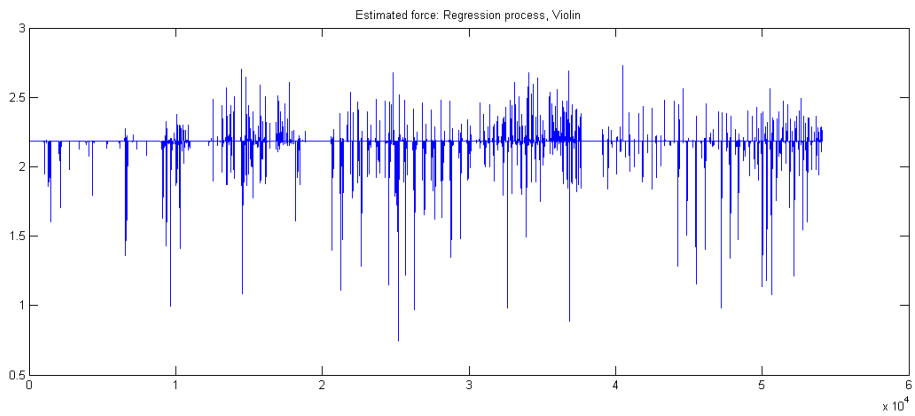


Figure 50 Estimated force of violin real performance (regression)

Estimated force of violoncello real performance:

In the case of violoncello any result has sense.

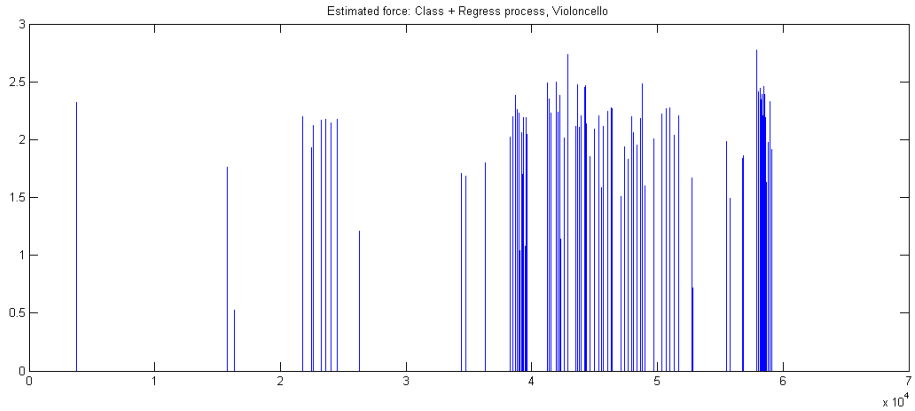


Figure 51 Estimated force of violoncello real performance (classification and regression)

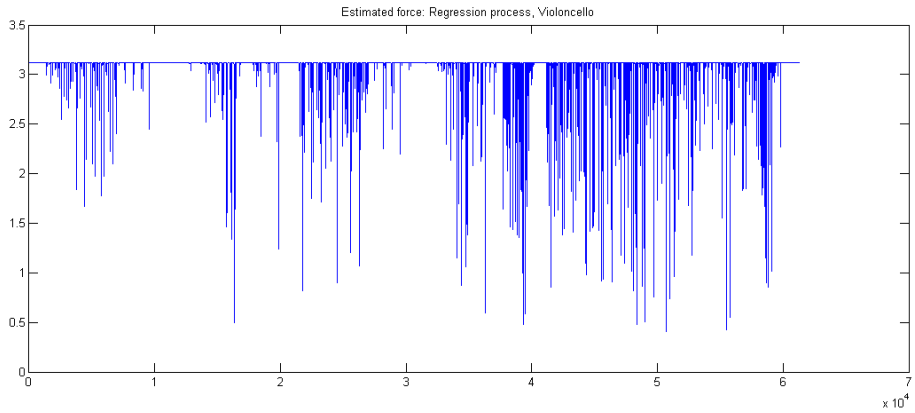


Figure 52 Estimated force of violoncello real performance (classification and regression)

Chapter 5

Conclusions

5.1 Contributions and conclusions

We obtain a method to estimate the bow pressing force using infra-red motion capture data. Some bow descriptors were developed in order to know the physical behave of the bow. With the descriptors data, a model was built to estimate the bow pressing force. We saw that if we combine the classification process and regression, the result is better than only used regression using a radial kernel with a gamma of 0.1. Correlation of ≈ 0.9 and RMSE of less than 0.2 were obtained.

The models computed with the calibration data were applied to data of real performance but the result wasn't what we expected, it was wrong. The movement of the bow during calibration process and real performance data is different, and the calibration bow movement was done by a different person than the real performance (non-experts musicians), so it could be possible that the calibration data doesn't cover all the possible behave of the bow as in a real performance.

It could be good acquire new calibration data in other to have the similar bow movement than in a real performance, and then it obtained the descriptors and computed the models for the estimation force

In conclusion, the goals proposed for this thesis in 1.2 were achieved; a method to estimate the bowing pressing force, depending on the bow deformation, bow position, tilt and pseudo force applied. Also, the methodology avoids the problems of previous work, as intrusiveness in [Guaus 2009] because the strange gages, and ferromagnetic distortion in [Marchini 2011] because the electromagnetic field sensing. It could be good reproduce the way to move the bow during the calibration process (using the load cell) as in the real performance, in order to train the models with the similar data in the both situation. The force estimated by the models will be more faithful.

Appendix

In this part of the memory are shown the most important and relevant plots.

A.1 Violin

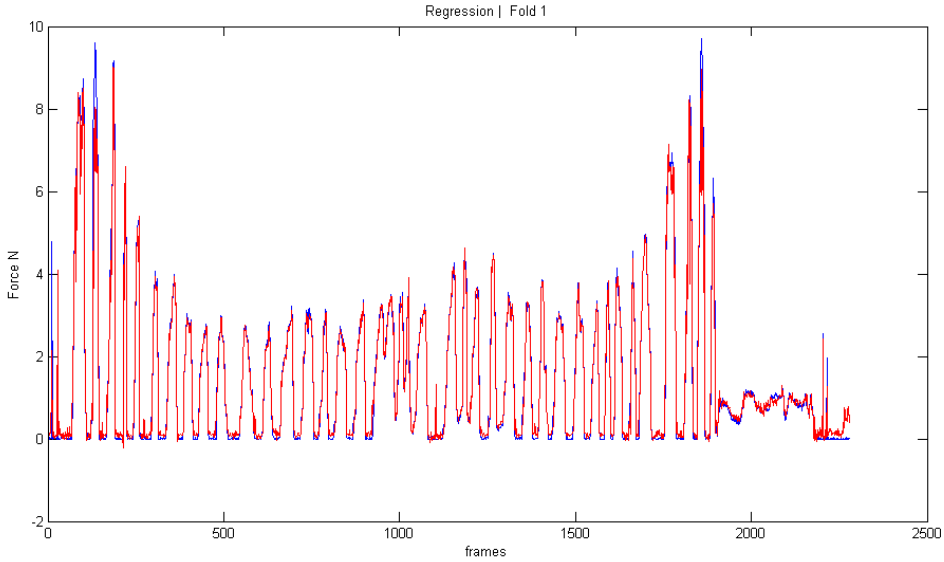


Figure 53 estimated force by regression

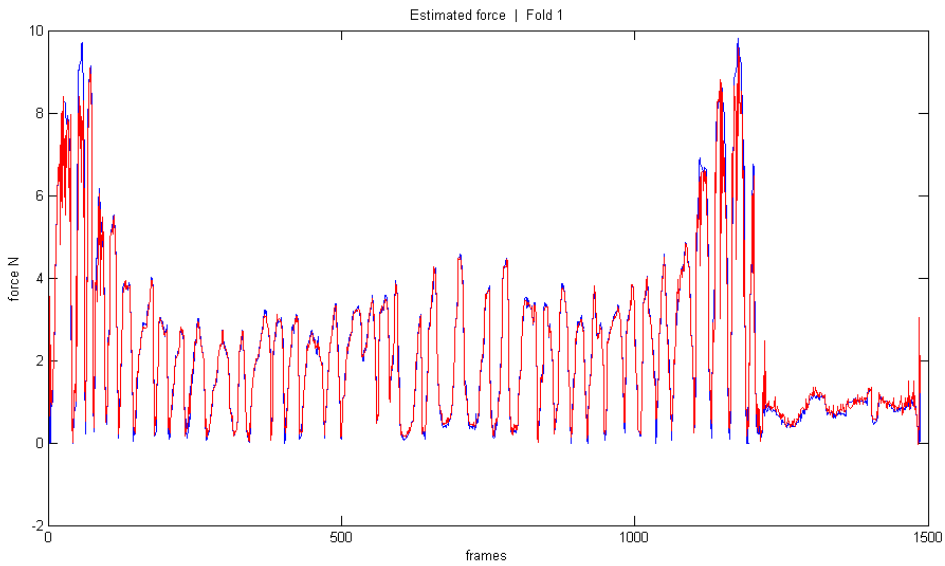


Figure 54 Gamma 0.1 Only “force applied” Regression – Violin1

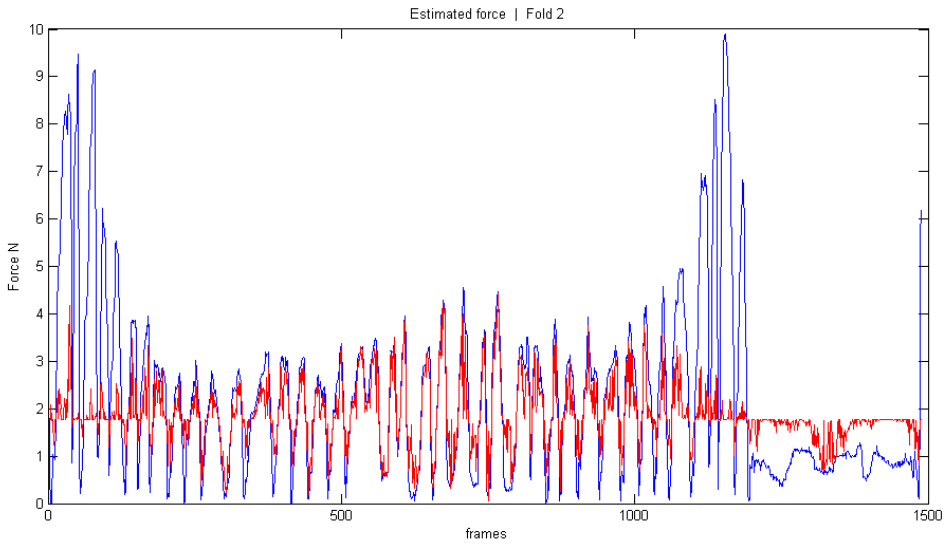


Figure 55 Gamma 10 Only Regression - Violin1

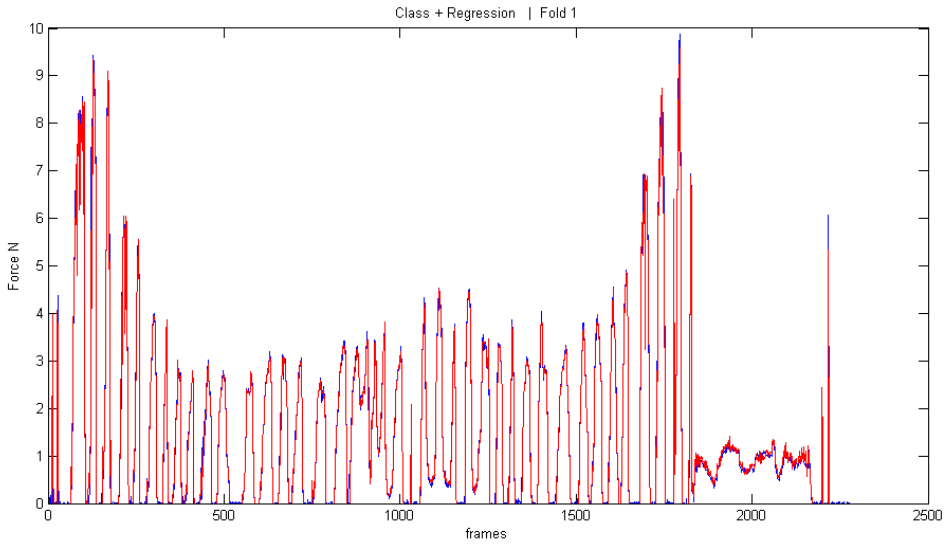


Figure 56 Gamma 0.1 Classification + Regression – Violin1

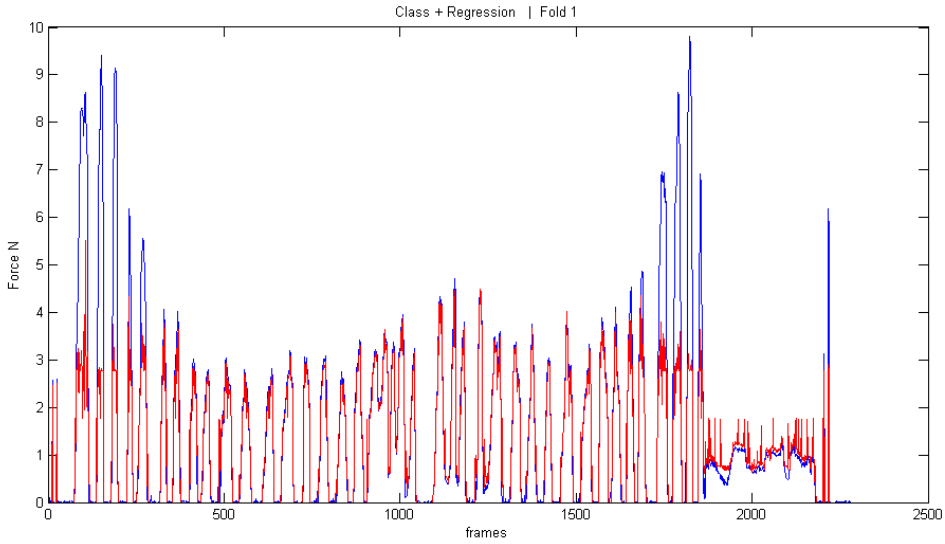


Figure 57 Gamma 10 Classification + Regression - Violin1

A.2 Viola

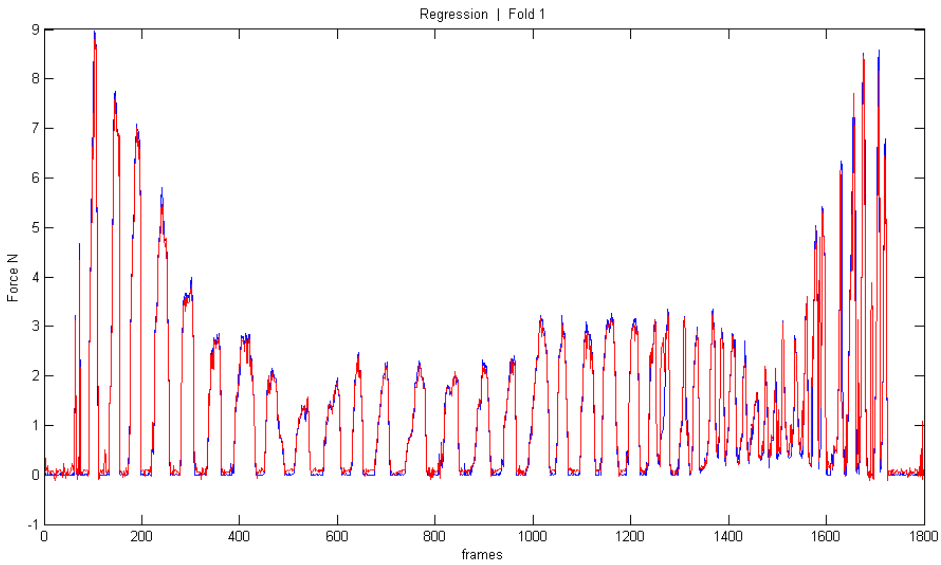


Figure 58 estimated force by regression

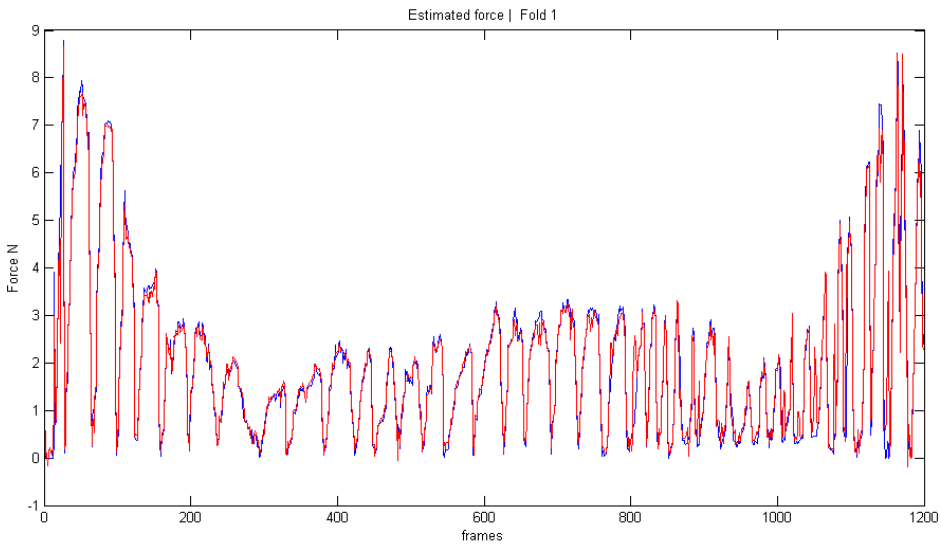


Figure 59 Gamma 0.1 Regression - Viola

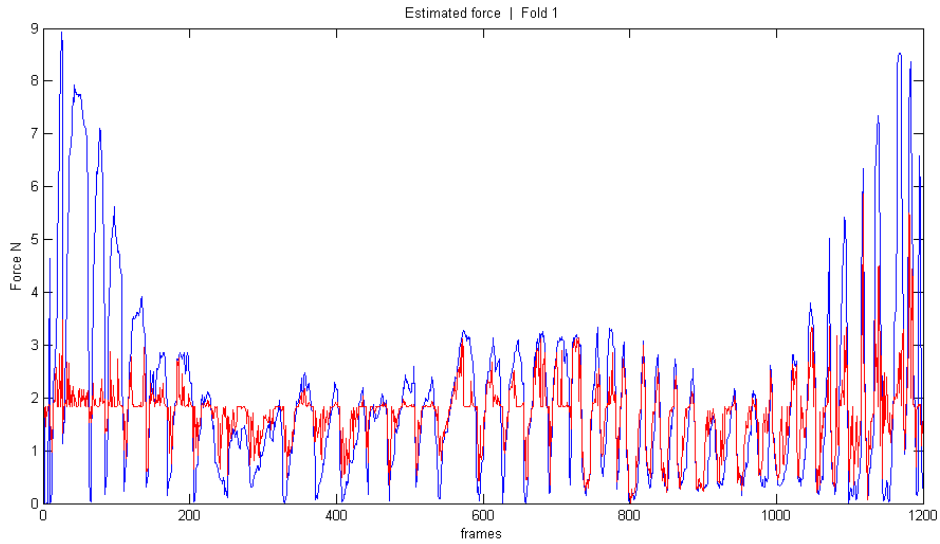


Figure 60 Gamma 10 Regression – Viola

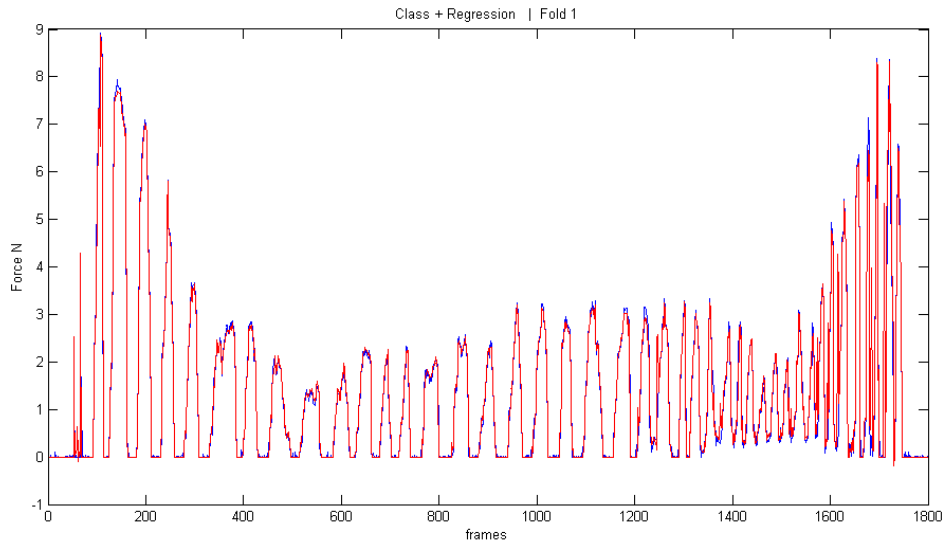


Figure 61 Gamma 0.1 Classification + Regression – Viola

A.3 Violoncello

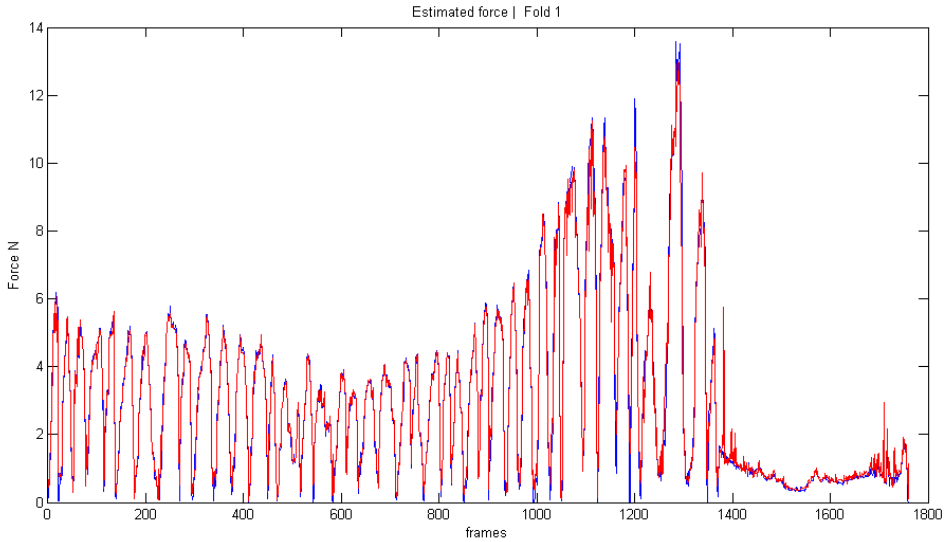


Figure 62 Gamma 0.1 Regression – violoncello

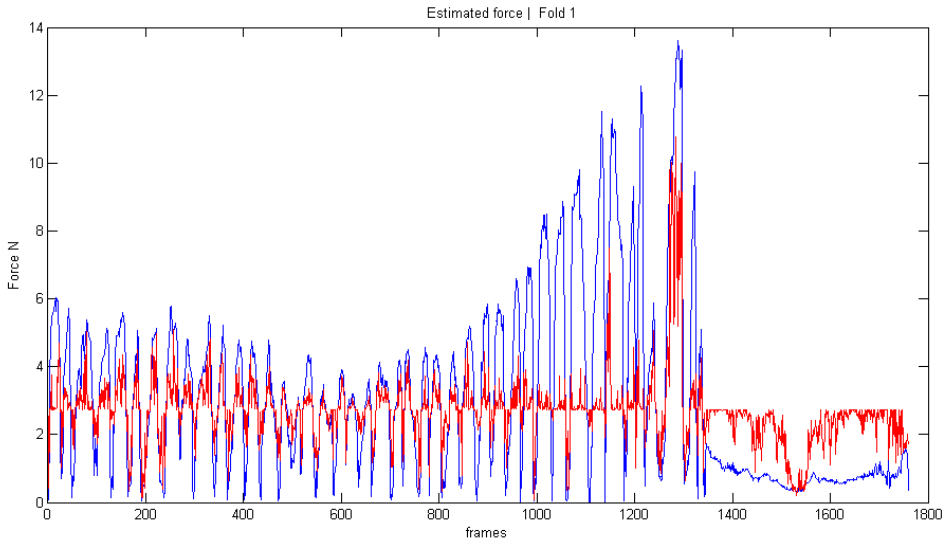


Figure 63Gamma 10 Regression – violoncello

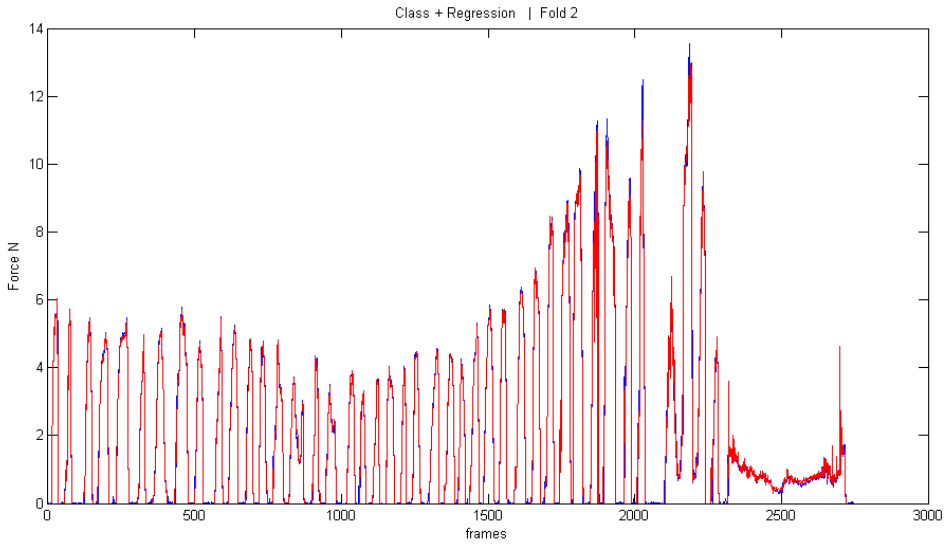


Figure 64 Gamma 0.1 Classification + Regression - violoncello

APPENDIX

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