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Matlab Based Music Analyses of Piano Recordings

An Attempt to Connect Quantitative Acoustical Parameters to Subjective Performance Intention

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PROBLEM DESCRIPTION

Quantitative analysis of piano pieces performed with three different timbral intentions. Detect physical differences in the audio signals from these recordings as well as looking for differences in the interpretation of the same timbre. Connect subjective perceived observations to physical properties of signals.

Abstract

Timbre is a well known concept in music and denotes adjectives describing a sound or sound sensation. All instruments possess a characteristic timbre making it possible to distinguish one type of instrument from another. An instrument can also produce a range of different timbres. It is highly relevant for a musician knowing about these innate properties of the instrument, as well as appropriate technical skills in order to change the musical expression.

In this thesis, piano timbre is studied by performing various analyses on several recorded versions of the same excerpt from *Symphonic Etudes op.13* by R. Schumann. The pianist has been asked to perform the piece with three different timbral intentions. Part of this project has been to study whether there are physical qualities in the recorded signals which support this subjective intention. Possible relations between perceived sound and relative physical properties found from analyses have been examined. This is a classic acoustic problem where a subjective comprehension exists and then analysing the signal in order to identify audible properties to support this sensation. Various features of the signals have been identified and looked into, and thereby also studied the possibility to quantitatively distinguish these three timbres from each other. Part of this project have been to become familiar with functions available from the MIR(Music Information Retrieval)Toolbox in Matlab.

Properties studied include temporal features, envelope amplitudes of signals, spectral centroids, rolloff frequencies, spectra and histogram envelopes, low-energy ratios and temporal development of energy together with average RMS energy for each signal. Length of each measure is found in order to examine the temporal development of each recording relative to average time per measure (inter-measure intervals). Smaller segments are studied, where analyses have been performed on various onsets. These analyses involve time between successive chords or notes (inter-onset intervals), in addition to attack time, attack slope and relative RMS energy for each onset.

Some of the performed analyses showed clear differences between recordings, but not all cases showed clear documented unambiguous results.

Sammendrag

Klang, eller klangfarge, er et velkjent musikkbegrep og betegner adjektiver som beskriver et lydbilde eller en opplevelse lyden gir. Ethvert instrument har karakteristisk klang og er en egenskap som gjør det mulig å skille instrumenter fra hverandre. Et instrument kan også produsere en rekke ulike klanger. For en musiker er det nødvendig å kjenne til disse egenskapene til instrumentet, samt de spilletekniske ferdigheter for å kunne endre det musikalske uttrykket.

Denne oppgaven ser nærmere på pianoklang ved en rekke ulike analyser av lydopptak inneholdende flere versjoner av det samme utdraget fra R. Schumanns *Symphonic Etudes op.13*. Pianisten har i opptakene blitt bedt om å fremføre stykket med tre ulike klanglige intensjoner. En del av dette prosjektet har vært å undersøke om det finnes fysiske egenskaper ved signalene som understøtter denne subjektive intensjonen. Det er studert mulige sammenhenger mellom oppfattet lydbilde og relative fysiske verdier funnet fra analysen av signalene. Dette er et klassisk akustisk problem hvor det foreligger en subjektiv forståelse og hvor man deretter undersøker om det er noe i signalet som kan underbygge denne opplevelsen. Det er i tillegg studert fysiske forskjeller mellom de ulike signalene, og dermed også muligheten for å kvantitativt kunne skille disse tre klangtypene fra hverandre. En del av denne oppgaven har vært å gjøre seg kjent med funksjoner tilgjengelig i MIR(Music Information Retrieval)Toolbox i Matlab.

Det er sett på tidsforløp av de ulike opptakene, studert envelope-amplituder av signalene, massesenter av spekteret (centroide), rolloff-frekvenser, spektre og enveloper av histogrammer, low-energy ratioer og tidsutvikling av energi, samt gjennomsnittlig RMS-energi for de ulike signalene. Lengden av hver takt er funnet for alle innspillinger for kunne studere tidsforløp i forhold til gjennomsnittlig tid per takt (inter-measure intervals). Mindre segmenter er valgt ut, der det er gjort analyser på ulike anslag. Disse analysene omfatter tiden mellom to påfølgende akkorder eller noter (inter-onset intervals), tid og stigningstall for anslag, samt relativ RMS-energi for hvert av de studerte anslagene.

Noen av analysene resulterte i klare forskjeller og variasjoner mellom de ulike opptakene, men det forelå ikke dokumenterbare entydige resultater i alle tilfeller.

Preface

The work in this Master's thesis has been carried out during the final semester of studies at NTNU. Research material acquired in Porto, Portugal in May 2012 has formed the basis for the project. Recordings were performed by an outstanding pianist in the international research group led by Dr. Daniela Coimbra, ESMAE, Politécnico do Porto.

Prior to this work, I have never studied piano timbre in a theoretical and analytical way. However, I have played the piano for almost 20 years and therefore I have a huge interest in piano timbre and how to make the instrument sound in different ways. Through 13 years of piano lessons I have had a lot of discussions with my teachers and thereby learnt and experienced a lot on how the piano works and how to produce various timbres. In this thesis I have therefore used my own experience and knowledge about music and the piano as a supplement to literature and conversations with pianist Annabel Guaita. Both my knowledge of music and the piano in addition to my background in physics and acoustics made me well suited for this work, and was the reason why I chose the project.

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Chapter 1

Introduction

Timbre is an adjective describing the ”color”, ”feeling” or ”quality” of a sound. Helmholtz introduced the term ”*klangfarbe*”(from German)[1][1]. One can distinguish between different instruments due to their various timbres and sounds. A trumpet might be said to produce a ”sharp” and ”metallic” timbre, while a cello can be described by adjectives such as ”round” and ”dark”. However, an instrument can produce a whole range of timbres, by changing playing technique and musical gestures resulting in changes in frequency spectrum and time structure. Here, only piano timbre is to be studied.
A musician’s awareness of an instrument’s timbral qualities is key to a good performance, as the musical expression can change drastically when exploring different playing techniques such as use of pedals, finger touch, weight of the arm or dynamic levels. Even though timbre is such a vital part of playing an instrument, the concept of timbre is not necessarily straightforward and accessible. It can be perceived as rather abstract in addition to the fact that the sensation of a timbre is subjective.

In this study, piano recordings have been analysed using both traditional acoustic analyses as well as programming procedures in Matlab. Music related information have been found from piano recordings using sound editing software Audacity as well as the MIR (Music Information Retrieval)Toolbox in MATLAB. The Department of Electronics and Telecommunications at NTNU is involved in research on musical performology and this thesis is part of this research.

The six audio files used for this work were recorded in Porto, Portugal, May 15 2012. In addition to these, MIDI-recordings were made as well, giving a large set of data. The work presented in this thesis are the first analyses having been performed on this research material. As there was such a substantial amount of data available, it was chosen only to study the audio files for this particular project. Material used for the analyses was the piano score, the six audio files from the different takes, some additional notes by the research group in Porto as well as three recorded conversations with the pianist. Exact timing data

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[1] from Ellis, A. (1954), translator’s note in Helmholtz(1877).

were available for all recordings, with an accuracy of 1 ms. Analyses of audio signals were performed using Audacity and Matlab in addition to analyses performed by applying various functions from the MIRToolbox.

The recorded piano piece is the second part of Variation IV-Anhang from *Symphonic Etudes* op. 13 by R. Schumann. Three timbres were chosen by the pianist, and the piece was to be performed with the intention to produce each of these timbres. The three timbres chosen were ”bright”, ”soft” and ”full”.

Aims for project

An aim for this thesis would be to enhance a greater understanding of how timbres are produced, as well as contributing to the knowledge of linking qualitative descriptions to quantitative data from acoustical analysis of recordings. That will give a broader idea and understanding of the concept of timbre. This work will hopefully contribute to the understanding of how to describe quantitative parameters as a basis for perception of music.

The following section addresses some of the various explanations of timbre. Then a number of publications on piano timbre are presented, before listing a selection of previous research on the topic. Further, various descriptions of timbres ”bright”, ”soft” and ”full” are listed. First, own subjective assessments, then descriptions found from literature and finally interpretations by pianist A. Guaita and some of her reflections on the subject of timbre descriptions. Towards the end of this chapter the MIRToolbox and sound editing software Audacity are presented.

Successive chapters present the method used for the analyses of the different recordings, followed by obtained results with discussions. Finally, conclusive remarks are made along with suggestions for future work.

1.1 The Concept of Timbre

It has not yet been established an unambiguous and unique definition of timbre. Multiple elaborations on the concept of timbre have been published, and they vary both in wordings and content.

In 1960, ANSI (American National Standards Institute)[2, p. 45] defined timbre as being ”*... that attribute of auditory sensation in terms of which a listener can judge that two sounds similarly presented and having the same loudness and pitch are dissimilar*”. The ANSI definition also includes that timbre is dependent on frequency content of the signal, the spectrum, waveform and sound pressure as well as being dependent on tempo.

Fletcher(1934) defined timbre as being first and foremost dependent on the overtone structure, but that intensity and frequency variations could have an influence as well. Changing the pitch or loudness of a sound, but keeping the overtone structure constant, would also change a timbre[3, p. 68].

Erickson(1975), however, expressed:"*Clearly timbre is a multidimensional stimulus: it cannot be correlated with any single physical dimension*"[4, p. 4]. Rasch and Plomp(1982) shared Ericksson's view on timbre being a multidimensional attribute, but also addressing some physical features that would have an influence on the sound. Some of these were the relative amplitude of harmonics, "onset effects" such as onset time and noise, "steady state effects" such as vibrato or smaller pitch variations, and finally "temporal characteristics of the tones"[5, p. 13-14].

Schouten(1968) explained timbre to be all features of a sound that could not be described as either loudness, pitch and duration[6, p. 35]. This understanding is somewhat similar to Dowling and Harwood(1986), who elaborates: "*Timbre has always been the miscellaneous category for describing the psychological attributes of sound, gathering into one bundle whatever was left over after pitch, loudness and duration had been accounted for*"[7].

Kinsler et al explains that the relative amount of higher overtones in relation to the fundamental frequency influences the timbre of the sound [8, p. 63]. A more recent publication by Halmrast et al(2010), present that our perception of timbre is most of all determined from the spectrum of the notes and fluctuations in the spectrum[9, p 187].

Deutsch[10, p. 12-14] defines timbre to be a multidimensional attribute and the third attribute of a subjective perception of sound, listed after pitch and loudness. Important contributors to the perceived timbre are mentioned to be relative amplitudes of the harmonics as well as temporal features of tones.

Mentioned above are only some of the definitions published, but they still give an idea of the imprecision related to the definition of timbre.

1.2 Piano timbre

The literature presented in the following is relevant in the discussion of piano timbre; how sound is produced on the piano and how a timbre can be modified, how the room may influence timbre, and how musical sensation changes with the room or musical gestures.

The piano The sound from a piano is caused by a series of closely successive events. The piano is a percussive, stringed instrument, where each string corresponds to a key on the piano keyboard. When a key is pressed down, this activates a set of levers connected to each other. The motion of the levers leads to a hammer hitting the string. Vibrations of the string are transferred to the soundboard via a wooden bridge, causing the soundboard to resonate [11, p. 12,83]. Accessible to the pianist (on a standard piano) are 88 keys and 3 pedals. The pedals include a *soft/una corda* pedal, a *sostenuto* pedal and *sustain* pedal.

Consequently, one can not influence the sound after having depressed the keys of the piano (disregarding the use of pedals)[11, p. 11][9, p. 39,42].

A timbre is both dependent on the instrument and of the musician playing the instrument [9, p. 184]. A pianist can be said to have an indirect control of the instrument, as (s)he does not produce the string vibrations directly[11, p. 39] This is in great contrast to other stringed instruments, such as the violin, where the violinist can directly control the sound of the instrument, by e.g. using different fingerings, change the vibrato or use various bowings.

Modifying a piano timbre Bellemare and Traube[12] classify piano timbres as either being produced from a single note or by a chord or a series of successive notes or ("complex timbres"). A timbre can change just by adding a different dynamic level[12] or playing in a higher or lower register[13]. Parncutt mentions this close connection between timbre and musical features pitch and loudness, as well as pointing out the fact that timbre relies on many other factors such as the physics of the piano, timing, dynamics and use of pedals[13].

Ortmann presents a discussion on how key-release can impact the color of the tone. However, there is little a pianist can do to change the key-release duration one way or the other. This means that the pianist is in control of how the key is depressed, but not what happens when the key is released[14, p. 352-353]. However, Ortmann states that the timbre can be changed by different use of pedals and how well this is coordinated with fingers on the keys [14, p. 374].

What affects timbre? As presented by Krokstad, the most important physical features of a tone are the fundamental frequency and the duration of the tone. In addition, spectrum and sound level are mentioned to be "necessary, but less important"[15, Part I, p. 9]. The fundamental frequency of a suspended string can be expressed by the relation

$$f_0 = \frac{1}{2L}\sqrt{\frac{T}{M}},$$

where L is the length of the string, T is the tension and M is mass per unit length[11, p. 33]. The string's stiffness becomes more and more apparent with higher frequencies, resulting in sharper overtones when pressing the higher register keys on the piano[8, p. 63].

According to Ortmann, a perceived timbre is a combination of tone intensity, duration and the noise-to-tone ratio [14, p. 355]. He presents the idea that tone color might not be exclusively produced by the depression of piano keys, but that timbre is rather produced by successive tones, and how they are played in relation to one another. The intensity of the tone is explained to only be dependent on the speed of the key as it is depressed [14, p. 358].

Krokstad mentions the relationship between sound level and intensity. The latter expression will be a perceived loudness level when listening and depends both on other simultaneous levels as well as previous levels. Sound levels, however, is an actual physical property which can be measured[15, Part III, p. 17].

A tone played on the piano consists of vibrations of the fundamental frequency, as well as its overtones/harmonics; Halmrast et al. refers to these as *partials*. Performing a Fourier transform on the sum of all these partials makes the total spectrum of the tone [9, p. 186-187]. The different partials are of great importance when it comes to tone quality. The amplitude of each of them, their frequency distribution, number and length of the various partials all play a role in how the note sounds. Fluctuations in the spectrum affect how a timbre is perceived. How the partials look is important, but more importantly how the partials appear in comparison with the others in the group. An important notion by Halmrast et al is the fact that a high percentage of high frequency partials results in a bright and harsh sound, whereas in the opposite case the sound will appear softer and more mulled[9, p. 187].

”The Psychology of Music” by Deutsch[10, p. 13] also mentions the harmonics' amplitudes relative to one another as as an important physical property when perceiving a timbre. Temporal properties of the tones are also described as essential for the perception of timbre. Here, referring to Schouten's research[6], these tone characteristics include the properties of the time envelope, i.e. rise, duration and decay. Recalling Rasch and Plomp[5] from section 1.1, and their discussion on timbre being dependent on both onset and steady state effects, which are also temporal tone characteristics.

Handel[16, p. 173] describes timbre as being defined by ”many changing and interacting acoustic properties”. One can thus not define only one physical signal property that separates two timbres from each other. Each of the partial's temporal evolution, change in intensity in relation to other partials contributes in making one timbre sound different from another.

From Askenfelt and Jansson's chapter *From touch to string vibrations* [11, p. 45], it is found that the time duration of the contact between the hammer and the string has a strong influence on the spectrum. A short time duration of contact results in a sound containing more high frequency partials than for the case of longer contact between hammer and string. Here, it is presented that the number of higher frequency partials increases with higher dynamic level, as a result of shorter contact duration between hammer and string in this case. This means that a note played with dynamic level *forte* will have more higher frequency partials, and therefore sound more shimmering than the same note played at a *piano* level. This latter note will sound softer, due to less higher frequency partials.

The hammer hitting the strings have a major impact on the sound produced by the piano, and the hardness of the hammers are described by Conklin Jr. to influence the loudness, brightness and timbre of the piano. A harder hammer will produce a brighter and louder sound, while a softer one will give a soft sound. The contact surface is covered in felt and the hammers' hardness increase with lower keys on the piano. Bass keys thus have the heaviest hammers and will thus stay longer in contact with the strings, compared to treble keys[11, p. 20-22].

How much does playing technique influence timbre? Playing the piano involves a lot of muscles, including muscles in the shoulders, upper arms, forearms and finally hands and fingers. This is extensively presented by Ortmann (1929)[14, p. 40-49]. Various muscles and key-touches may be used for different playing techniques. Playing the piano is described to be a combination of lateral(along the keyboard) movement of the arm and vertical arm movement, combined with arm-lift and arm-drop[14, p. 160]. He introduced several drawn pressure curves to illustrate key attack, release and duration, and then linking these curves to various timbres[14, 338-352].

Ortmann presented the idea that a tone may be perceived as sounding the same if the listener cannot see the pianist. The note can be produced by relaxed muscles or by tense arm muscles, but still sound the same. If only auditory perception exists, these two notes can perfectly well sound the same [14, p. 356]. This study was however for singular tones, not a chain of successive notes. Hence, technical hand gestures when playing the piano can be said to be somewhat individual.

As for technique, research published by Pipa[17] informs that a typed fingering in the piano score might be due to attaining a musical effect, as the fingers possess different qualities. The right fingering can thus help producing the desired timbre.

Room acoustics and timbre Parncutt refers to timbre as being a subjective feeling depending on sensory impressions as well as your relevant knowledge about the music and where you are when listening. Listening to a piece in a concert hall is a different experience than hearing the same piece performed in a small practice room; both room acoustics changes as well as individual emotional experiences in different spaces[13].

Halmrast et al mentions the degree of influence the room has on timbre. A great hall with long reverberation time may ”remove” some of the extremes of the tone, and the musical expression may sound more polished. Or the opposite may happen, some rooms may highlight certain overtones more than others, and thereby changing the musical expression completely. The comb filter effect is important here. This is created by various reflections from surrounding walls/ornaments/chandeliers etc. and added together this results in some frequencies being highly attenuated while others are emphasized. This is due to the fact that the various sound waves have different phases when being added together. Sound waves of opposite phases give a cancellation of the signal whereas sound waves of the same phase give an amplification of the frequency in question [9, p. 192].

Krokstad’s technical report on piano as a source of noise(1967) had a pianist play an excerpt at different rooms and at various locations within each room. He found that the pianist performed similar dynamical note onsets regardless of the acoustics of the room. Deviations between measurements of different piano positions were within 1.5 dB with an uncertainty of 0.5 dB. It is thus stated by Krokstad that a professional pianist’s ability to reproduce note onsets is a fully trained motorised skill. However, it was found that tempo changed with the room; the pianist tended to play faster in the anechoic room, while playing at a slower tempo in a more reverberant room[18].

Additional factors influencing the perception of timbre As stated by Ortmann, a listeners’ imagination is an important aspect of performing music [14, p. 356]. He elaborates an interesting train of thought, concerning the listener’s relevant knowledge (as mentioned by Parncutt[13]): A person’s knowledge about the music will have an impact on the perception of timbre. This is due to the fact that if you know the musical piece being played, you know what is coming and you know the various phrasings and passages. You might even be able to vision the pianist playing and how (s)he performs the music. Ortmann points out here that perceived phrasing might not be the phrasing actually used by the pianist, but rather something imagined by the listener due to his/her experience with the piece [14, p. 357-8]. An interesting fact by Ortmann is how the visual impression plays a part in the perception of timbre. A staccato note might not be as staccato as we might think. But from looking at the pianist's gestures, the produced timbre might be perceived as more staccato than it really is [14, p. 353].

1.3 Previous Work Related to Piano Timbre

Ortmann's "The Physiological Mechanics of Piano Technique" from 1929[14] gives an elaborate review of the parts of the skeleton used for piano playing as well as the relevant muscles. He also presents various timbres, provided with descriptions and playing techniques. Drawings of lines and arrows explaining movement of the arm are presented, found from his research on piano technique[14, p. 161]. He used a pantograph for some of his studies. This device registered lateral(along the keyboard) arm-movement by attaching one end to the pianist's hand and where the other end was equipped with some kind of chalk in order to draw the pianist's movements directly onto a board. Another method used for registration of arm-movement was attaching a light bulb to the pianist's finger or hand, and then photographing the performance session[14, p. 164].

Krokstad's technical report from 1967[18] considers the piano as a source of noise. Several piano recordings were performed both in an anechoic room and a more reverberant room. Publications by Ortmann and Krokstad proves that analysis and measurements of sound from the piano have been of interest and relevance for a long time, both of them being forerunners for subsequent piano acoustics research.

More recent research such as Silva et al [19] have studied different recordings of the same music. Performed analyses included computing self-similarity matrices in order to detect structural similarities between the audio signals as well as chroma-based signal properties, and their method proved to be successful. Chroma give information on the harmonic nature of the signal. For the chroma analysis, the Chroma Toolbox in Matlab was used. Hélène Papadoupolus was co-author of this publication; she has also been involved in analyses of signals by use of Markov Logic Networks(MLNs), such as [20]. MNLs are used in order to study chord progression as well as uncertainties. The work contributes with bringing relevant information to a possible"*..unified multi-scale description of audio..*".

A MIDI analysis can identify temporal and dynamic properties of signals. Saue and Tro published "MIDI-based Analysis of Music Performance" in 1990 [21]. Various events in excerpts of different musical styles were analysed. This was the first publication in a Norwegian academic journal using MIDI recordings in a musicology context, showing that there is a long tradition for using MIDI analysis to detect timbral nuances.

Bellemare and Traube [12], requested pianists to link onomatopoeia to various timbres, and found that there was a correlation between certain groups of sounds and playing techniques. E.g. "*A full sound is usually imitated with an open \a*".

Bernays and Traube [22] performed mapping of timbre descriptions from 17 pianists. The musicians were asked to rank 14 timbres based on how well they were familiar with each term. 4D Multidimensional Scaling (MDS) was performed, based on pianists' evaluation of semantic proximities between the 91 pairs of timbre descriptors. This resulted in two plots showing how the various timbres related to each other when considering the musical qualities corresponding to the four dimensions. In plots like these, timbres perceived similar to each other are placed close together. The musical qualities were related to brightness or sharpness(1D), warmth(2D), loudness(3D) and presence(4D). It was elaborated that brightness was linked to the amount of higher frequencies compared to lower, while warmth was a measure on the low-to-mid frequency ratio. Clustering of timbres from the MDS calculations was further analysed to produce a dendrogram, a graphical representation showing the degree of similarities between the timbres. The analysis resulted in five main adjectives best suited to describe the whole range of piano timbres; these were ”bright”, ”dry”, ”dark”, ”round” and ”velvety”.

These five timbres found have been further used in research regarding production of timbres, such as Bernays and Traube(2013) ”Expressive Production of Piano Timbre: Touch and Playing Techniques for Timbre Control in Piano Performance”[23]. Here, four pianists each were to perform four different piano pieces with the five timbres given. The performances were studied, observing variations in the various recordings. The four pieces were composed so that a wide range of piano techniques could be applied. Altogether 60 recordings were made for each of the pianists, giving a total of 240 recordings to be analysed.
General descriptions of each of the five timbres were finally identified, describing timbres ”*..independently of the performer and the musical context*”. The results included differences in dynamics, note attacks, use of pedals, depression of keys and articulation of notes. Relevant descriptions from these results are included in section 1.4.

As the publication ”Verbal expression of piano timbre: Multidimensional semantic space of adjectival descriptors” by Bernays and Traube [22], formed the basis for the selection of timbres for the piano recordings carried out in the research group in Porto, it seemed natural to study publications by Bernays and Traube. The pianist was informed about the different defined timbres found from Bernays and Traube[22], and from them he chose the timbres he wanted to explore. These were ”bright”, ”soft” and ”full”.

Eerola et al[24] studied sensations of timbre by introducing various isolated musical sounds to a test group. Three experiments were conducted and part of the analysis was performed using the MIRToolbox. As the publication introduces previous application of the toolbox and shows some of the features available, it seemed appropriate to use the MIRToolbox for some of the analysis procedures in this thesis.

1.4 Verbal descriptions of timbre and piano-technical hand gestures

As mentioned, the sensation of timbre is individual. Some different interpretations follow in the next three subsections, starting with a section of own, personal descriptions of the three timbres and thoughts on how to play in order to produce the different sounds.

1.4.1 Subjective descriptions of timbres ”bright”, ”soft” and ”full”

”Bright” is a timbre that feels more natural to play at a higher tempo. ”Bright” is played with crisp and sharp note onsets, giving a distinct sound. It would be challenging to play ”bright” at a lower dynamic level. The articulation would be rather staccato notes with short onsets, and not use the sustain pedal too much to avoid that notes are heavily bound together. The weight of the forearm should not be used as much when playing bright. As for a ”soft” timbre, this provides a very introvert and dampened sound quality. This would be the opposite to the ”bright” timbre; it does not feel natural to produce a soft timbre at a higher dynamic level. The una corda pedal would possibly be used to help dampen the sound, as well as performing longer and more gentle onsets than as for the ”bright” timbre. Notes would be played more legato as well as heavier use of the sustain pedal than for the ”bright” timbre. The ”full” timbre is rich and resonating. As opposed to the ”soft” timbre, the ”full” timbre represents a very extrovert and forward sound. More sustain pedal would be used here and possibly a higher dynamic level, to make the notes sound more. Notes would be played slightly longer than for ”soft” and ”bright” timbres, as well as playing with a heavy forearm and upper arm. Note onsets would be longer than for the ”bright” timbre, possibly also longer than for the ”soft” timbre.

1.4.2 Verbal piano timbre descriptions found from literature

From Bernays and Traube [22] it was apparent that ”soft” was considered to be the timbre the pianists felt the most familiar with. ”Bright” came in second, while ”full” was ranked as number 8 out of 14. As for the ratings of semantic proximity between timbres, these were displayed so that timbres perceived similarly appeared close to each other. Results showed that ”bright”, ”soft” and ”full” appeared in three different clusters, in terms of brightness and warmth qualities. As for loudness and presence qualities, results were more difficult to interpret. Timbres did not appear in distinct clusters but ”bright”, ”soft” and ”full” were located some distance from each other. The dendrogram showed timbres ”bright”, ”soft” and ”full” in separate clusters. ”Bright” was perceived to be in close relation to ”clear”, ”soft” with ”velvety” and ”full” with ”round”. Of the three timbre descriptors, ”soft” and ”full” were perceived the most similar timbres of the three, when considering the dendrogram. Timbre descriptions interpreted from the plots are further presented below.

The adjective ”full” is interpreted as having the same meaning as ”full-bodied” (norsk:fyldig) as both terms were used for the same timbre in Bernays and Traube [22] and that this paper formed the basis for the recordings made in Portugal.

Bright Bellemare and Traube [12] describes the ”bright” timbre as a sound with ”luminous, bursting and somewhat percussive quality”. Their research has shown that to obtain a ”bright” sound, the hand should be positioned close to the keyboard, depressing the keys with rigid fingers. From Bernays and Traube [22] it was found from the 4D MDS plots of the semantic space, that the ”bright” timbre was perceived to have a larger high-to-low frequency ratio compared to the two others. In Bernays and Traube [23], ”bright” is described as a timbre of high intensity with slightly more emphasis on right-hand notes. There is very little use of soft pedal and not much use of sustain pedal. Notes have short attacks, with keys being depressed all the way down. The articulation is described as quite non-legato.

Soft From Bernays and Traube [22], the 4D MDS plots of the semantic space characterizes ”soft” and ”velvety” as closely related in terms of perceived brightness and warmth. Of the three timbres ”bright”, ”soft” and ”full”, ”soft” is perceived to be the timbre with the least brightness/sharpness. In fact, the plots show that ”soft” and ”brassy” are perceived to be timbres with about the same warmth. In the same paper the ”velvety” timbre was presented in a dendrogram as being the one with closest proximity to ”soft”. As no exact description of the ”soft” timbre was found, the classification of the ”velvety” timbre is included here, as found from Bernays and Traube [23]. Here ”velvety” is characterized as a low intensity timbre with much use of the soft and sustain pedals, legato play with long note attacks and not very deep depression of keys.

Full The ”full” timbre is produced by slightly legato play, described by Bernays and Traube [25]. Bellemare and Traube [12] present ”round”, ”rich” and ”full-bodied” as being mutual extensions of each other, played at different dynamic levels. A ”full-bodied” sound is described as being similar to a ”rich” timbre, but played at a higher dynamic level. They present that the dynamic level of a ”full-body” sound can be obtained up to *fff*, while timbres ”rich” and ”round” are played with dynamics lower than *f*. ”Rich” is described as a sound obtained by placing the hand lower towards the keyboard, using the softer part of the fingertips applying a slow attack to the keys. It is desirable to have overtones to resonate, in order to produce the ”rich” timbre and thus also the ”full-bodied” sound. From Bernays and Traube [22] the 4D MDS plots of the semantic space showed that the ”full” timbre was perceived to be a warmer sound than the two others. In the dendrogram from the same publication, ”round” is presented to be the timbre of closest proximity to ”full”. Descriptions of the ”round” timbre from Bernays and Traube [23] are therefore included here: ”round” is a timbre of ”no salient trait”(of the five timbres investigated), ”moderate, well-balanced, and constant intensity and attacks; key depressions are not very deep”. The ”round” timbre is produced by heavy use of sustain pedal and legato play.

1.4.3 Verbal piano timbre descriptions provided by pianist A. Guaita

Including a pianist's thoughts on the subject will give a fuller and more comprehensive image of the relevant timbre descriptions. As stated by pianist A. Guaita, two pianists will most likely give two different answers when being asked to define a piano timbre. Her interpretations of the three timbres are presented here[26]. As the conversations were conducted in Norwegian they are also chosen to be presented in Norwegian, with some key notes in English below.

Bright *Klar og crisp klang, skinnende og brilliant uttrykk. Anslag der tonene er mer distinkte. Produseres ved høye fingerløft. Mer fingerspill enn bruk av håndledd og overarm. Tangentene slippes raskt.*

Sounds clear, crisp and brilliant. Distinct onsets. More use of fingers, less arm and wrist. Keys are quickly released.

Soft *Mykt og bløtt. Kan fås frem ved to typer anslag: med og uten kjerne/substans i tonen. Mer kjerne i tonen kan fås ved å gå mer til bunns i tangenten, tillegge mer vekt i anslaget og spille mer legato. En tone uten kjerne vil være uten substans og høres mer "fluffy" ut. Denne spilles med et lavere tyngdepunkt og mer bruk av håndledd. Fingrene ligger generelt mer på tangentene her, mindre løft. Tonene limes ikke like mye sammen her slik at klanger muligens blandes mer. I tysk musikk, som i Schumann gir man mer kjerne i tonen ved a gå mer til bunns i tangenten.*

Onsets with or without a core/substance could be used to produce the soft timbre. In German music, such as Schumann, notes would be given more substance by fully depressing the keys. Adding substance to a note could also be to add more weight to the onset and more legato play. A note without substance will sound more fluffy. The "soft" timbre is played with fingers closer to the key bed, compared to the "bright" timbre where you lift them more.

Full *Mettet klang. Viktig med timing, så man spiller i et tempo slik at overtonene får tid til å åpne seg og klinge ut før neste klang overtar. Pedal kan gi mer fylde, men ikke nødvendigvis mer klarhet i uttrykket. Fokus på nedre register for å få flere overtoner, mer bass vil gi klangen mer "body". Punkteringer spilles slik at klangen får tid til å åpne seg. En "full" klang oppnås ved å spille mer nedi tangenten, du vil få mer fylde når du bruker vekten av armen.*

Timing is important here, as overtones should be given time to resonate. Use of sustain pedal could bring more fullness to the sound, but not necessarily a more distinct musical expression. Bass notes are important as these will resonate more overtones as well as giving the sound more "body". For a "full" timbre, using the weight of the arm is important and to sink more into each key.

In addition to descriptions of timbres and piano technique, Guaita had some interesting reflections on the subject of timbre and performance. She found such qualitative descriptions challenging as they are made on a general basis detached from a musical context. She was clear on the fact that you change the way you play with the room; a larger room requires a slower tempo. A musician's description of a timbre depends on his/her vocabulary, but the physical and musical context might also affect and change the vocabulary used. A timbre perceived to be bright in one room might not be perceived as bright in another, even though the music is played similarly. Hence, the musical and physical context will influence the experience of sound and affect the vocabulary you would use to describe it.

Guaitas ”Texts ans Essays on Critical Reflection”[27] reflects on the artistic process and result of her project ”The ”Atonal” Piano-Performative analysis of the piano music by Fartein Valen inspired by the performance practices of The Second Viennese School”. Some of her reflections on performing are presented below, which illustrates how context and musical gestures may affect a performance. These quotations highlights the fact that music happens in the moment, making it challenging to give timbres a global description.

”I want to listen to the sounds I produce and try to relate them to one another. I am in a state of being inside the music, but yet keeping a distance so I will be able to listen to myself.”[27, p. 42].

”... I discovered that tempi is something that is ”alive”. A tempo taken in a rehersal room feels completely different on stage. The distance to the audience, the instrument, the acoustics are all variables that I as a musician must adjust to, on a conscious or a subconscious level”[27, p. 55].

”I realized I cannot change anything after the chord or the note is struck. I can only listen to what is sounding. I noticed that when I kept still, and didn't move in the silences, I, and maybe the audience could listen better”[27, p.45].

1.5 The MIRToolbox

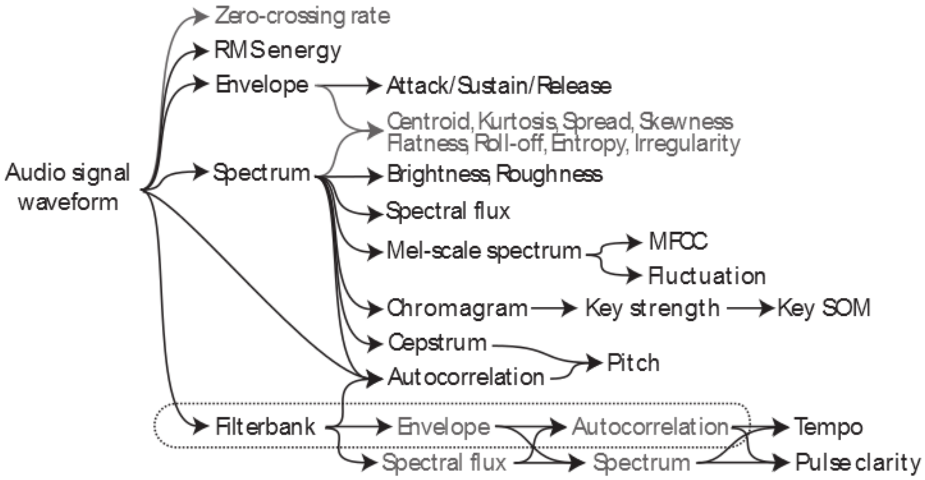

Figure 1.1: Diagram showing various procedures that may be performed using the MIRToolbox[28].

The MIR(Music Information Retrieval)Toolbox is developed by Olivier Lartillot, Petri Toiviainen and Tuomas Eerola at *Finnish Centre of Excellence in Interdisciplinary Music Research*, University of Jyväskylä, Finland[29]. They describe it as a set of functions to extract musical features from audio files [28]. Version 1.3.4 is used for this project. The toolbox has a wide range of functions presented in the MIRToolbox User's Manual[30]. Main groups of musical features extractors include *dynamics*, *rhythm*, *tonality*, *pitch* and *timbre*. Main groups of post-processing functions are *structure and form*, *statistics*, *classification*, *similarity and retrieval* finally *exportation*. In addition there is a set of basic functions, such as functions for plotting audio signals, envelopes or spectra. Each group contains several functions which operate in the temporal domain or spectral domain, both domains or neither one. Each function of the toolbox offers a number of options by changing the input argument. A chain of operations are presented for each function in the user's manual, giving a graphical overview of possible inputs[30]. Figure 1.1 presents possible series of commands. Outputs from a MIRToolbox function are MIRToolbox variables and can only be used by other functions within the toolbox. However, by extracting these variables they are stored in a structure and may be used for calculations and plotting by use of ordinary Matlab functions.

1.6 Audacity

Audacity is a free sound editing software with a lot of features for e.g. adding affects, performing signal analysis, changing sound quality or cutting or mixing signals[31]. It also allows the user to record sound. For this project, recordings were uploaded to the program in order to display the spectrogram. The time resolution could be as low as 1 ms.

Chapter 2

Method

This chapter presents and labels the six recordings. This is followed by a section of subjective observations from analytically listening to them. Various musical features were noted, as well as perceived differences between the versions. Following up, the Matlab analysis procedure is explained, first presenting manually performed analyses and finally studying various musical features by use of functions from the MIRToolbox.

The pianist was presented to timbres studied in the research paper on verbal expression of piano timbre by Bernays and Traube [22]. He chose to interpret timbres ”bright”, ”soft” and ”full”. Six versions of the Schumann piece were recorded, two for each of the three timbre descriptors.

It is assumed that the pianist has the ability to remain consistent in his interpretation of each timbre throughout the piece. In addition, it is reckoned that the pianist holds a perception of the various timbres within general global understandings by professional pianists. By this it is meant that all musicians are thought to have a certain common idea of different timbres, even though the wording might vary. In this case, ”bright”, ”soft” and ”full” timbres seems to be sufficiently different for this assumption to be valid.

The pianist was asked to give performances with timbral intentions corresponding to each of the three chosen adjectives. One recording of each timbre was first made, followed by a conversation between the pianist and the research group. He was asked about his interpretation of the music and the various timbres as well as being encouraged to exaggerate his interpretation of the timbres in the second round of performances. After this, a new set of recordings were made.

Research material from the recording session is available at the Department of Electronics and Telecommunications, NTNU. The six recordings are listed below. Original titles of recordings were kept as they were named in the research material available. When referring to a specific recording in the following text, names of recordings will be presented in italic and with these titles:

1. *Bright*

2. *More bright* (after conversation, second round of recordings)

3. *Soft*

4. *More soft* (after conversation, second round of recordings)

5. *Full*

6. *More full* (after conversation, second round of recordings)

The Schumann score is included in the Appendix. ”Part A” denotes the section from measure 1 through 17, while ”part B” denotes the section from measure 18 and to the end, also marked in the score.

2.1 Subjective Analysis of Recordings

The recordings were firstly listened to thoroughly in order to gain a better view of what would be interesting musical features to study further. As it turned out, the conversations with the pianist did not contribute any further to the understanding of his interpretation. Hence, these conversations are not further discussed. Included below are noted characteristics of and comparisons between the various piano recordings when listening analytically to them as well as rehearsing the piece on the piano.

Bright

The first chord is played without arpeggio. The bass sounds more bright here than in *more bright*. Fast arpeggios and singing top notes. Fast, clear and determined onsets. Rhythms ’dotted 8th note - 16th note’(e.g. measure 27) and ’double dotted quarter note - 16th note’(e.g. measure 20) are played more sharply. Very little use of pedals, the notes and chords appear to be very separate from each other.

More bright

The first chord is without arpeggio. The tempo seems to be faster and the progression of the music more forward than for *bright*. More accentuated top notes in part B. Firm and sharp onsets of each note. The treble is perceived to have a more bright expression than the bass, but a less ”singing” treble than as for *bright*. Less ritardando at the end of part A leading into part B. The treble chords in part B are played more attacca here than for *bright*. As was also the case for *bright*, there is very little use of pedals. All onsets of notes and chords are clear and can easily be distinguished from each other.

Soft

The first chord is played without arpeggio. Note onsets are more round and gentle. There is less emphasis on each note. Notes seems to be played with less determination in the high register (e.g. the end of part A). The tempo is perceived to be slower than for the recordings of bright and full timbres. Rhythms 'dotted 8th note - 16th note'(e.g. measure 27) and 'double dotted quarter note - 16th note'(e.g. measure 20) seems to be played slower and less forward than as for *bright*. The dynamic level is lower here than in the other takes and there is less crescendo and progression towards the end of part A and B. Singing top notes, but at a lower dynamics than the other timbres. Possibly use of the soft pedal/una corda pedal. The recording sounds very hollow and fuzzy compared to the other timbres. There is more use of sustain pedal here and more legato play than for bright timbre recordings. Both *soft* and *more soft* recordings are perceived to be the recordings with least dynamic variation throughout.

More soft

The first chord is played without arpeggio. Gentle onsets, less crescendo or no crescendo at the end of part A. Slower arpeggios throughout the piece than for the other timbres. As was the case for *soft*, rhythms 'dotted 8th note - 16th note'(e.g. measure 27) and 'double dotted quarter note - 16th note'(e.g. measure 20) seems to be played more slowly. Singing top notes, though at a lower dynamic level than the other timbres. Possibly use of soft pedal/una corda pedal. More use of sustain pedal and more legato play than for the bright timbre recordings.

Full

The first chord is played arpeggio. The melody seems to have slightly less progression and be a bit more laid back than in the bright timbre recordings. It sounds as if the pianist "sinks" more into every note, adding greater weight to each tone. Softer onsets of every chord/note than for the bright timbre recordings. The dynamic level is higher here, compared to soft timbre recordings. Rhythms 'dotted 8th note - 16th note'(e.g. measure 27) and 'double dotted quarter note - 16th note'(e.g. measure 20), are perceived to be played both longer and softer compared to bright timbre recordings. Bass notes are prominent. Throughout the piece, the notes seem to be held longer than for the other timbres. More use of sustain pedal and more legato play than for bright timbre recordings.

More full

The first chord is played arpeggio. Each tone seems to be emphasized more. The arpeggios are slower. More crescendo towards the end of part B. As for *full*, rhythms 'dotted 8th note - 16th note'(e.g. measure 27) and 'double dotted quarter note - 16th note'(e.g. measure 20) are perceived to be played both longer and softer than in bright timbre recordings. The dynamic level is higher, compared to soft timbre recordings. The melody seems more forward than for *full*. More legato play than for the bright timbre recordings.

2.2 Analyses in Matlab

2.2.1 Manually performed analyses

As an introductory analysis of timing data and tone statistics the piano score was studied as well as sound spectrograms in Audacity in order to acquire relevant data. Calculations and plotting were executed in Matlab. Procedures performed manually were:

- Tone Distribution
- Inter-Measure Intervals (IMIs)
- Inter-Onset Intervals (IOIs)

Thus, is was first gathered information to get an overview of the harmonic nature of the music. Further, temporal variations were detected by first considering each recording as a whole (IMIs) and then concentrating on smaller segments studying intervals between onsets (IOIs). Each procedure is presented below, together with a paragraph discussing timing data for the recordings.

Timing Data

Timing data was provided from supervisor Jan Tro, found from manual inspection using the software *Cool Edit Pro*. The timing data was found with an accuracy of 1 ms. It was decided to define the onset of the next last chord to be the end point of the recording. This gave the most precise end point, as the next last chord was the last clearly defined onset. Hence, recordings were cut so that their time window spanned from the onset of the first chord to the onset of the next last chord of the piece. Cutting the recordings this way was essential in order to achieve similar evaluation of timing. The two last chords of the piece were thus excluded from the analysis. However, as each recording was over 60 s long, it seemed fair to say that excluding these chords would have a rather small influence on the overall result. Musical variations and timbre characteristics would most likely be expressed more fully elsewhere in the piece.

Tone Distribution

The piano score was studied and all onsets of each tone were counted, as well as the total duration of each tone throughout the piece. This is of relevance as it shows all frequencies represented, as well as an overview of the distribution of frequencies.

Inter-Measure Intervals (IMIs)

IMIs give an overview of the overall temporal progression of the various recordings. The IMI simply shows the duration between two downbeats, i.e. the length of each measure. An accelerando will typically result in a shorter IMI, whereas a riterdando will correspond to a longer IMI value. The Schumann piece consists of 28 measures. However, having defined end cuts of recordings at the onset of the next last chord, this corresponds to less than 28 measures. IMI calculations were thus made for 27 measures, so that lengths of all measures could be precisely found. The length of measure 27 was then accurately found, as this corresponded to the time from the first beat of measure 27 to the downbeat of measure 28. All downbeats were found by manual inspection of the Audacity spectrogram.

(a) Measures 22, 23 and 24.

(b) Measure 27

Figure 2.1: Measures 22-24 and 27.

Inter-Onset Intervals (IOIs)

IOIs are of interest as these may be an indicator of temporal progression of a phrase or a rhythmic figure. Interpretations of timbres are thought to give rise to variations in how notes/chords are played in relation to preceding and successive onsets. It should be emphasized that IOIs do not give any information on the duration of each tone, only intervals between the onsets. Based on subjective observations from section 2.1, it was chosen to study the first two onsets of measures 22-24 and the first three onsets of measure 27, shown in Figure 2.1. The grace notes seen in measures 22-24 were not placed on the downbeat, which was observed from listening to the recordings. Temporal locations of chord onsets were found from manual inspection using the displayed sound spectrogram in Audacity, and finally calculating IMI intervals and plotting them in Matlab.

2.2.2 Analyses performed using MIRToolbox functions

When the MIRToolbox was used for the analysis, the output was stored as a ”MIR variable”. In order to use this data for plotting and further calculations in Matlab, the MIR variables had to be exported by different applications of the *mirgetdata* and the *get* command.

Due to Matlab memory handling when using the MIRToolbox, the toolbox divided large files into smaller pieces, and MIRToolbox commands were executed in turn on each of these chunks. When calculation finished on one of the pieces of the signal, this was erased from the memory when proceeding to the next chunk. Resulting data from each calculation was stored in the memory, and finally results were summed together [30]. The various MIRToolbox functions and input arguments are further described in the descriptions below. All Matlab scripts are included in the Appendix.

No calibrated recordings were made in the studio. Hence, no material exists making it possible to set a reference for determining exact sound pressure levels in the performances. Nor are there any recordings where the pianist demonstrates different dynamic levels; this could have been helpful, providing energy references for various dynamics. As there was only performed two recordings of each timbre, this is a too small number for a statistical analysis. However, a quantitative analysis can still be made, as it is the differences between timbres that are of interest.

As seen in Chapter 1, various timbres can be described qualitatively both by adjectives and by sounds such as onomatopoeia. The following analysis study each timbre quantitatively performing a technical signal analysis on the recordings in Matlab using the MIRToolbox. Musical features studied were chosen on the basis of subjective perceptions from analytically listening to the recordings, input on timbre description and playing technique by pianist A. Guaita, research material on piano timbre and conversations with supervisor Jan Tro. The challenge here was to interpret and translate these musical features into physical properties, terms and concepts that could be found and studied with help of Matlab and the MIRToolbox. Of all functions available from the MIRToolbox, a set was chosen that seemed to be relevant for the analysis. The musical features examined were as follows:

- Time Analysis
- Peak Detection
- Centroids
- Rolloff frequencies
- Spectra and Histograms
- Low Energy Ratio and Temporal Evolution of Energy
- Attack Time
- Attack Slope
- RMS Energy

It was decided to first perform a macro analysis examining the six recordings as a whole, followed by a micro analysis studying certain chords and segments. Applied features from the MIRToolbox are presented in Table 2.1, followed by descriptions of calculations and physical concepts.

Table 2.1: Applied MIRToolbox functions listed with additional descriptions[30]. Also included is the domain in which the functions operate, as well as the the subgroup of functions each of them fall under.

Function	Domain	Feature Group	Description
miraudio	T	BO	Waveform of input signal
mirlength	T	BO	Temporal duration of input signal
mirenvelope	T	BO	Envelope of signal waveform
mirpeaks	T	BO	Detects peaks of input data
mirrms	T	FE - Dynamics	Computes RMS energy of input signal
mirattacktime	T	FE - Timbre	Estimates start of attack for each onset and outputs temporal length of the note attack
mirattackslope	T	FE - Timbre	Computes average attack slope of each detected onset
mironsets	T	FE - Rhythm	Computes an onset detection curve and estimates note positions
mirlowenergy	T	FE - Dynamics	Outputs the ratio of frames having energy below the average
mirspectrum	S	BO	Performs FFT of input signal
mirrolloff	S	FE - Timbre	Outputs the frequency so that 85% of the signal energy is found below this frequency
mircentroid	S	PP - Statistics	Geometric centroid of spectrum
mirhisto	-	PP - Statistics	Outputs histogram of input data
mirgetdata	-	E	Stores MIRToolbox data in a structure, for use outside of the toolbox
mirsave	-	BO	Saving temporal MIRToolbox data to file

S = Spectral, T = Temporal, BO = Basic Operator,
FE = Feature Extractors, PP = Post-Processing,
E = Exportation.

Time Analysis

Recordings were cut and stored as new audio files to be used for further analyses. The time window of the cut recordings were thus set to be from the onset of the first chord to the onset of the next last chord, as discussed in section 2.2.1. The timing data of the relevant onsets were used as input arguments in the *miraudio* function in order to extract the part of interest. The cut recordings were then stored by use of the *mirsave* command. These cut recordings were used in the following analyses, in the cases when the whole recording was to be analysed. Finally, exact duration of each recording was found using the *mirlength* command.

Peak Detection

Peak detection is of interest as it gives an overview of the temporal evolution of the signal amplitude. Presenting peaks of different timbres in the same figure gives an overview of amplitude differences between the recordings at various parts of the piece. The *miraudio*, *mirenvelope* and *mirpeaks* functions were applied for the analysis. Peak detection was performed on the whole recordings. As the audio signals were more than 60 seconds, they were quite messy and it was rather challenging to extract any useful information from them. This was also the case for the signal envelope, and so it was decided to study only the highest peaks. The threshold of the audio signal amplitude was set to 0.40, to only detect peaks above this value. Peak detection was performed on the envelope, due to memory problems when performing peak detection directly on the audio signal. Amplitudes of the MIRToolbox audio signal are dimensionless and normalized. Hence, results from peak detections will only present relative values between the various recordings.

Centroids

The spectral centroid is a physical property helpful when describing timbres, as the centroid corresponds to the centre of gravity of the spectrum. As presented in Chapter 1, a firmly depressed key played *forte (f)* on the piano will give a more shimmering sound due to more resonating overtones, and thereby a spectrum with more high frequency components than if the same key was played *piano (p)*.

Spectral centroids of the whole recordings were calculated with help of MIRToolbox commands and compared to each other. The spectral centroid was executed directly on the audio files by use of the *mircentroid* command. By inspection of the MIRToolbox scripts and the command window in Matlab, it was observed that a summed spectrum was first computed before calculating the spectral centroid from this.

Rolloff frequencies

From the MIRToolbox manual[30] it was found that the *mirrolloff* function outputs the frequency for which 85 % of the total signal energy is found below this value. It will thus provide information of the brightness of the signal, as more excited overtones will result in a higher rolloff frequency.

The calculation was executed on the spectrum of the signal found from *mirspectrum*. Rolloff frequencies were found both for the whole audio signals as well as cut signals including the first two onsets of measure 24.

Spectra and Histograms

Spectra and especially histograms give an overview of the distribution of magnitude. While the spectrum shows magnitude as function of frequency, the histograms plotted show the number of occurrences of each magnitude(dB). Spectra were computed for the whole recordings, i.e. a time window from the onset of the first chord to the onset of the next last chord.

Spectra were calculated using the *mirspectrum* command, which performs an FFT of the input audio signal. Additional arguments were 'dB' defining the unit of the ordinate axis, together with minimum and maximum frequency values set to 20 Hz and 10 kHz, respectively, so that frequencies within the human hearing range were included as well as filtering out noise. Histograms based on the spectra were plotted using the *mirhisto* command, with additional arguments 'Number' set to 200 to specify a number of 200 columns. In order to modify the MIRToolbox plotted histograms, relevant data were extracted and plotted using standard Matlab plotting tools.

Low Energy Ratio and Temporal Evolution of Energy

The low energy ratio corresponds to the percentage of frames with RMS energy below the average value[30]. A signal with overall low RMS energy values, but with various high peaks is thought to result in a rather high low energy ratio. A more even and smooth signal will give a lower low energy ratio.

For an overview of evolution of energy throughout the piece and for a better understanding of the concept of low energy ratio, the RMS energy was calculated for each frame of the signal using the *mirrms* command. The optional 'Frame' argument divided the signal into half overlapping frames of 50 ms and calculated the RMS energy for each frame. The output was a plot of a dimensionless coefficient value of the RMS energy as function of time. These values were then plotted together with the average RMS energy. The MIRToolbox variable from the frame calculated RMS energy was used as an argument in the *mirlowenergy* function, in order to compute the low energy ratio.

Attack Time

It was desirable to investigate how note attack times varied with different timbres. The same onsets were used for these calculations as for the IOI analysis, i.e. the first two onsets of measures 22-24 and the first three onsets of measure 27, shown in Figure 2.1. Audio files were cut, so that they only contained the onsets of interest. This was performed by manually inspecting temporal location of onsets in the sound spectrogram in Audacity and then extracting desired segments. This was executed by use of *miraudio* and *mirsave* functions as described for the Time Analysis.

For measure 27, recordings were cut 0.200 s before and after the first and third onset, respectively. The same procedure followed for measures 22-24, but here recordings were cut 0.100 s before the first onset and 0.200 s after the second onset. This was due to the

16th grace note right before the first beat, and so the cut was made closer to the downbeat, but without cutting into the slope of the peak.

Onsets were detected using the *mironsets* command with some additional arguments, resulting in a plot of the envelope curve with marked onsets. The 'Attack' argument was included in order to have the attack slopes displayed in the plot as well. A 'Contrast' argument was added, meant to filter out onset detections of smaller peaks not of interest. The *mirattacktime* command was executed on the MIRToolbox variable containing the detected onsets, giving an output plot marking attack time with corresponding temporal location of attack. Sometimes the output resulted in more detected onsets than desired. Manual inspection of the envelope with temporal location of detected attacks were then cross-checked with values found from using the *mirattacktime* function. The attack times of interest could then be extracted and studied further.

Attack Slope

Attack slopes were thought to possibly give relevant results that could be linked to playing technique of the various timbres. The attack slopes were found for the first two onsets of measures 22-24 and the first three onsets of measure 27. The *mirattackslope* command was executed on the cut audio files, displaying plots for detected onsets and calculated slopes as function of time. As was the case for the *mirattacktime* function, sometimes more onsets were detected than desired. By manual inspection, as described in the previous paragraph, relevant attack slopes were extracted from the output and then plotted.

RMS Energy

The RMS energy of the first two onsets of measures 22-24 and first three onsets of measure 27 (Fig. 2.1) was calculated using the *mirrms* command and the optional 'Frame' option. The frames were 50 ms and half overlapping, and RMS energy was computed for each frame.

Chapter 3

Results and Discussion

As seen from the piano score included in the Appendix, there are not many additional musical instructions besides the notes. A decrescendo(measure 16) and an accellerando(measure 7) is included, as well as an accentuation(measure 16) and various slurs to indicate phrasing. Some fingerings are also noted. Hence, there are less constraints for the pianist to relate to. The pianist thus stands very freely in his interpretation which seems to be a good starting point when performing the piece with three different timbral intentions.

In the next sections, results from analysis procedures are presented and discussed. Results from manually performed methods are followed by the analyses carried out by use of MIRToolbox functions.

3.1 Tone Distribution

A total of 151 note onsets using 51 piano keys were counted in the piano score. Measures 1 through 28 were included. The number of onsets of each tone is presented in Figure 3.1. As the Schumann piece is written in the key of C# minor, the plot was expected to show a majority of notes C#, E and G#, as these constitute the C# minor chord. Figure 3.1 shows the trend of a high number of C#, E and G# onsets, relative to other notes. The tones span from contra E (E1) to a 4 line D#, i.e. the range is almost 6 octaves. Figure 3.2 shows the number of beats in order to establish the duration of each tone in the Schumann score. As anticipated, notes C#, E and G# are represented by a large number of beats compared to other notes. Of the 10 notes with the highest number of beats, 9 of these are either C#, E or G#. Finally, these plots show few onsets and note durations of the highest and lowest keys, the majority of note onsets and tone durations are thus located in the mid frequency range of the piano.

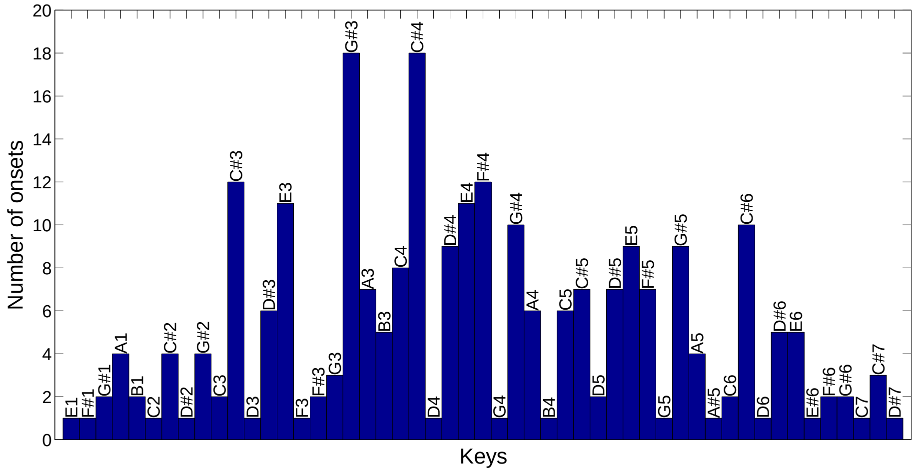

Figure 3.1: Number of onsets of each tone.

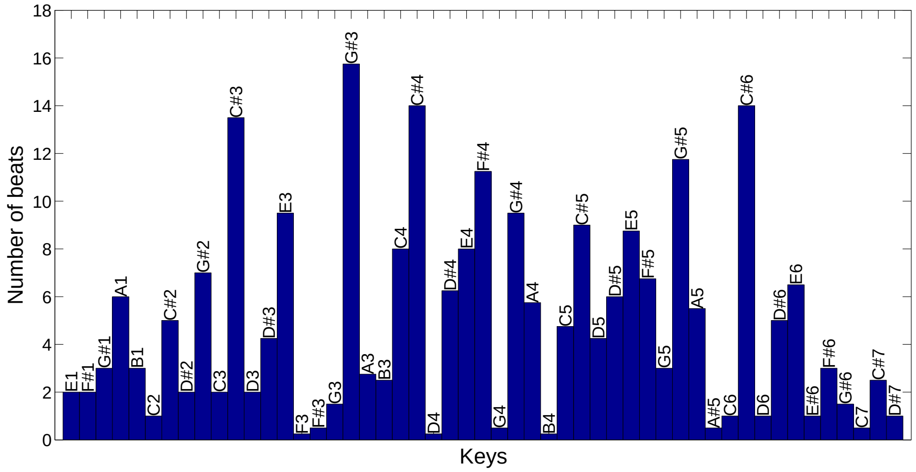

Figure 3.2: Number of beats of each tone.

3.2 Inter-Measure Intervals (IMIs)

Inter-measure intervals for all six recordings are shown in Figures 3.3-3.5. These are plotted together with average measure time. Both from studying the piano score and listening analytically to the recordings, a few things were noted regarding tempo variations throughout the piece.

Temporal variations may be caused either by notations in the score, phrasings proposed by the pianist or phrasings added as a result of timbre interpretations. The accellerando through measures 7 to 12 was reckoned to show a faster tempo for the IMIs. However, as the musical climax was interpreted as the 3 line E# in measure 15, the tempo was assumed to be slightly faster building up to this point. The diminuendo in measures 16 and 17 marks the end of part A and is a transition to part B, hence these measures were expected to be played slightly slower. A ritardando was also predicted in measure 27, as this is the next last measure of the piece.

BRIGHT recordings

Figure 3.3 displays IMI results for the bright timbre recordings and show a higher-than-average tempo through measures 2 to 13. The overall tempo of *more bright* is interpreted as faster and more steady from studying the plot, while the pianist performs more phrasings with tempo in the *bright* recording.

For the *more bright* interpretation, it was commented on the lack of *ritardando* at the end of part A when listening to the recordings. This can also be read from the IMI results, comparing IMIs from measure 15 and onwards, where the *more bright* curve shows a clear trend of shorter duration of each measure as well as a steadier tempo compared to *bright*.

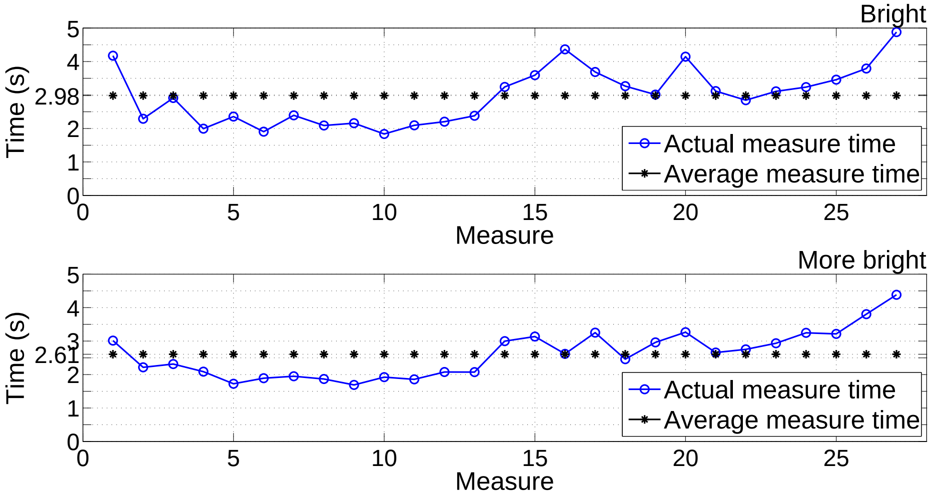

Figure 3.3: Inter-measure intervals for *bright* and *more bright* recordings.

For the *bright* recording it is noted that the first measure has ∼1 s longer playing time than for *more bright*, which rhymes well with perceived playing style when listening to the recordings. The latter does indeed feel more rushed and forward compared to the *bright* recording.

SOFT recordings

The soft timbre IMI curves in Figure 3.4 follow the same trend as the bright timbre recordings. From measures 2-13 the tempo is slightly faster than the average measure time. The *soft* curve shows that part A holds a tempo close to the corresponding *bright* measures, around 2.25 s/measure. The *more soft* curve shows a slower part A, around 2.5 s/measure. The *soft* tempo drops from ∼4.5 s/measure to ∼2.75 s/measure from measure 17 to 18. This tempo change is due to the beginning of a new phrase, but is not found for the *more soft* timbre, where temporal variations seems to be slightly smaller.

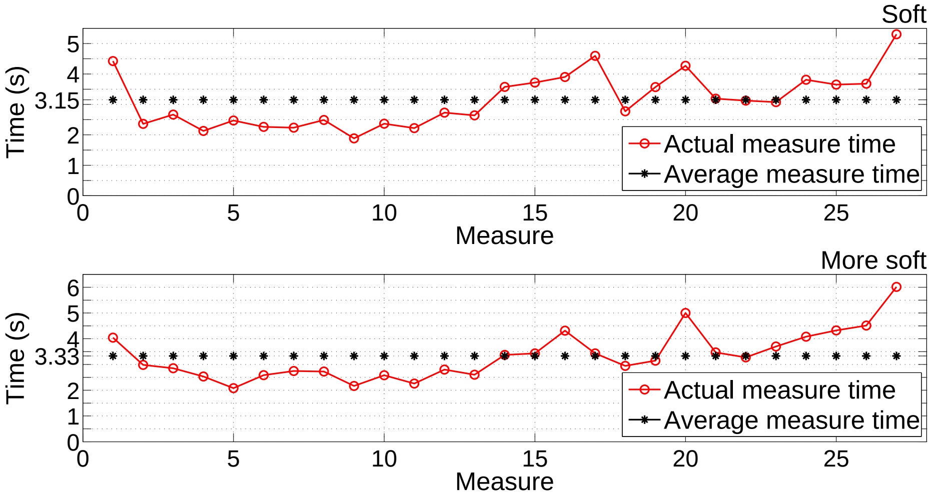

Figure 3.4: Inter-measure intervals for *soft* and *more soft* recordings.

FULL recordings

Figure 3.5 shows the full timbre IMI results. The *more full* timbre shows a rather fast tempo in the very first measure. It is played roughly 2 s faster than for the *full* recording. From subjective analyses presented in Chapter 2.1, it is noted slightly less progress and a slower tempo of the melody for *full* than for *more full*. The *more full* timbre recording is possibly perceived as being played more forward than *full* due to more temporal variations from one measure to the next in the *more full* recording, as can be observed in Figure 3.5. Nevertheless, the curves for the full timbre recordings are the two showing the most similar tempo phrasing of the three timbres.

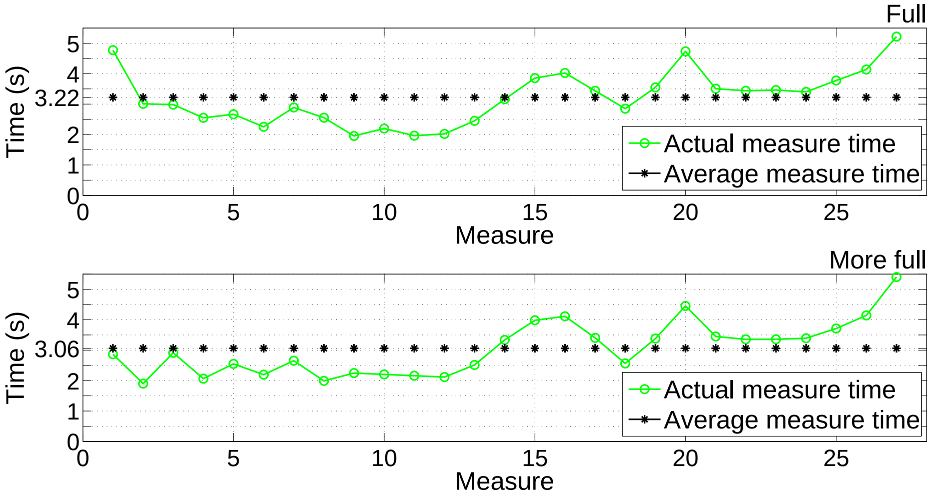

Figure 3.5: Inter-measure intervals for *full* and *more full* recordings.

3.3 Inter-Onset Intervals (IOIs)

Uncertainty considerations of detected note onsets

As for the uncertainty of the measurements and calculations, these vary slightly with each audio file and with the segments being considered. It was chosen to find exact note onsets in the sound spectrogram in Audacity, as this gave most precise results. Onsets were found with and accuracy of 1 ms, but with varying uncertainty. It was particularly difficult to determine exact first beat onsets in part A. These downbeats were all bass notes and not all of these onsets could be clearly detected in the spectrogram. The melody in the treble was (and should be) more prominent, so the bass notes stayed more in the background. It proved to be most challenging to find downbeat bass onsets for the soft timbre recordings. Arpeggios on the downbeats also made it more complicated detecting exact temporal locations.

As seen from the piano score, the melody line in part A follows the same rhythm all the way to bar 16. This syncopated rhythm always carry over the last eighth note of each measure to the first beat of the next. This rhythm, in addition to using the sustain pedal, makes it more challenging to distinguish one onset from another. Sometimes the frequency spectrum changed remarkably little when the downbeats were being played.

Not all chords were precisely depressed, and this was also a source of uncertainty. Uncertainties in chord depression were estimated on the basis of work by Tro [32]. His research found that average key attack times for two consecutive chords varied between 1.2 to 16.8 ms and 0.8 to 13.6 ms for the first and second chord, respectively. These results together with the manual inspection of the spectrogram and the uncertainty in reading exact note onsets from Audacity, a combined uncertainty of ±5 ms was considered to be adequate.

For a macro analysis concentrating on the recording as a whole, the estimated onset uncertainty of ±5 ms is less relevant as this has little influence on the overall musical tends. For the analyses dealing with smaller segments and extracted onsets, the note onset uncertainty will be more heavily considered when interpreting the results.

3.3.1 IOIs - Measure 27

The first three chords of measure 27 are studied, seen in Figure 3.6. The rhythm is a dotted eighth note followed by a sixteenth note and a half note. IOIs are interesting to study, as rhythms like these can be adjusted slightly to fit a musical intention. The IOIs can be seen in Figures 3.7 and 3.8.

Figure 3.6: Measure 27.

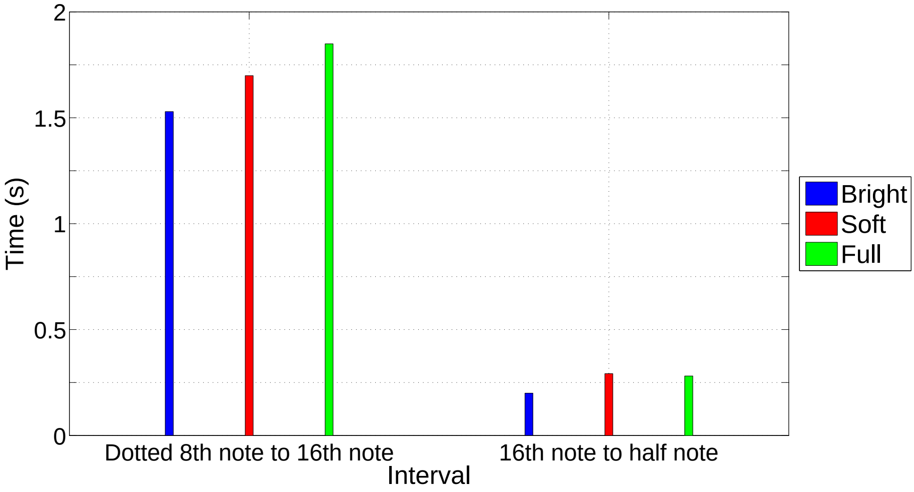

Figure 3.7: Inter-onset intervals for *bright*, *soft* and *full* recordings. IOIs are found for the 'dotted 8th note - 16th note - half note' figure in measure 27. Estimated uncertainty is ±5 ms.

Differences between the IOIs are largest for recordings *more bright*, *more soft* and *more full* seen in Figure 3.8. As was observed when listening to the recordings, notes seemed to be held longer for timbres *soft* and *full*. This perception is supported by the IOIs plotted in Figures 3.7 and 3.8. As for the second interval, 16th note to half note, differences between the three timbres are smaller. With the 16th note having such a short note value, there was not expected huge differences here.

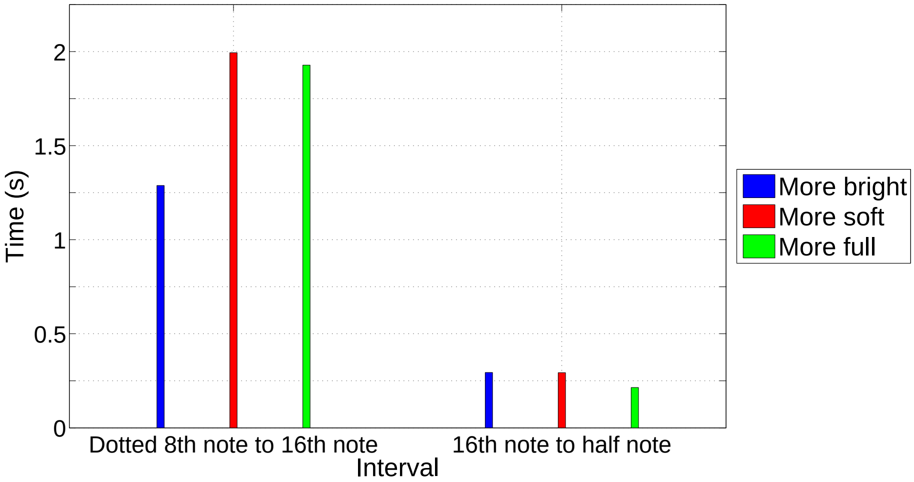

Figure 3.8: Inter-onset intervals for *more bright*, *more soft* and *more full* recordings. IOIs are found for the 'dotted 8th note - 16th note - half note' figure in measure 27. Estimated uncertainty is ±5 ms.

As for the timbres presented in Figure 3.7 they show smaller differences between the IOIs. *Full* has ∼0.3 s longer IOI than *bright* for the first interval, whereas *soft* is played with an IOI slightly below 0.2 s longer than for *bright*. Even though the differences between the IOIs are not as big as in Figure 3.8, they still follow the same trend with the bright timbre IOI being shorter. As for the second interval, the *bright* IOI is the shorter one, about 0.1 sec shorter than *full* and *soft*. Uncertainty considerations concerning note onsets have been discussed in the previous section and could have an influence on the results for the second interval. The first interval show such large differences between the timbres, that the uncertainty of ±5 ms will not affect the result.

3.3.2 IOIs - Measures 22, 23 and 24

Figure 3.9: Measure 22.

IOIs for the first two onsets of measure 22, seen in Figure 3.9, are plotted in Figure 3.10. These are rather similar except for *more soft* and *full* recordings. The first deviates from the rest by only ∼0.25 s, while the latter differs from the rest by ∼1.25 s. This is quite a lot, and was noticed when listening to the recordings. It was commented in the observations presented in Chapter 2.1 that the *full* recording seemed to have less progression relative to the others, as well as the notes were perceived to be held longer. This longer IOI for the *full* recording might be intentional by the pianist, however it is not found in the *more full* recording. As this is in the beginning of a tonal build-up of tension, it might explain this temporal phrasing. A longer IOI for full timbre interpretations might support verbal descriptions from section 1.4, as a longer interval between subsequent chords will give tones more time to resonate.

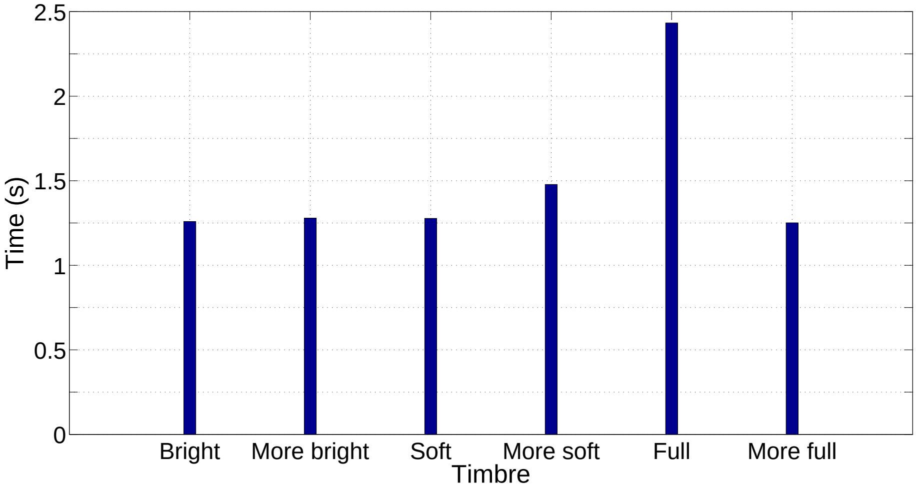

Figure 3.10: Inter-onset interval for the first and second onset of measure 22. Estimated uncertainty is ±5 ms.

IOIs for the first two onsets of measure 23, seen in Figure 3.11, are presented in Figure 3.12, and show slight differences between the various recordings. It is noted that the *more soft* and *full* recordings show the longest IOIs, as was also the case for measure 22.

Figure 3.11: Measure 23.

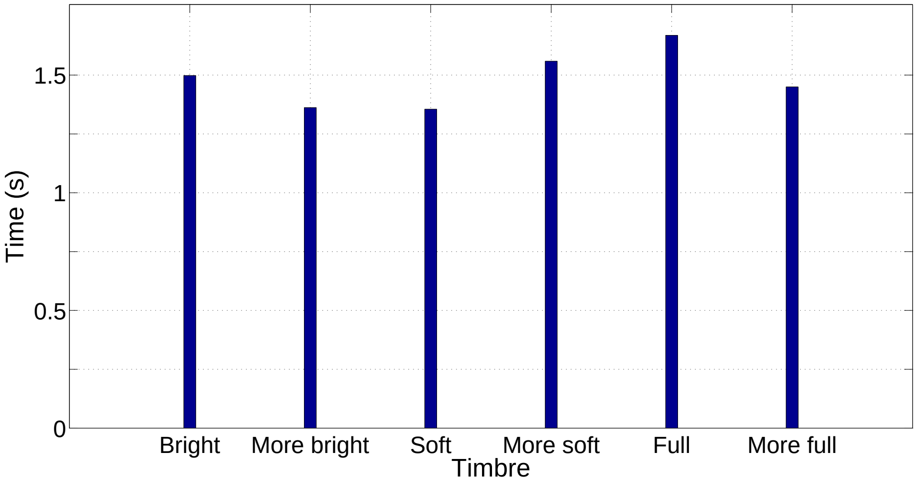

Figure 3.12: Inter-onset interval for the first and second onset of measure 23. Estimated uncertainty is ±5 ms.

Figure 3.14 presents the IOIs for the first two onsets of measure 24, shown in Figure 3.13. The *full* recording still shows one of the longest IOIs, which is satisfactory, but it is difficult to read some very clear tendencies from this plot. The *bright* recording shows the longest IOI here, for an unknown reason. However, IOI differences between the various recordings are < 0.25 s, which is not that much in this musical context.

Figure 3.13: Measure 24.

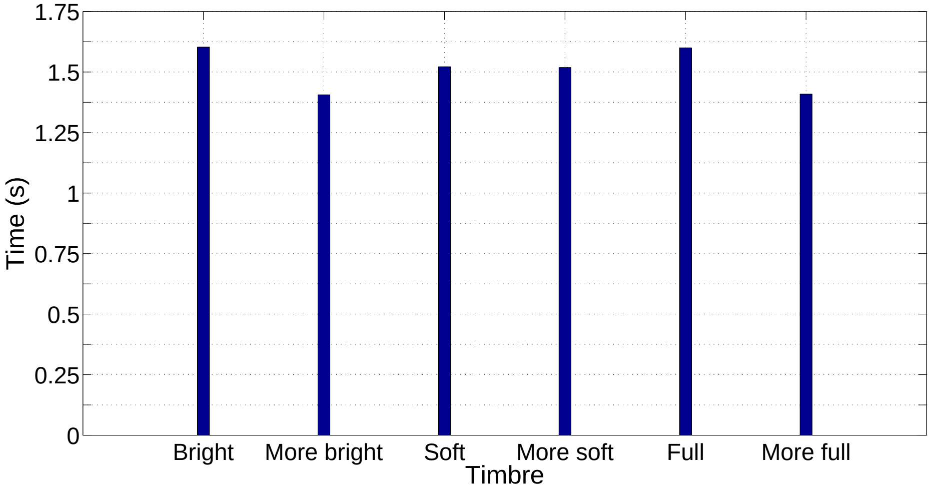

Figure 3.14: Inter-onset interval for the first and second onset of measure 24. Estimated uncertainty is ±5 ms.

More temporal progress is thought to result in an overall shorter IOI, thus it was expected that especially the *more bright* recording would show clearly shorter IOIs, but this was not the case as seen from Figures 3.10,3.12 and 3.14. The opposite was expected for the full timbre recordings, and the results showed a slight trend of this timbre having overall long IOIs. This would support the subjective sensation presented in section 2.1 as well as descriptions from Chapter 1.4 referring to the full timbre as a sound where timing of onsets should be adjusted in order to giving overtones the time to resonate. However, this trend was not consistent for all measures studied.

3.4 Time Analysis

Lengths of all recordings are listed in table 3.1. Recall that these correspond to the duration from the onset of the first chord to the onset of the next last chord of the piece.

Table 3.1: Measured lengths of the six piano recordings.

Recording	Time (s)
Bright	83.446
More bright	72.533
Soft	87.847
More soft	92.873
Full	89.817
More full	85.092

Bright timbre recordings differ by about 11 s which is a lot relative to the other recordings. As for the other timbres the pianist gives a performance of about the same length for each timbre, about ±4 s. Bright timbre recordings are the ones with the highest tempo, which corresponds well with the subjective perception described in chapter 2.1. It was somewhat expected that the bright recordings would be the ones with shortest duration and soft recordings to have longest duration; it can often be difficult to sustain a high tempo when playing very soft and *piano (p)*.

The *more bright* recording is the one of highest tempo; it is not unlikely that the pianist exaggerated his musical gestures more after the conversation with the research group. It is also possible he changed his perception and interpretation a bit. The *more soft* recording is correspondingly the one of longest duration, where the same argumentation seems valid. A difference of ∼20 s between these two recordings mentioned is probably not a coincidence and can thus be said to be timbre related. As for smaller temporal differences of about ±5 s between recordings, they can not as easily be interpreted the same way; these differences might just be coincidental.

3.5 Peak Detection

Peaks were detected on the envelopes of the whole signals, i.e. a time window from the onset of the first chord to the onset of the next last chord of the piece. Only peaks above 0.40 amplitude of the original audio signal were detected to narrow down the number of markers in the plot.

The Schumann extract consists of two main parts, presented in chapter 2 as part A and part B. Both parts have a somewhat musical ”peak” towards the end. Such peaks may be the end of e.g. a tonal, dynamic and/or a temporal build-up, all of these are more or less represented in the Schumann piece. Building up musical tension like this may be noted in the music score, sometimes with dynamic descriptors such as a crescendo, temporal notations such as an accellerando, or bows representing desired phrasing. Phrasing concerning dynamics and tempo may also be added by the pianist, if not denoted in the score. In this Schumann piece the musical peak in part A was thought to be the E# in measure 15, as this marks the end of a long succession of measures with the same bass and treble rhythms as well as there is a tonal build-up as the treble melody modulates further and further up in pitch. There is also an accellerando denoted in the score, ending part A with a diminuendo and also a natural ritardando leading the melody into part B.

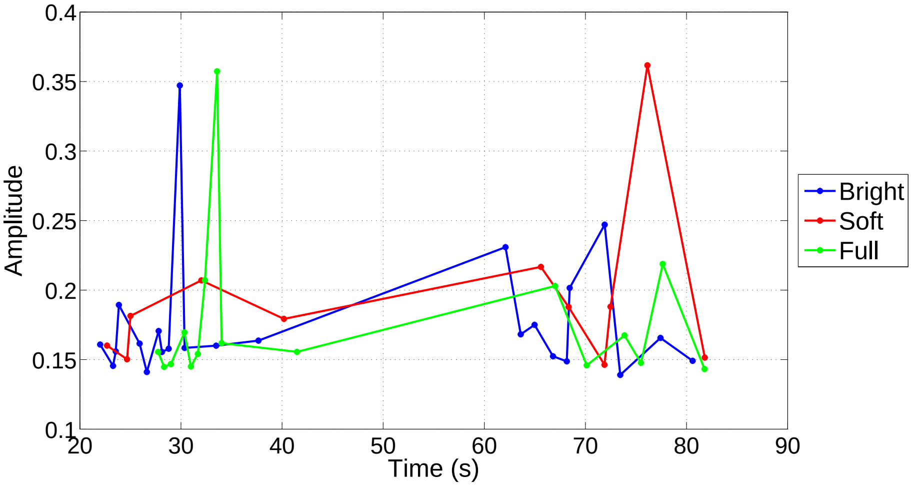

Figure 3.15: Peak detection above amplitude threshold 0.40 of audio signal curve. Peaks are detected on the envelope of the signal. *Bright*, *soft* and *full* recordings.

A corresponding tonal build-up is also found in part B, from measure 21 and onwards to measure 27. Hence, high amplitudes are expected towards the end of parts A and B. The soft timbre recordings were not assumed to have peaks that would stand out much as the dynamic level was perceived to be rather steady here, with little or no crescendo towards the end of parts A and B, as described in section 2.1.

Figures 3.15 and 3.16 show the peaks detected on envelopes of the six recordings. The highest peaks of bright timbre and full timbre signals were found at the end of part A, as predicted, as well as some lower peaks towards the end of part B. Soft timbre recordings show a lower amplitude at the end or part A, and surprisingly the highest amplitude of all timbres at the end of part B. A very unexpected result. A heavier use of the sustain pedal together with a higher amount of resonating overtones might have an influence on the high soft timbre amplitudes. There is also observed more detected peaks in Figure 3.16 relative to 3.15, which may indicate more use of dynamics or a higher dynamic level in the second round of recordings.

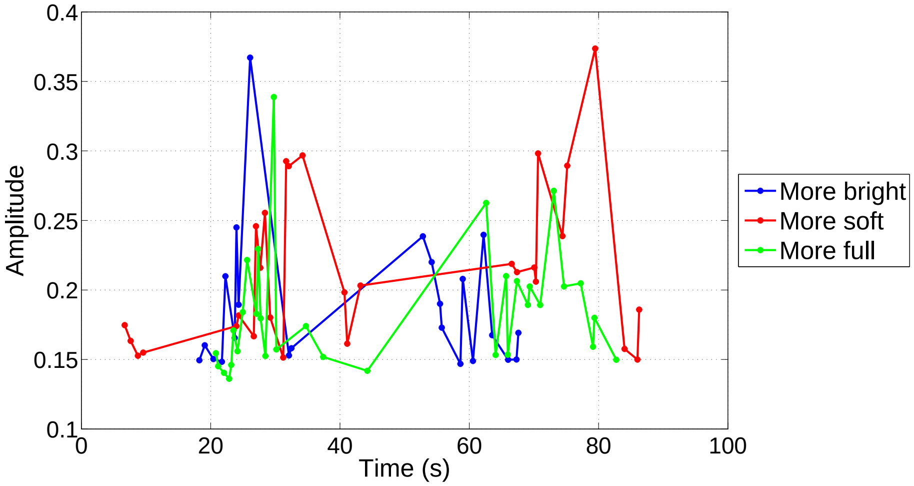

Figure 3.16: Peak detection above amplitude threshold 0.40 of audio signal curve. Peaks are detected on the envelope of the signal. *More bright*, *more soft* and *more full* recordings.

Location of the highest peaks were cross-checked with the audio recordings. The Matlab plots were studied to find the temporal location of the peaks, and then cross-checking this with onsets found in the Audacity spectrograms of the various recordings. The onsets were found within 10 ms of the detected time found from the Matlab plots. Interestingly, it was found that the highest peaks for all recordings appeared at the same onsets in the piano score. The first peak occurred at the onset of the 3 line G# in measure 13 and the second peak at the downbeat of measure 26, for a not understood reason.

3.6 Centroids

Centroids of all six recordings are plotted in Figure 3.17. Centroids were found for the whole recordings, i.e. a time window spanning from the onset of the first chord to the onset of the next last chord of the Schumann piece.

Soft timbre recordings resulted in spectral centroids within the interval 900 Hz - 1kHz, and these were significantly lower values than for bright and full timbres. This was a satisfying result, as a lower dynamic level and a softer attack on the piano keys will result in fewer resonated overtones and thus less higher frequency components.

Full timbre recordings had about the same spectral centroid for both recordings, slightly less than 1400 Hz. The centroids for the bright timbres could be expected to have higher values than for the full timbre. This was due to the difference in playing technique. As described in section 1.4, the bright timbre may be produced with firm finger movements, hard onsets and a staccato playing style using little or no sustain pedal. As the full timbre was perceived to be produced with rounder and longer onsets (section 2.1), as well as these observations supports the verbal descriptions from section 1.4, a lower spectral centroid value might be expected for full timbres compared to bright. However, a full timbre is also characterized by a higher dynamic level and a high amount of resonating overtones. In addition, the sustain pedal is more heavily used for full timbres than for bright, helping overtones to resonate longer. Thus, predicting which timbre should result in a higher spectral centroid is not straightforward. The resulting bright and full centroids can therefore be said to be reasonable, as they are within the same interval, roughly 1250 Hz - 1450 Hz.

The results from the bright timbre recordings were interesting, as they showed a difference of about 150 Hz. It was expected that the spectral centroid for *more bright* would be higher than for the *bright* recording, as the perception was that the pianist played even more staccato, attacca and firm onsets with possibly a stronger dynamic. A more exaggerated interpretation of the bright timbre was also thought to possibly result in even more higher frequency partials due to sharper onsets and staccato play. However, this is not the case as seen in Figure 3.17, and it is not straightforward to understand why. 150 Hz is not a huge difference, and may just be a coincidence. However, since the full timbre recordings gave such similar results, this difference is interpreted as relatively large.

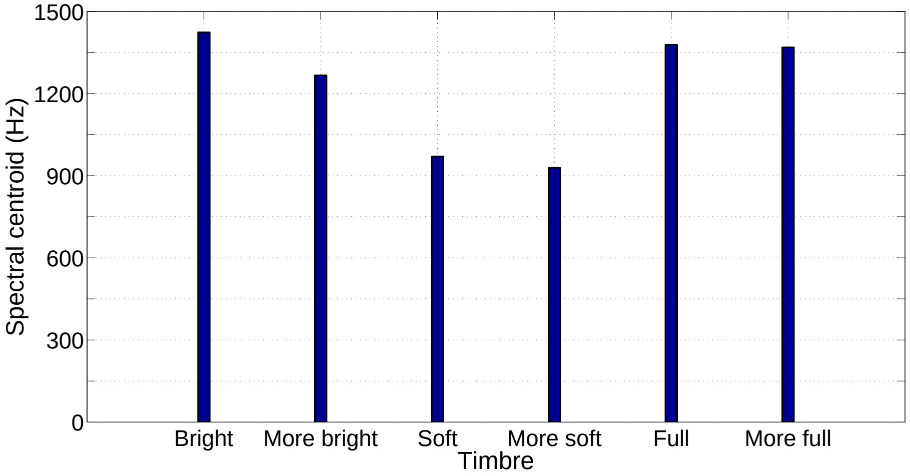

Figure 3.17: Spectral centroids (Hz) for all six piano recordings.

3.7 Rolloff frequencies

Figure 3.19 is included to clarify what is actually performed by the *mirrolloff* function in the MIRToolbox. This plot shows the spectrum of the first two onsets of measure 24 (Fig. 3.18). The spectrum is cut at 5000 Hz, as fluctuations in the spectrum caused by excited overtones were relatively small above this frequency. The red line marks the rolloff frequency of 2063.8 Hz, meaning that 85% of the total signal energy is found below this frequency. This also looks reasonable when studying the plot.

Figure 3.18: Measure 24.

Rolloff frequencies for the first two onsets of measure 24 are shown for all timbres in Figure 3.20. Here, the rolloff frequency for the two bright timbre recordings differ by slightly more than 250 Hz, whereas the soft and full timbres each show very similar values for the first and second round of recordings. This may indicate that these onsets are performed fairly similar in both rounds of recordings of soft and full timbres.

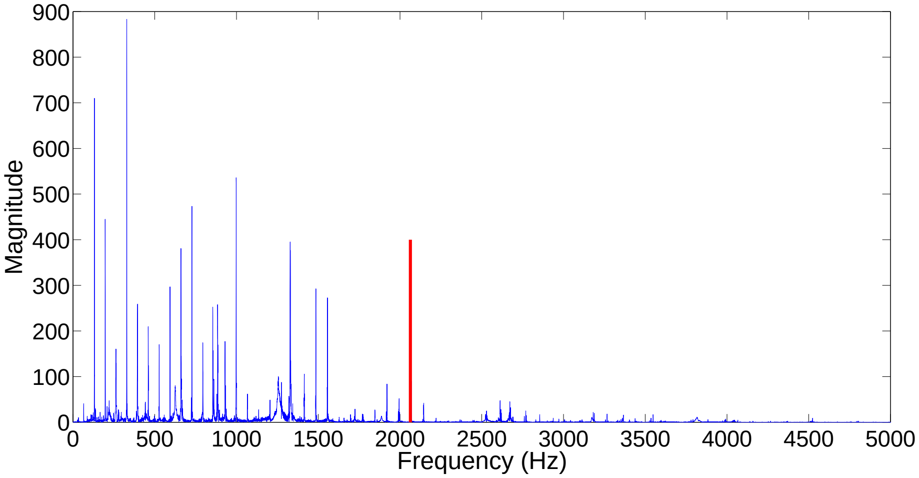

Figure 3.19: Spectrum for the first two onsets of measure 24, with the rolloff frequency of 2063.8 Hz drawn in as the red line. The magnitude is defined as dimensionless from the MIRToolbox.

Figure 3.21 shows rolloff frequencies for each of the six recordings as a whole, i.e. a time window spanning from the onset of the first chord of the piece to the onset of the next last chord. These results show the same tendencies as the calculations for measure 24 in Figure 3.20. Bright and full timbres clearly show values of about the same rolloff frequency, whereas the soft timbre shows a lower calculated rolloff frequency. It is found from e.g. the histogram analysis (presented in the next section) that the soft timbre was being played at a lower dynamic level relative to the other timbres. This was also observed from analytically listening to the recordings (section 2.1).

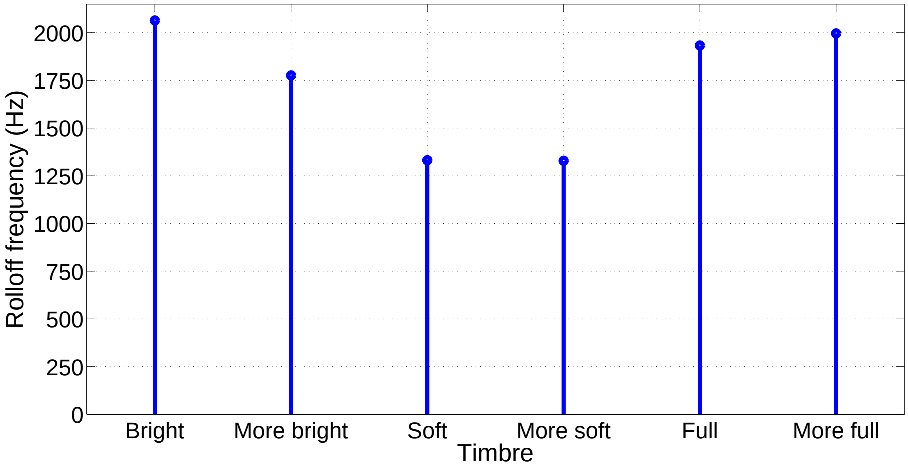

Figure 3.20: Rolloff frequencies found for the first two onsets of measure 24 for all six recordings.

It is known from Chapter 1 that fewer higher frequency partials are excited when playing at a lower dynamic level[11, p. 45] (and that this is in fact what makes the notes sound softer), which makes these rolloff frequencies seem reasonable. The *more bright* recording stands out in both plots with having a rolloff frequency slightly more than 250 Hz below the *bright* recording. This corresponds to fewer resonating overtones in the *more bright* recording, whereas the opposite would be expected for a more exaggerated interpretation of the bright timbre. This was also discussed in spectral centroid results.

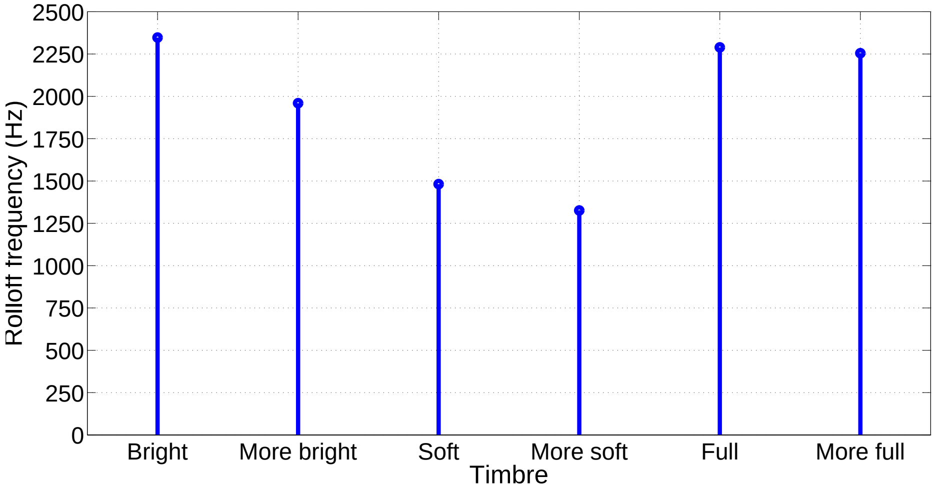

Figure 3.21: Rolloff frequencies found for all six recordings.

3.8 Spectra and Histograms

The spectrum of the *bright* recording is shown in Figure 3.22, and thus show the magnitude(dB) for frequencies in the range 20 - 10000 Hz. Spectra were found from the whole recordings, i.e. a time window from the first chord onset to the next last chord onset of the piece. It was decided to plot histograms from these spectra, as they would give a better overview of the magnitude distribution in the various signals.

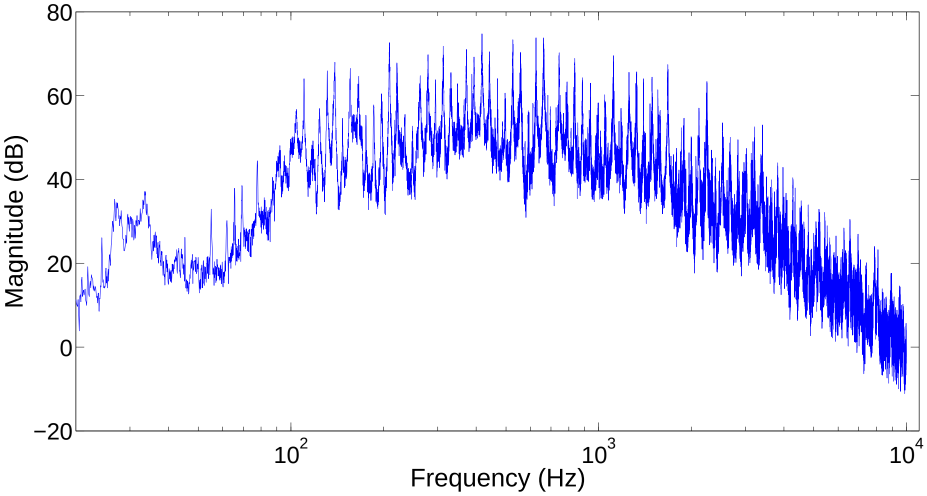

Figure 3.22: Spectrum of *bright* recording.

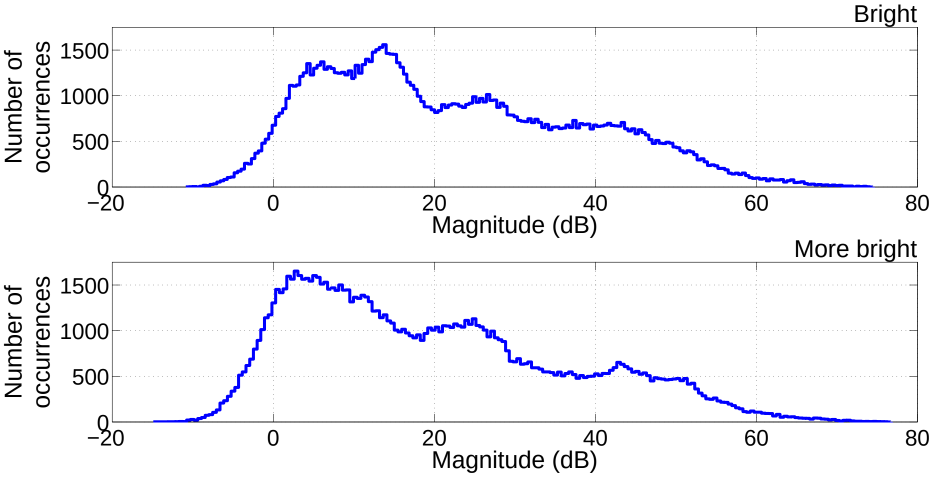

Figure 3.23: Histogram envelope calculated from magnitude(dB) spectrum. *Bright* and *more bright* recordings.

Histogram envelopes are shown in Figures 3.23-3.25. As the 200 column histograms show the number of occurrences for each magnitude, these will be an indicator of relative dynamic level for the various recordings. As seen in the soft timbre plots in Figure 3.24, their magnitude distribution clearly deviate from those of bright and full timbres. The soft timbres show a clear majority of occurrences for very low magnitudes relative to the two other timbres.

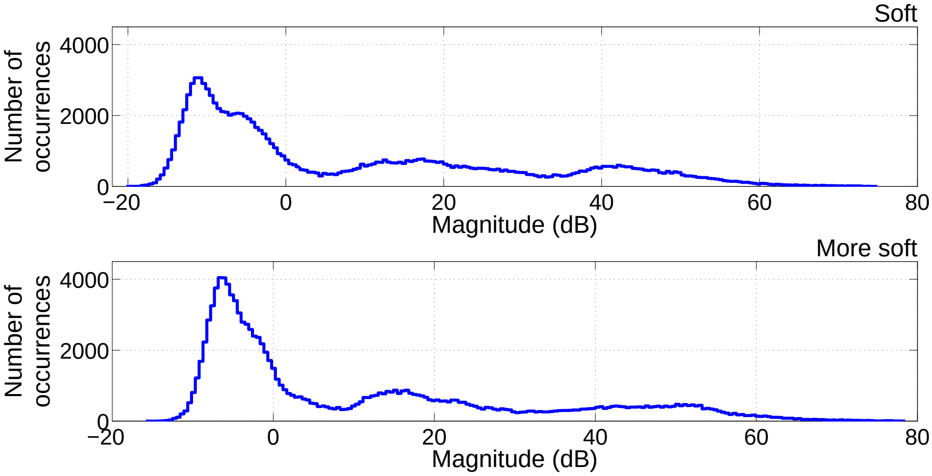

Figure 3.24: Histogram envelope calculated from magnitude(dB) spectrum. *Soft* and *more soft* recordings.

Both bright and full timbres show distinct peaks, but overall they have a more even distribution of magnitudes compared to the soft timbre. The magnitude range seems to be roughly the same for all recordings, even though the distribution differs. The soft recordings were perceived as being played at a lower dynamic level than the others. These histograms thus provides a satisfying result, as it supports soft timbre descriptions presented in section 1.4 as well as subjective observations presented in section 2.1. As for bright and full timbres, the majority of occurrences seems to be centred at about the same magnitude range, indicating a rather similar dynamic level in these recordings.

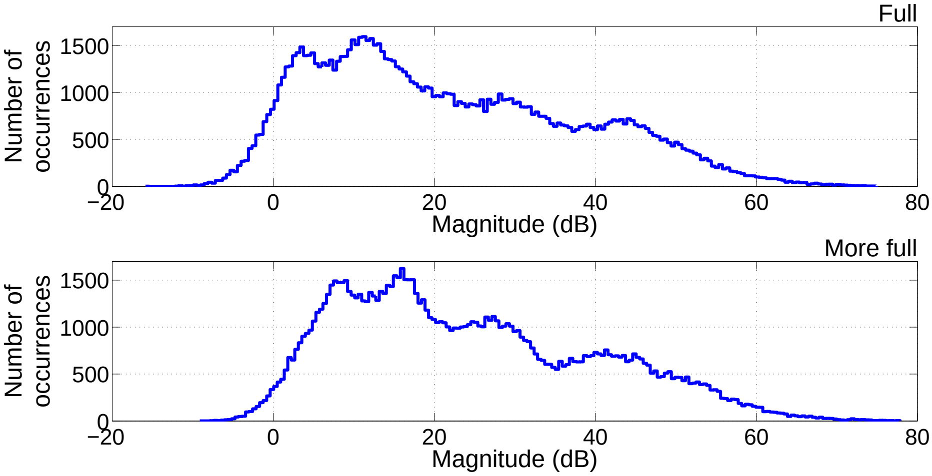

Figure 3.25: Histogram envelope calculated from magnitude(dB) spectrum. *Full* and *more full* recordings.

3.9 Low Energy Ratio and Temporal Evolution of Energy

Figure 3.26 shows the low energy ratio for the six recordings. These were calculated from the whole recordings, i.e. a time window from the onset of the first chord to the onset of the next last chord of the piece.

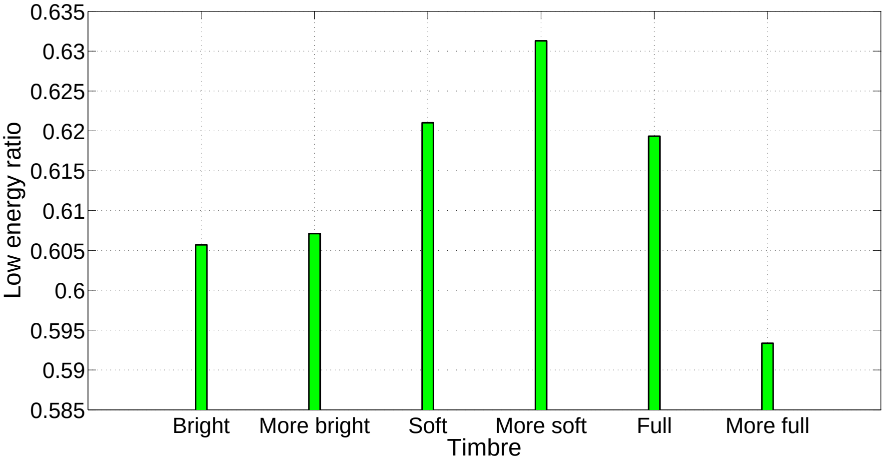

Figure 3.26: Low energy ratio for all six recordings, showing the percentage of frames with energy below average RMS energy.

As for e.g. the *bright* recording, shown as the top plot in Figure 3.27, the low energy ratio of 0.6057 for this recording corresponds to 60.57 % of the frames having RMS energy below the red line marking average RMS energy. Results from the low energy ratio calculation do not vary that much, all ratios are within the interval $\sim 59.4 - 63.2\%$.

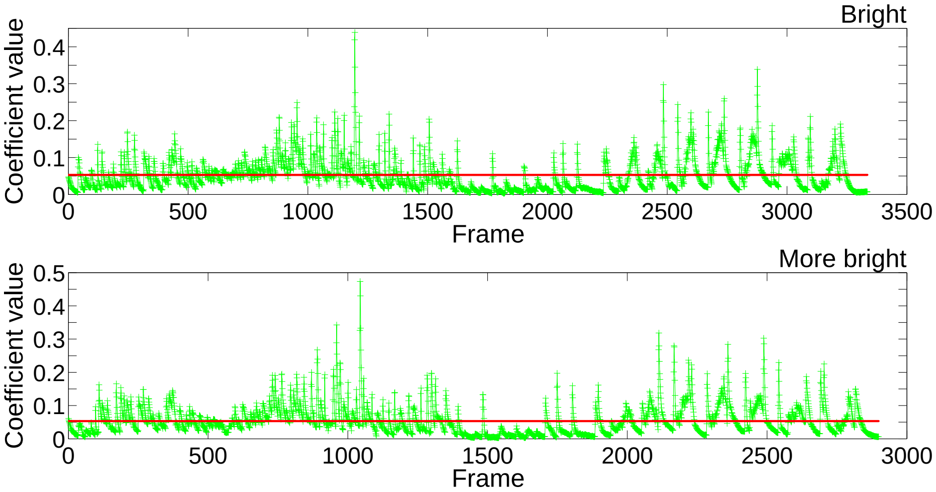

Figure 3.27: RMS energy for the *bright* and *more bright* recordings. The average RMS energy coefficient value is 0.0532 and 0.0533 for *bright* and *more bright*, respectively, marked with red lines.

Low energy ratios are possibly more easily interpreted and understood if studied together with frame-computed RMS energy. These curves are therefore included in Figures 3.27-3.29, where RMS energy is plotted as a function of frame. These were also calculated from the whole recordings. Average RMS energy is marked with a red line. Each frame is 50 ms and the frames are half overlapping. A marker is set for every beginning of a new frame, i.e. there is a marker for every 25 ms. RMS energy is calculated for each frame.

Average RMS energy is almost identical for bright timbre recordings, as seen in Figure 3.27. This may indicate a similar playing style for the interpretation of the bright timbre, possibly are dynamic levels and/or onsets performed rather similarly in the two recordings. Soft and full timbre recordings in Figures 3.28 and 3.29, respectively, show a much higher average RMS energy for the timbre interpretations in the second round of recordings. This is due to several higher peaks seen in the RMS energy plots of the *more soft* and *more full* recordings. These peaks may be caused by a higher dynamic level for these recordings, compared to *soft* and *full*, respectively. Peaks may also be a result of more resonating overtones, which may sound reasonable for a more exaggerated interpretation of the full timbre. If the pianist interprets the soft timbre as discussed in section 1.4.3: playing notes with more substance, adding weight to the onset and fully depressing the keys, this may contribute to a sound containing more higher frequency partials and hence result in some of the higher peaks shown for the *more soft* recording.

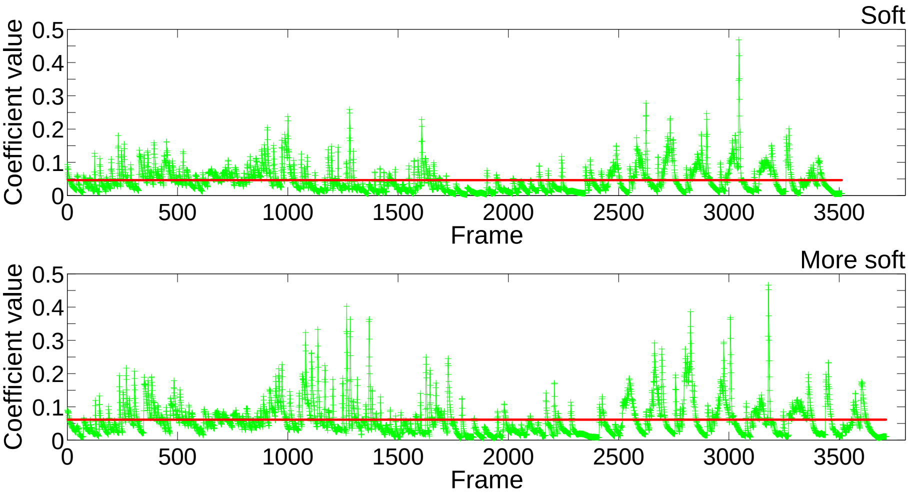

Figure 3.28: RMS energy for the *soft* and *more soft* recordings. The average RMS energy coefficient value is 0.0466 and 0.0618 for *soft* and *more soft*, respectively, marked with red lines.

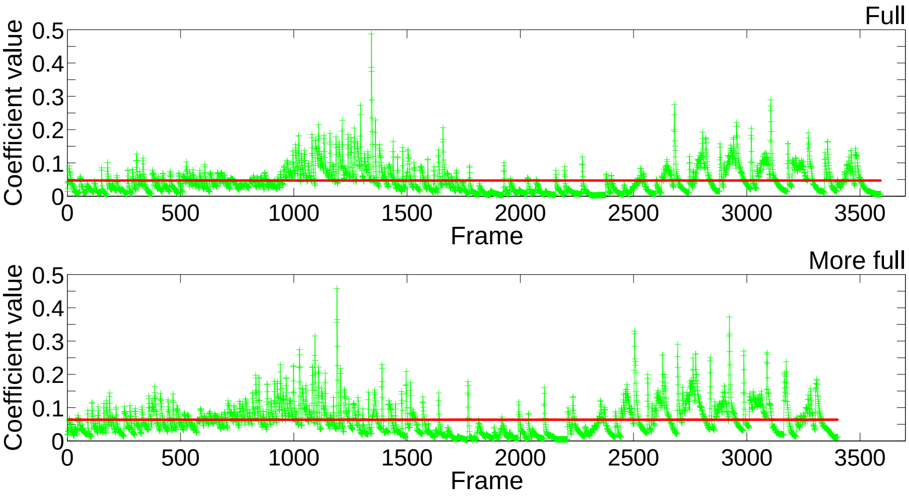

Figure 3.29: RMS energy for the *full* and *more full* recordings. The average RMS energy coefficient value is 0.0468 and 0.0639 for *full* and *more full*, respectively, marked with red lines.

As for the units of the ordinate axis of Figures 3.27-3.29, this is a dimensionless coefficient value. It has not been successful to determine how this is computed, from looking into the scripts of the MIRToolbox. The results should therefore be treated as relative values. This work concentrates on distinguishing between different timbres by studying various physical properties; for this reason it should be sufficient to examine relative values of the features studied.

3.10 Attack Time

3.10.1 Attack Time - Measure 27

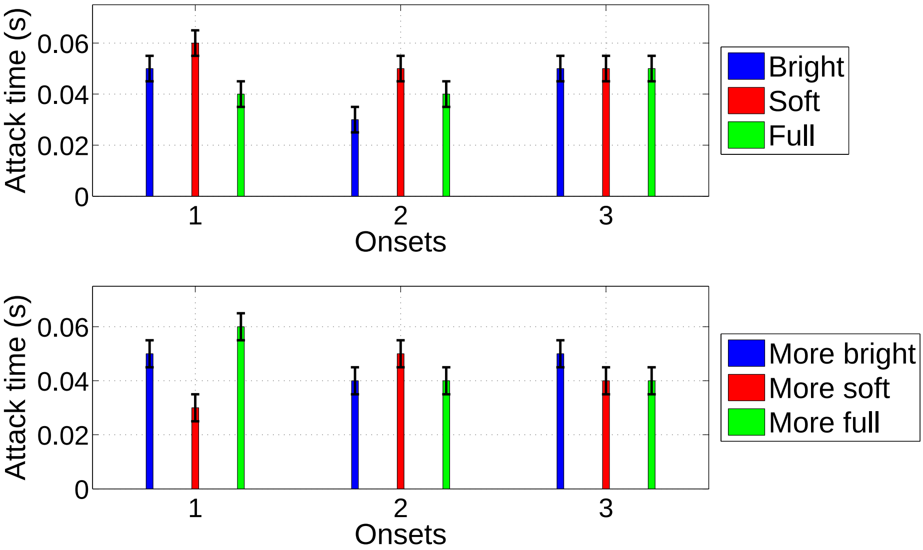

Figure 3.30: Attack time for the first three chords of measure 27. Estimated uncertainty is ±5 ms.

Figure 3.31: Measure 27.

Figure 3.30 shows attack time for the first three chords of measure 27 (Fig.3.31). Error bars are included, taking into consideration both the uncertainty of chord onsets from Tro[32] and the uncertainty from onset detection in Audacity, discussed in section 3.3.

Noticed in Figure 3.30 is the remarkably short attack time of the first onset of the *more soft* timbre. Plotting onset attacks with help of the MIRToolbox resulted in the curve presented in Figure 3.32. This shows the output from the MIRToolbox interpretation of the various slopes and the start of attack for each onset. As seen from this curve, the start of attack is set to be very high up on the first peak. This is highly unexpected, and it has not been found a reason for why the MIRToolbox places the start of the attack at this point. However, as the same MIR functions and algorithms were used for all calculations, results from this must be included even though they do not fully coincide with expectations. Audio files used for calculations in Figure 3.30 started 0.200 sec before the first onset of measure 27. Experimenting with an increase or decrease of this interval proved to be of no significance for the MIRToolbox estimation of the start of attack.

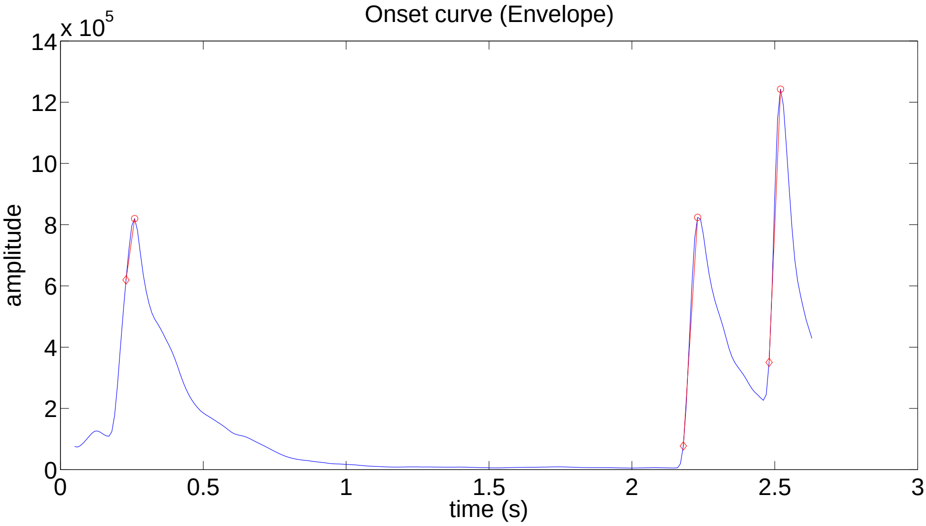

Figure 3.32: Detected onsets and attack time for the first three chords of measure 27. *More soft* recording. The plot is as plotted from the MIRToolbox, and is the output when applying the *mironsets* function. The curve shows amplitude of the audio signal as a function of time (s).

Largest differences between timbres were expected on the first onset and possibly the second onset of this rhythmic figure of measure 27. This is due to the second onset being a sixteenth note, which is such a short note value that it is assumed to be difficult to make very large variations on the subsequent chord (third onset). Estimated uncertainties should also be considered, possibly making differences between recordings smaller. Bright timbre recordings were expected to have the overall shortest onset attack time, as this way of playing was described as firm depression of the piano keys. The soft timbre recordings were expected to show the longest onset attack times, as interpreted by piano-technical descriptions presented in section 1.4.

The top plot of Figure 3.30 might show a slight tendency of the soft timbre having longer attack time relative to the others. The same tendency is not as clear in the bottom figure, but the MIRToolbox-estimated start of attack for the *more soft* recording discussed above should be kept in mind. However, the soft timbre attack times for the sixteenth note (second onset) seems to be longer relative to the other timbres. This corresponds well with subjective perceptions presented in section 2.1. Full timbre recordings were expected to show longer attack times, but this was not found as seen in Figure 3.30. The third onsets proves to have quite similar onset attack time; this was anticipated as discussed in the previous paragraph. The bright timbre was expected to show the shortest attack time of the three, but no such tendency could be found from the results.

3.10.2 Attack Time - Measures 22, 23 and 24

For measure 22 (Fig. 3.33), onsets seemed to be rather imprecise, the envelope did not show just one clear peak for each onset. E.g. for the *full* recording the first onset appeared as two smaller peaks. As for *more bright* and *more full*, the first onset was not shown as a clear single peak but rather many small ones. For a not understood reason, in these recordings the start of the attack of the second onset was set by the MIRToolbox to be very high up on the peak, thus giving a smaller attack time than anticipated for the second onset. This is the same issue discussed in the previous subsection together with calculations for onset attack time of measure 27 (section 3.10.1).

Figure 3.33: Measure 22.

Hence, results from this measure are not appropriate to study isolated, but should rather be viewed together with subsequent measures 23 and 24 to see if the results show somewhat the same tendency. And to see if the imprecise onsets had a large influence on the calculations.

From Figure 3.34 showing the attack time of the first two onsets of measure 22, the first onset seems to be be played with the same attack time in all recordings. Attack times for the second onset of bright and full timbres are notably longer in the first round of recordings than the second. From manually inspection of the plots, this is due to the odd MIRToolbox placement of the start of attack, mentioned above.

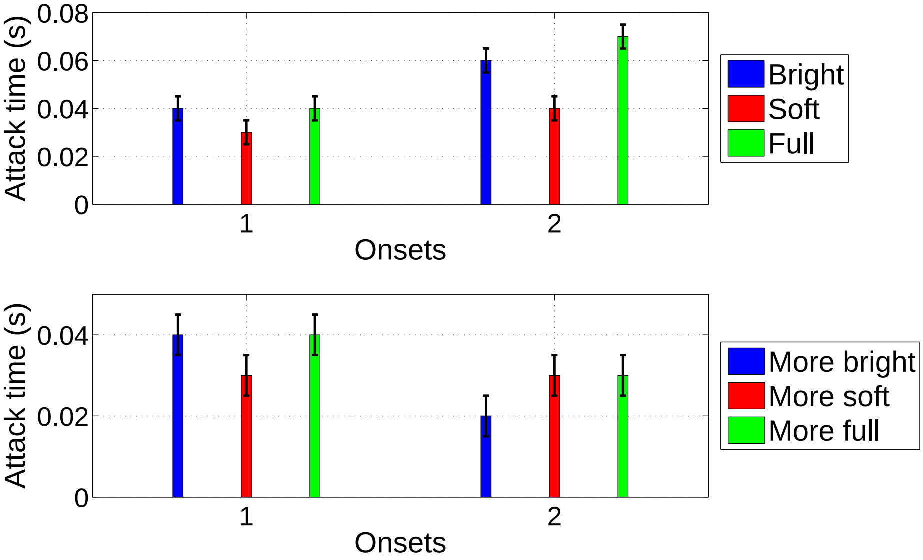

Figure 3.34: Attack time of first and second onset of measure 22. Estimated uncertainty is ±5 ms.

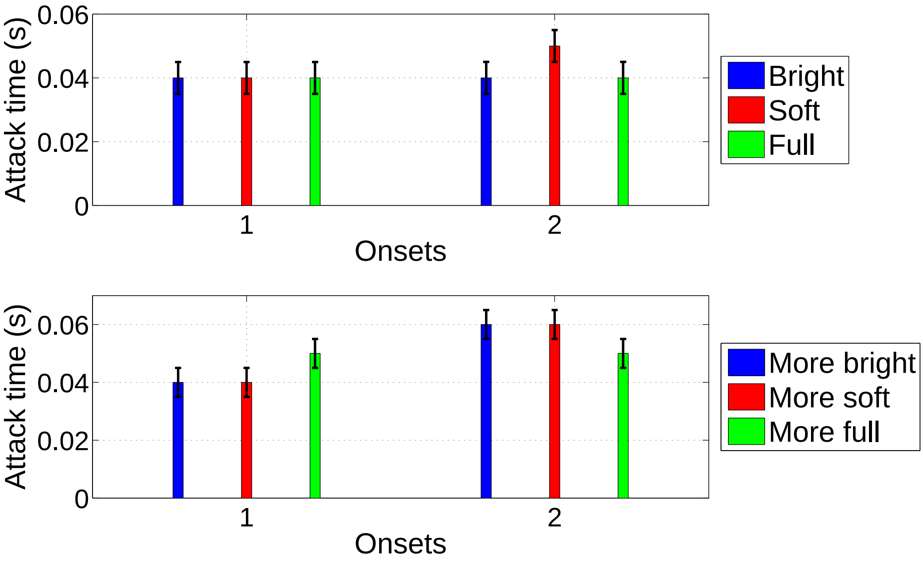

Figure 3.35: Attack time of first and second onset of measure 23. Estimated uncertainty is ±5 ms.

Figure 3.36: Measure 23.

The onsets of measure 23 (Fig. 3.36) were clearly shown as two distinct peaks in the envelope curve of the signal. The start of the attack was also placed at expected locations on the peaks. Figure 3.35 shows calculated attack times for the first two onsets of measure 23. Taking into consideration the uncertainty of ±5 ms, it is safe to say that these plots show no clear result or trend, as they are fairly similar. The first onset have the same attack time for all recordings except for *more full*. The second round of recordings show longer attack times for all timbres. This does not seem unreasonable for *more soft* and *more full* recordings, but for *more bright* the opposite was expected. As the playing style was perceived to be more attacca here, described in section 2.1, the attack time was thought to be even smaller than for *bright*.

Also for the onsets of measure 24 (Fig. 3.37), these were clearly shown as two distinct peaks in the signal envelope. From studying the plots, the start of attack seemed to be placed at reasonable positions. Figure 3.38 shows attack time for the first two onsets of measure 24. These results show no clear tendency. E.g. looking at the first onset, there is a tendency of soft and full timbres having longer attack times, while in the second round of recordings the tendency is completely opposite. Here, the *more bright* recording shows 20 ms longer attack time than the other timbres.

As for the clearly increasing precision of onsets, especially from measure 22 to 23, this might indicate that precision improves with repetitive musical figures. There might be a somewhat subconscious learning process involved when playing, even for a professional pianist. The research by Tro[32] showed the same tendency. His analysis of two subsequent chords showed that if the first one was played imprecisely, the following chord was most likely played very precisely, and vice versa. The pianist's muscular control and motor skills is obviously important here. It is assumed that the recording pianist possesses the same motor skills and ability to perform onsets of same quality as any other concert pianist.

Figure 3.37: Measure 24.

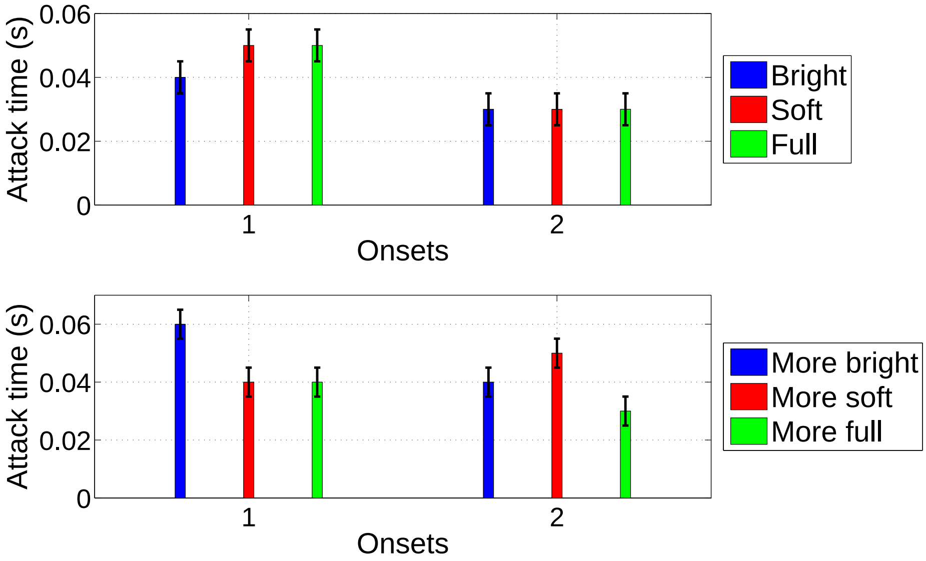

Figure 3.38: Attack time of first and second onset of measure 24. Estimated uncertainty is ±5 ms.

3.11 Attack Slope

3.11.1 Attack Slope - Measure 27

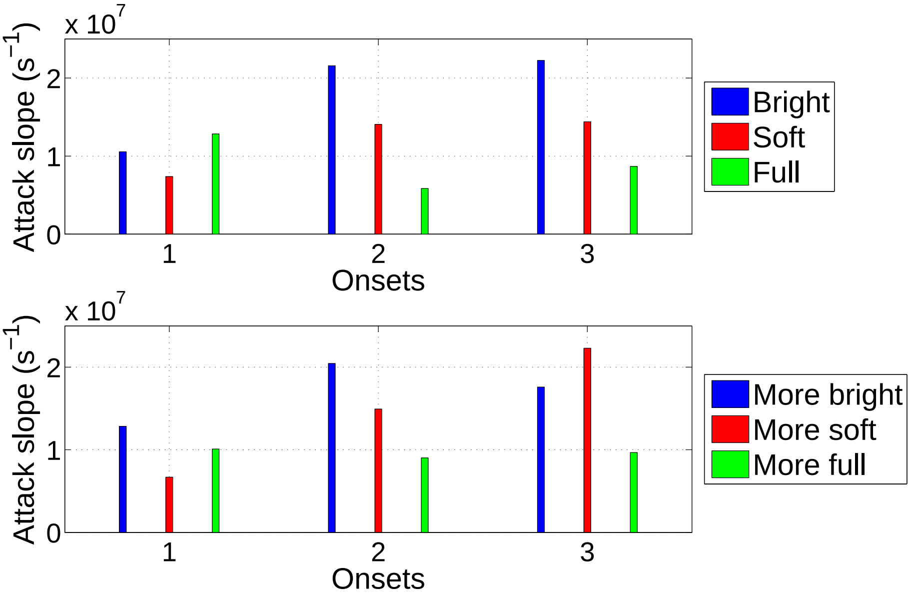

Figure 3.39: Attack slopes for the first three onsets of measure 27.

Figure 3.39 shows calculated attack slope for the first three onsets of measure 27 (Fig.3.40). A high slope value will correspond to a fast key depression. The bright timbre recordings show high slope values for the second and third onset. The notes were perceived to be played fast and determined and more attacca in these recordings, described in section 2.1; a high attack slope value corresponds well with this observation.

Figure 3.40: Measure 27.

As for full and soft timbres, they show the same tendencies in both plots. The full timbre has a larger attack slope for the first onset, whereas the soft timbres show a larger attack slope for onsets 2 and 3. The notes of this rhythm were perceived to be played both longer and more softly than the bright recordings, as described in section 2.1. A lower attack slope value may support this observation.

Why the soft timbre recording show such high values for onsets 2 and 3 is unexpected. The hand does not move much either from chord 2 to 3, most likely the index finger depresses the same key(B#) twice, giving the pianist more control to perform the onsets he wants. The soft timbre has been described to be performed with low center of gravity of the hand as well as keeping fingers close to/on the keybed[26]. The velvety timbre which was found to be the timbre of closest proximity to the soft timbre[22] was described to have long note attacks and not very deep depression of the keys[23]. As timbres velvety and soft are perceived to be very similar, it is reason to believe that the playing technique is somewhat the same. These mentioned factors would indicate a lower attack slope for the soft timbre relative to the bright timbre.

3.11.2 Attack Slope - Measures 22, 23 and 24

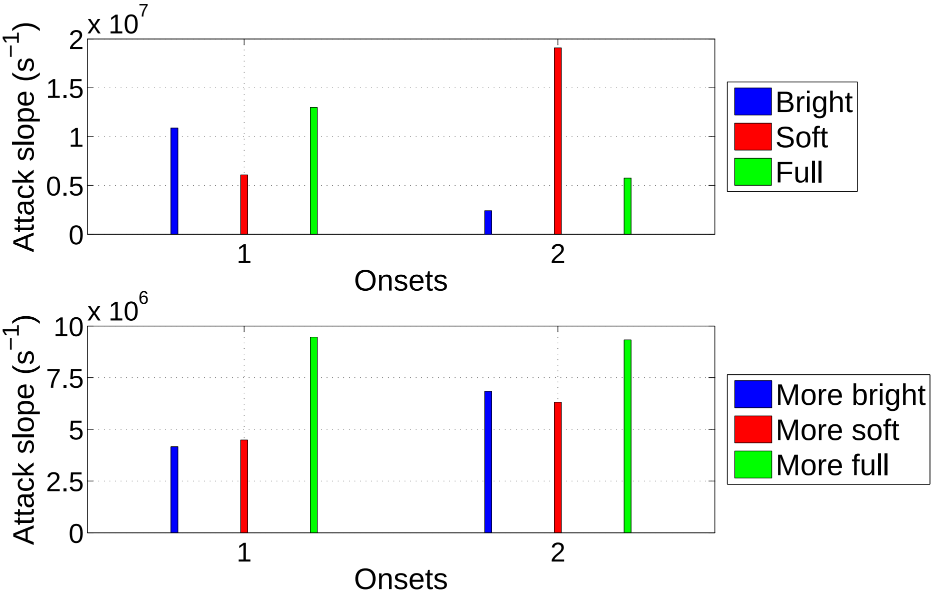

Figure 3.41: Attack slopes for the first and second onset of measure 22.

Figure 3.42: Measure 22.

Attack slopes for the first two onsets of measure 22 (Fig. 3.42) are shown in Figure 3.41. As the top plot ordinate axis is in the range $\sim 10^7$ and the bottom plot $\sim 10^6$, it is obvious that the first round of recordings resulted in much higher attack slope values for some unknown reason. As for the attack slope analysis of measure 27, high attack slope values were expected for bright timbres, while soft timbres were expected to show lower values. As seen in Figure 3.41, there is no clear trend. The *more full* recording stands out showing very steep attack slopes relative to the others. As for the *soft* recording, the second onset attack slope is surprisingly high.

For measures 22-24 it is assumed that the second onset of each measure is played with more control. The 16th grace note with an overlay to every downbeat might affect the sound of the first beat as it can be more challenging to produce the desired sound with the thumb stuck at one key. The middle note of the first beat chord is also held through three beats. This note is however most likely played with the index finger which makes the hand a lot more flexible causing no disturbance for the octave to be played on the second beat.

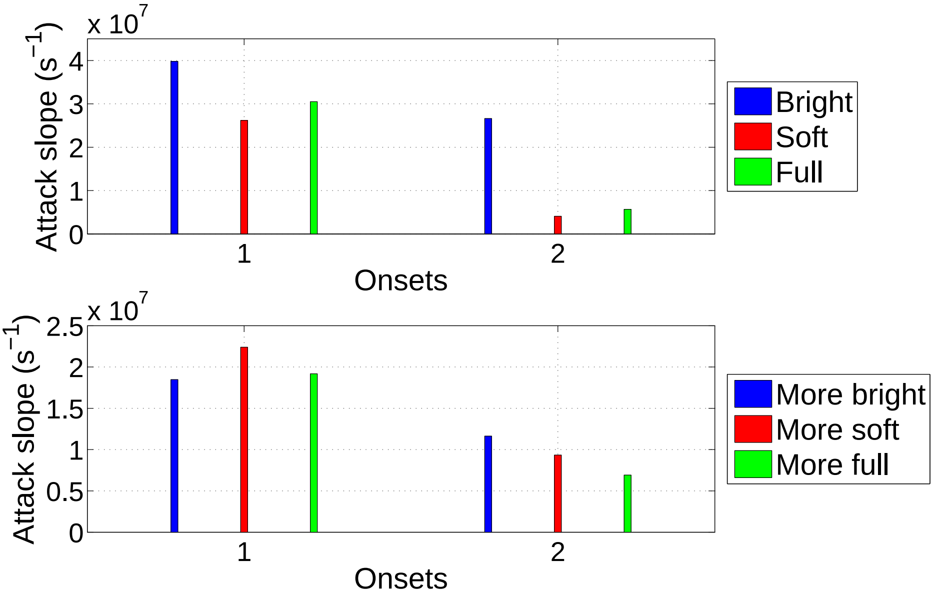

Figure 3.43: Attack slopes for the first and second onset of measure 23.

Figures 3.43 and 3.46 present attack slopes for the first two onsets of measure 23 (Fig. 3.44) and 24 (Fig. 3.45), respectively. The plot from measure 23 shows a tendency of the bright timbre having steeper slopes relative to the others, which would support verbal descriptions (section 1.4) and subjective observations (section 2.1). However, this tendency is not that clearly found in the plot for measure 24, so this might just have been a coincidence. Figure 3.46 shows quite similar slope values for the first onsets, while the soft timbre recordings clearly show low attack slope values for the second onset.

Figure 3.44: Measure 23.

No clear results or conclusions could be drawn from the analysis of the attack slopes. Some of the results were as expected, corresponding well with theory, playing technique and perceived musical expression. But quite a few results also deviated from anticipated relative values.

Figure 3.45: Measure 24.

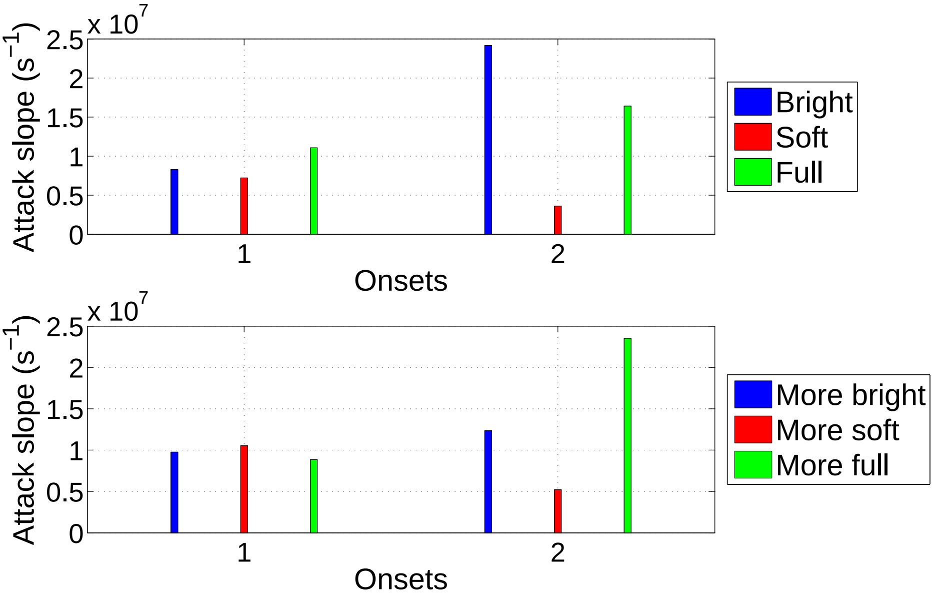

Figure 3.46: Attack slopes for the first and second onset of measure 24.

3.12 RMS Energy

3.12.1 RMS Energy - Measure 27

Figures 3.48 and 3.49 show RMS energy as function of frames for the first three onsets of measure 27 (Fig.3.47). Each frame is 50 ms and half overlapping. The various peaks are therefore not positioned at the same places of the abscissae axis, since recordings are of different lengths. As the RMS energy is estimated by the MIRToolbox to be a dimensionless coefficient value, these plots and the following show relative RMS energy amplitudes.

Figure 3.47: Measure 27.

Results show first onsets with very similar energy amplitude and slopes. The energy seems to be decreasing somewhat in the same manner for all recordings. The energy does not fall all the way to zero, as use of the sustain pedal keeps the chord resonating after the onset. The bright timbre shows highest relative energy for the last onset in Figure 3.48, whereas the soft timbre energy is clearly higher for the corresponding onset shown in Figure 3.49.

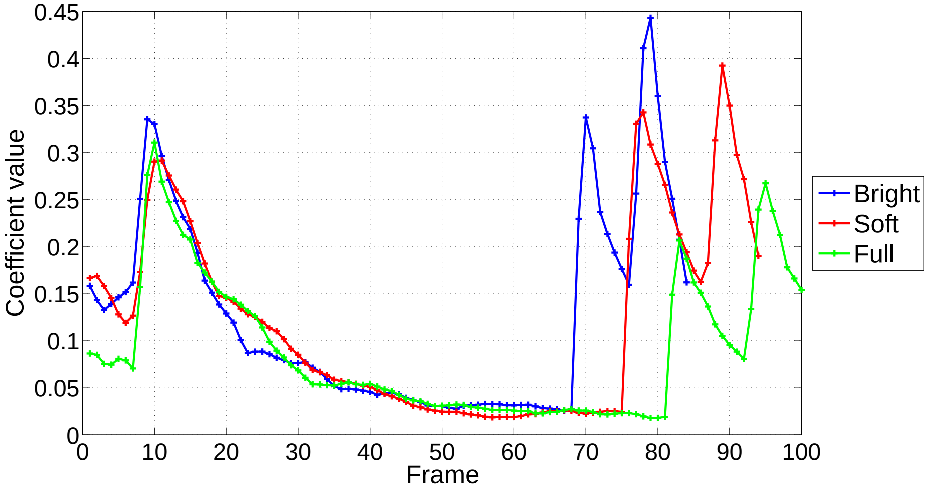

Figure 3.48: RMS energy shown for the first three onsets of measure 27. *Bright*, *soft* and *full* recordings.

The full timbre energy amplitudes are significantly lower for the last two onsets compared to the other recordings. This trend is the same for both plots and is a surprising result. The full timbre recordings are played at a higher dynamic level relative to the soft recording, which is both a subjective perception described in section 2.1 as well as being confirmed by the histograms in section 3.8. Also, considering descriptions presented in section 1.4, a full timbre is expected to be played with a heavy forearm adding weight to every note with the intention of getting more resonating overtones. As both a higher dynamic level and more resonating overtones will result in a higher energy, it is not fully understood why the full timbre amplitudes are much lower than the soft timbre.

Some unanticipated high amplitudes were also found in the results from peak detection on signal envelopes presented in section 3.5. As the dynamic level was perceived to be very stable for the soft timbre recordings, without any large crescendos, it was discussed whether the sustain pedal and a higher relative amount of overtones than expected could be causing the high amplitudes for the soft timbre recordings. These factors might also explain the higher RMS energy amplitudes of these recordings, which were also observed in the RMS energy plots in section 3.9.

The soft timbre recordings had singing top notes, though at a lower dynamic level relative to the other recordings, as observed when listening. From soft timbre descriptions in section 1.4 it was e.g. found that adding weight to the onset and fully depressing the keys could produce a soft timbre. Such a playing technique might result in more resonating overtones and hence a higher relative energy than anticipated. On the other hand, Bernays and Traube[22] present the soft timbre being perceived to have the least brightness of the three(bright, soft, full). This would indicate less higher frequency partials compared to the other timbres, and thus a lower energy. The high energy amplitudes shown for the soft timbre recordings are thus not completely understood. RMS energy for onsets of measure 22-24 will be studied next to see if the results show a similar trend.

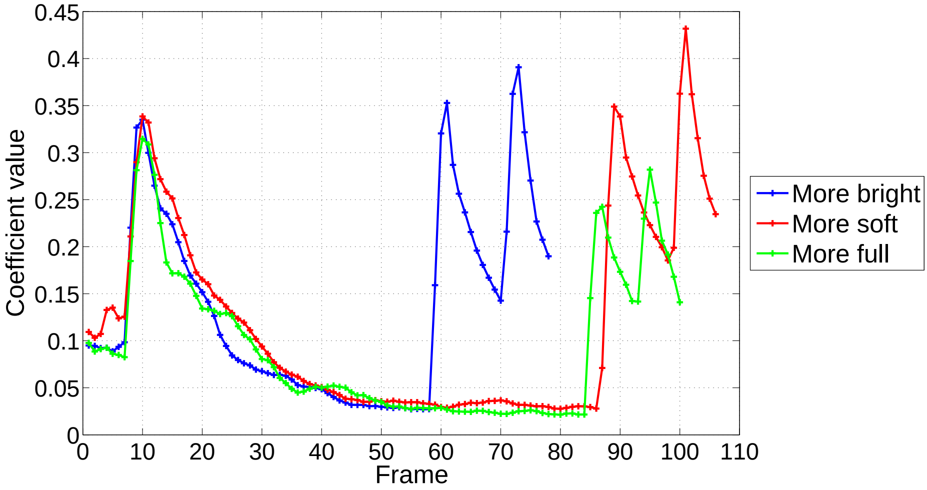

Figure 3.49: RMS energy shown for the first three onsets of measure 27. *More bright*, *more soft* and *more full* recordings.

3.12.2 RMS Energy - Measure 22, 23 and 24

As mentioned in onset attack time results in section 3.10.2, the first onsets of measure 22 were rather imprecisely played compared to corresponding onsets of measure 23 and 24. This is evident from Figures 3.51 and 3.52, showing RMS energy for the first two onsets of measure 22 (Fig. 3.50). Here, all recordings apart from *bright* displays a very indistinct first peak with some smaller fluctuations.

The second onset seems however to be played much more precisely. Again, the study by Tro[32] corresponds well with this result, as he found the tendency that an imprecise chord was followed by a very precisely set chord, and vice versa. Also here, values for soft timbre recordings are very high relative to the other recordings.

Figure 3.50: Measure 22.

The soft timbre recordings stand out by showing the highest energy amplitude for the first onsets, but especially by the *soft* recording showing such a high peak for the second onset shown in Figure 3.51. Here, the *bright* timbre shows a very low amplitude compared to both full and soft timbres, and it is not straightforward to understand why. This relation changes however in Figure 3.52, where the bright timbre shows the highest relative energy of the second onset and with the soft timbre representing the smallest peak of the three.

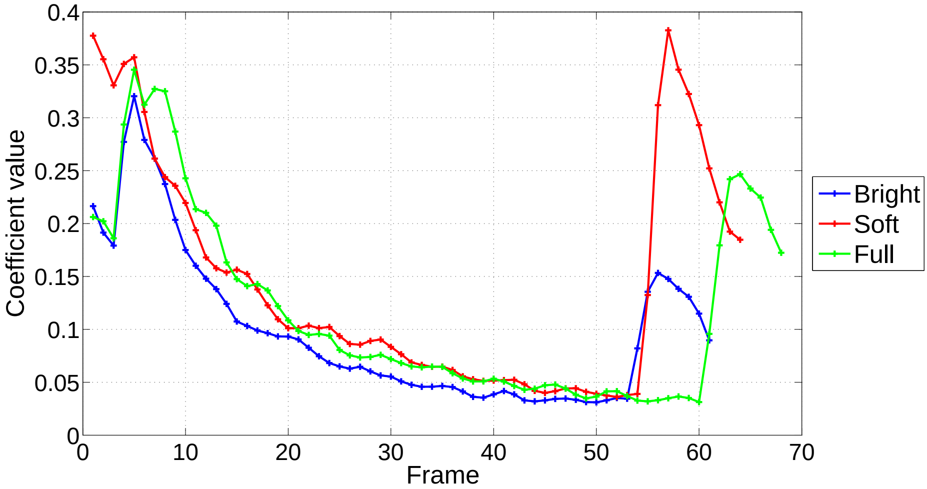

Figure 3.51: RMS energy shown for the first and second onset of measure 22. *Bright*, *soft* and *full* recordings.

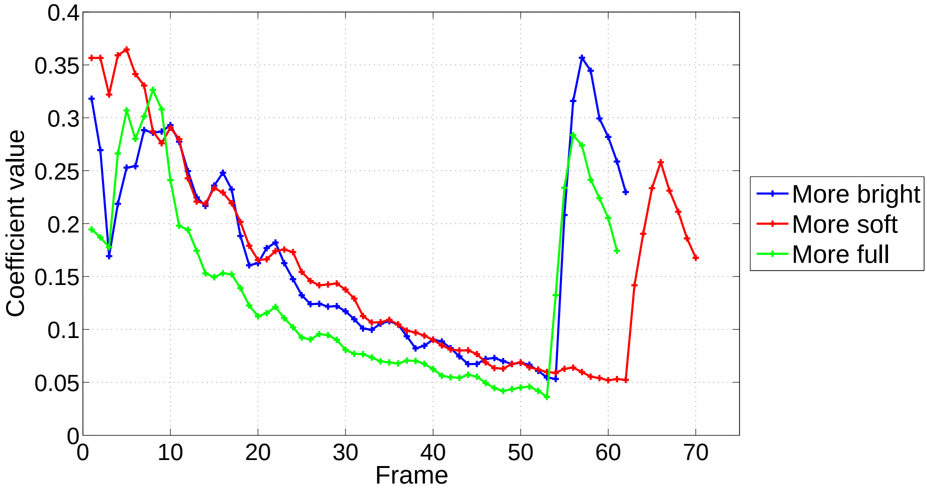

Figure 3.52: RMS energy shown for the first and second onset of measure 22. *More bright*, *more soft* and *more full* recordings.

A possible explanation for the small second onset peaks of full and bright recordings in Figure 3.51, might be that this measure is positioned in the beginning of a crescendo. The soft timbre recordings were perceived to be played at pretty much the same dynamic level. But this still does not explain the unexpectedly high energy of the soft timbre onset. The same discussion performed for measure 27 onset results would also be valid here. There might be more resonating overtones than expected due to playing technique and use of pedal.

RMS energy calculated for the first two onsets of measure 23 (Fig. 3.53) is shown in Figures 3.54 and 3.55. The first onset still shows quite similar energy peaks for all recordings, with the soft and bright timbre alternating on showing the highest peak. However, for the second peak the bright timbre shows highest relative energy values, which is a more satisfying result. The soft and full timbre recordings show very similar energy amplitudes for the second onset displayed in Figure 3.54, whereas in Figure 3.55 the soft timbre shows a higher relative energy than the full timbre.

Figure 3.53: Measure 23.

Both bright and full timbres were expected to show higher relative energy values compared to soft. A bright timbre is naturally perceived as being the timbre of more brightness (Bernays and Traube [22]), and so it would be natural to think that this timbre would have more higher frequency partials giving the sound more sharpness (Halmrast et al [11]). However, with the full timbre playing technique being described as giving chords the time to resonate and for overtones to sound, it is not straightforward to predict which timbre would show the highest RMS energy.

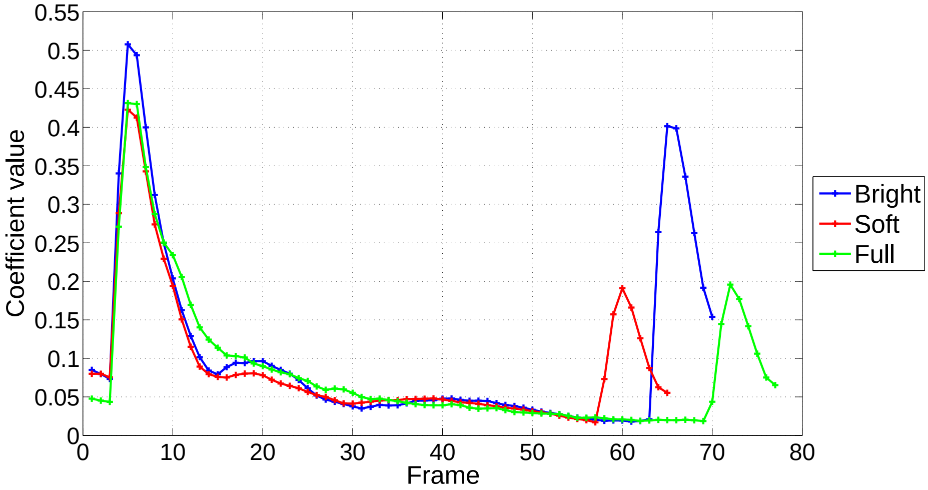

Figure 3.54: RMS energy shown for the first and second onset of measure 23. *Bright*, *soft* and *full* recordings.

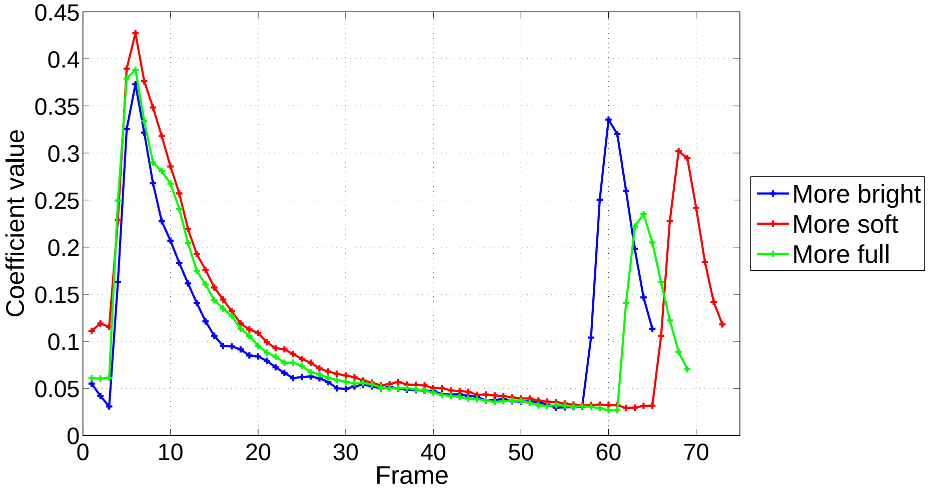

Figure 3.55: RMS energy shown for the first and second onset of measure 23. *More bright*, *more soft* and *more full* recordings.

Figures 3.57 and 3.58 show relative RMS energy for the first two onsets of measure 24 (Fig.3.56). From these it is evident that there is not a clear tendency for one or the other. For the first onsets, bright and soft timbres show quite similar energy peaks, while the full timbre deviates slightly from this. These results from measure 24 show a somewhat consistency in the fact that both bright and full timbres show larger energy amplitudes for the second onsets, relative to the soft timbre.

Figure 3.56: Measure 24.

For studied onsets of measures 22-24, the majority of plots show a higher energy for either the bright or full timbre relative to soft for the second onset. Differences are smaller for the first onsets.

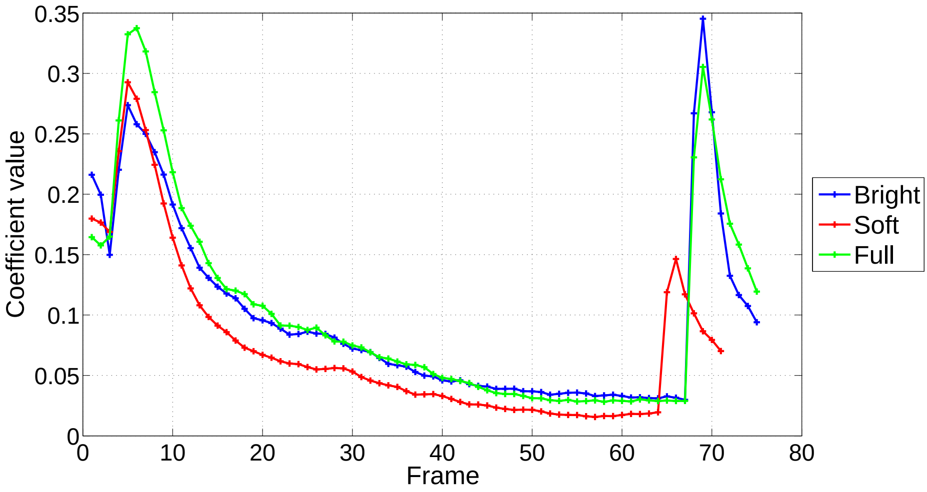

Figure 3.57: RMS energy shown for the first and second onset of measure 24. *Bright*, *soft* and *full* recordings.

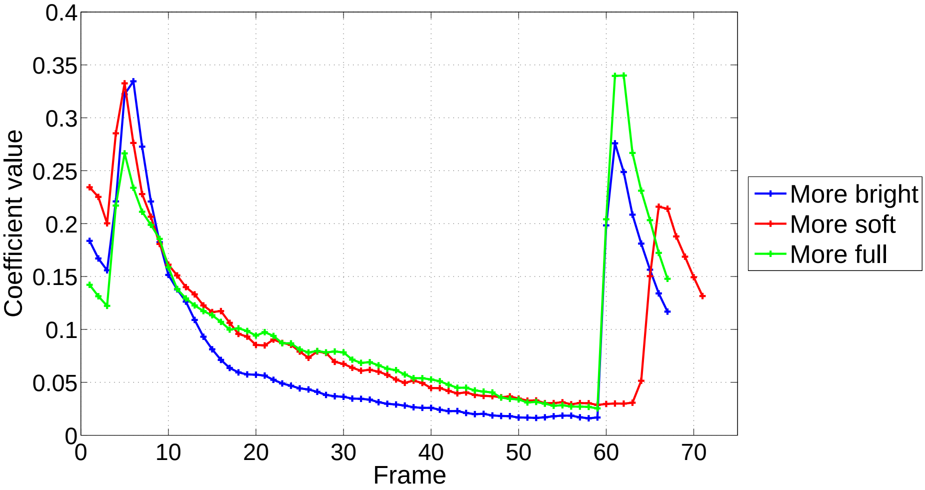

Figure 3.58: RMS energy shown for the first and second onset of measure 24. *More bright*, *more soft* and *more full* recordings.

Chapter 4

Conclusion

Various analyses have been performed on audio recordings using both manual procedures with help from Matlab and sound editing software Audacity as well as relevant functions from the MIRToolbox.

As seen from presented results, not all analyses show consistent trends. Nor were all results as expected on the basis of verbal descriptions of timbre, piano technique and observations from listening to the recordings. Some uncertainties about the recording sessions should be mentioned. The pianist might not have performed the piece in accordance with instructions from the research group. His performance might have had nuances which did not coincide exactly with what one might expect. Or possibly that he was not able to perform a perfect interpretation of the timbres. Did the research group communicate their expectations and instructions clearly enough to the pianist?

Giving a performance of one page with a fully implemented musical expression is challenging, it is therefore a possibility that not all elements of the performance are played perfectly within the nature of each timbre. Forcing the pianist away from his original, year-long rehearsed interpretation of the piece might have had an influence on his performance. Results might have shown different trends if smaller excerpts had been recorded, e.g. a few measures or a musical phrase. If the pianist found it difficult to maintain a timbre throughout the piece, it is possible that larger differences between recordings could be found in the beginning. This was however not studied further, as differences here were not evident relative to other parts of the piece.

The analysis procedure performed might not be the best fitted for detecting such differences in timbre. Perhaps should other procedures have been conducted outside of the MIRToolbox, or possibly that some features should have been studied differently. It is possible that analysis of other physical properties not discussed here might show larger differences between recordings.

The bright timbre recordings showed the highest tempo, while the overall slowest tempo was found for the soft timbre. As for the IMIs, full timbre recordings seemed to be played with similar temporal phrasing. Especially the *more bright* recording stood out showing the least change in temporal phrasing, this was also the musical interpretation perceived to be the most forward and rushed. The full timbre recordings showed a slight tendency of longer IOIs, while bright timbre recordings showed a slight tendency of shorter IOI values. However, these were not consistent trends.

Studying the highest amplitudes of the audio signal envelopes showed very similar results for bright and full timbres. For some unknown reason the temporal location of the highest amplitudes appeared to correspond to the same chord onsets.

Spectral centroids of the six recordings showed satisfying results, with the soft timbre recordings showing a lower value relative to the others. Bright and full timbres gave very similar output.

Comparing rolloff frequencies for the six recordings, the overall trend was somewhat the same for the first two onsets of measure 24 and results from the whole recording. As expected, the soft timbre showed lower values. Soft and full timbre frequencies were very similar for both takes, may indicating a well developed skill for reproducing a playing technique or perhaps implying a clear and consistent interpretation of these timbres.

Soft timbre recordings resulted in a high number of occurrences for lower magnitudes relative to other recordings, indicating a lower dynamic level. Full and bright timbres resulted in very similar histograms for magnitude values and corresponding amplitudes.

Low energy ratios showed very similar results for the two bright timbre recordings. It was found a considerably higher average RMS energy for *more soft* and *more full* recordings caused by several higher energy peaks throughout the signal, as could be observed from plotting the temporal evolution of energy. These higher peaks were possibly a result from a higher dynamic level relative to *soft* and *full* recordings, respectively. More resonating overtones is also a possibility. Bright timbre recordings showed a practically identical average RMS energy value, this could indicate less variation in dynamic level and note onsets.

Some onsets showed slightly shorter attack time for *more soft* recordings relative to *soft*. This is not a consistent trend, but may explain more higher frequency partials for the *more soft* recording and hence higher RMS energy peaks as previously commented. Unexpectedly, there was no trend showing a longer attack time for soft timbre recordings relative to the others. Bright and full timbres showed a tendency of quite similar onset attack time.

Attack slopes did not show unambiguous results for analysis performed on different measures, nor for first and second round of recordings of the same measure.

Unexpectedly, RMS energy amplitudes for full timbre recordings were lower compared to the others. Soft timbre recordings showed much higher amplitudes than anticipated, perhaps due to more resonating overtones than expected for this timbre.

It has not been successful in all cases to identify sufficiently clear nuances in the performances. However, it is not known if a lack of detected differences in fact means that predicted nuances are non-existent. Certain trends have been detected and commented. Most evident differences between recordings were found from the temporal analyses, including IMIs and IOIs. In many cases bright and full timbres were found to give very similar results.

4.1 Suggestions for Future Work

The performed method of analysis seems to be insufficient. A large amount of research material is available from the piano recording sessions making it possible to perform additional analyses. The MIRToolbox procedures may be partly inadequate for analysis detecting timbral differences, or possibly should additional MIRToolbox functions be considered.

Other analysis procedures may be developed or improved in order to contribute to mapping perceived timbral properties with actual physical features of the signal.

MIDI recordings may be studied in order to give a more precise dynamic and temporal analysis. The latter enables a better identification of differences in timing.

Conducting hearing tests may be considered. Introducing the various recordings to a group of people unfamiliar with the content of the project might be informative in terms of finding out more about how the various timbres are perceived.

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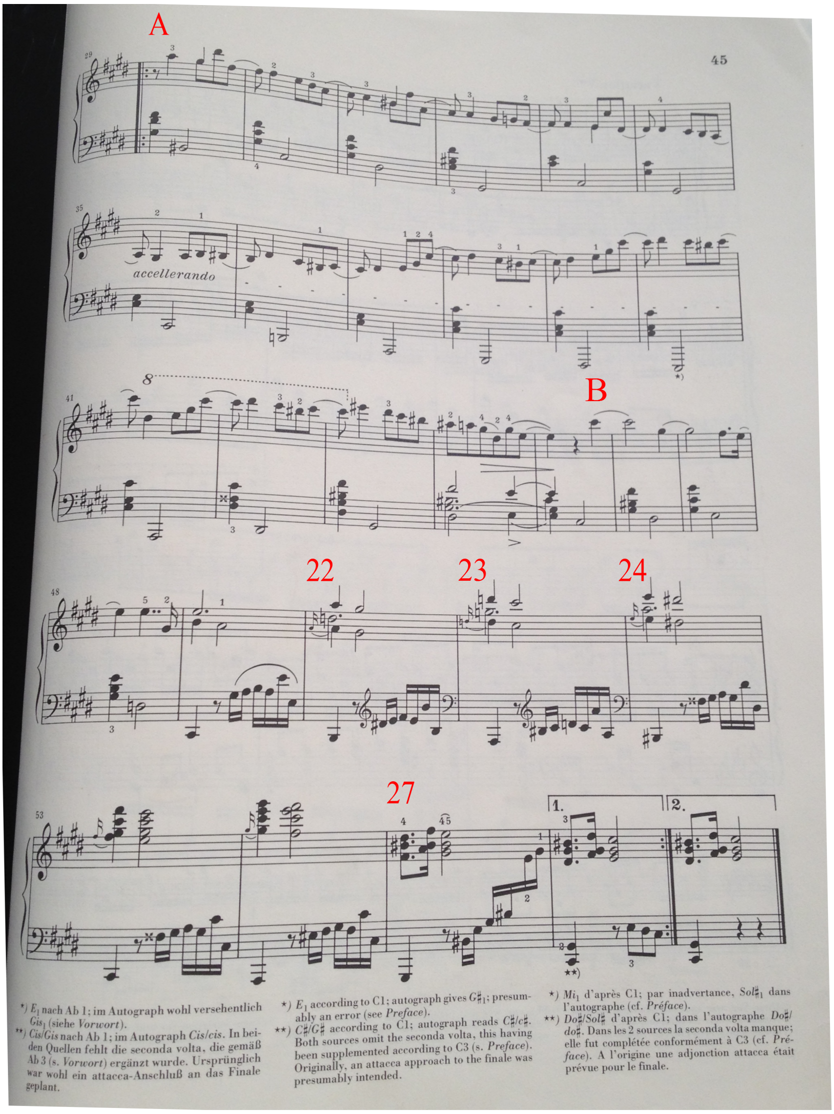
Appendix

A.1 Piano Score



*) E_1 nach Ab 1; im Autograph wohl versehentlich Gis_1 (siehe *Vorwort*).
**) *Cis/Gis* nach Ab 1; im Autograph *Cis/cis*. In beiden Quellen fehlt die seconda volta, die gemäß Ab 3 (s. *Vorwort*) ergänzt wurde. Ursprünglich war wohl ein attacca-Anschluß an das Finale geplant.

*) E_1 according to C1; autograph gives $G\sharp_1$; presumably an error (see *Preface*).
**) *C♯/G♯* according to C1; autograph reads *C♯/c♯*. Both sources omit the seconda volta, this having been supplemented according to C3 (s. *Preface*). Originally, an attacca approach to the finale was presumably intended.

*) Mi_1 d'après C1; par inadvertance, $Sol\sharp_1$ dans l'autographe (cf. *Préface*).
**) *Do♯/Sol♯* d'après C1; dans l'autographe *Do♯/do♯*. Dans les 2 sources la seconda volta manque; elle fut complétée conformément à C3 (cf. *Préface*). A l'origine une adjonction attacca était prévue pour le finale.

Figure A1: Piano score, excerpt from *Symphonic Etudes Op.13 - Variation IV Anhang* by R. Schumann.

A.2 Matlab Scripts

Tone Distribution

```
%% PITCH ANALYSIS
%% PLOTTING NUMBER OF ONSETS (MANUALLY COUNTED FROM PIANO SCORE)
% Measures 1-28. Tied 16th grace notes counts as one onset.
x = 1:51;
y = [1 1 2 4 2 1 4 1 4 2 12 1 6 ...
    11 1 2 3 18 7 5 8 18 1 9 11 ...
    12 1 10 6 1 6 7 2 7 9 7 1 9 4 ...
    1 2 10 1 5 5 1 2 2 1 3 1];

close all;
figure; bar(y,1);
xlabel('Keys','Fontsize',20);
ylabel('Number of onsets','Fontsize',20);

keys = {'E1','F#1','G#1','A1','B1','C2','C#2','D#2','G#2','C3','C#3'...
    'D3','D#3','E3','F3','F#3','G3','G#3','A3','B3','C4','C#4','D4'...
    'D#4','E4','F#4','G4','G#4','A4','B4','C5','C#5','D5','D#5','E5',...
    'F#5','G5','G#5','A5','A#5','C6','C#6','D6','D#6','E6','E#6','F#6',...
    'G#6','C7','C#7','D#7'};

axis([0 52 0 20])
% remove labels on x-axis:
set(gca,'XTick',1:51,'XTickLabel','','YTick',0:2:20,'Fontsize',16);
text(x,y,keys,'Rotation',90,'Fontsize',16);

%% PLOTTING NUMBER OF BEATS (NB OF QUARTER NOTES)

x = 1:51;
y = [2 2 3 6 3 1 5 2 7 2 13.5 2 4.25 9.5 0.25 0.5 1.5 ...
    15.75 2.75 2.5 8 14 0.25 6.25 8 11.25 0.5 9.5 5.75 0.25 4.75 ...
    9 4.25 6 8.75 6.75 3 11.75 5.5 0.5 1 14 1 5 6.5 1 3 1.5 0.5 2.5 1];

close all;
figure; bar(y,1);
xlabel('Keys','Fontsize',20);
ylabel('Number of beats','Fontsize',20);

keys = {'E1','F#1','G#1','A1','B1','C2','C#2','D#2','G#2','C3','C#3'...
    'D3','D#3','E3','F3','F#3','G3','G#3','A3','B3','C4','C#4','D4'...
    'D#4','E4','F#4','G4','G#4','A4','B4','C5','C#5','D5','D#5','E5',...
    'F#5','G5','G#5','A5','A#5','C6','C#6','D6','D#6','E6','E#6','F#6',...
    'G#6','C7','C#7','D#7'};

axis([0 52 0 18])
set(gca,'XTick',1:51,'XTickLabel','','YTick',0:2:18,'Fontsize',16);
text(x,y,keys,'Rotation',90,'Fontsize',16);
```

Inter-Measure Intervals (IMIs)

```
%%% INTER-MEASURE-INTERVALS
close all; clear all;
nb_meas = 27; % number of measures to be included for the IMI-plotting
```

```
meas = 1:27;
descr = {'Actual measure time','Average measure time'}; %  use for legend
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

%% BRIGHT
%%%%% ——— Bright ——— %%%%%
% From Audacity:
time_bright = [0 4.175 6.464 9.375 11.370 13.726 15.631 18.025 20.115 ...
    22.273 24.109 26.204 28.408 30.789 34.031 37.625 41.990 45.678 ...
    48.943 51.955 56.099 59.215 62.061 65.169 68.404 71.863 75.654
    80.535];

avg_bright = time_bright(28)/nb_meas; % average duration of each measure

% calculates 27 intervals:
interval_bright = zeros(1,27);
for i = 1:27
    interval_bright(i) = time_bright(i+1) - time_bright(i);
end

%%%%% ——— More bright ——— %%%%%
% From Audacity:
time_mbright = [0 3.014 5.231 7.545 9.632 11.357 13.249 15.197 17.064 ...
    18.754 20.677 22.533 24.608 26.681 29.679 32.814 35.432 38.684 ...
    41.144 44.104 47.370 50.026 52.779 55.713 58.959 62.175 65.979
    70.362];

avg_mbright = time_mbright(28)/nb_meas; % average duration of each measure

% 27 intervals:
interval_mbright = zeros(1,27);
for i = 1:27
    interval_mbright(i) = time_mbright(i+1) - time_mbright(i);
end
%% BRIGHT PLOTS

close all; figure; subplot(2,1,1);
plot(meas,interval_bright,'b-o',meas,avg_bright,'k-*','LineWidth',1.50,...
    'Markersize',8);
grid on; axis([0 28 0 5])
len = legend(descr,'Location','SouthEast');
set(len,'Fontsize',24);
xlabel('Measure','Fontsize',24);
text(28,5,'Bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);
%ypos = ylabel('Time (s)','Fontsize',24); %set(ypos,'Position',[-1.3 4.25
    0])
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 avg_bright 3 3.5 4 4.5 5])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' round(100*avg_bright)/100 '' '' 4 ''
    5})

subplot(2,1,2);
plot(meas,interval_mbright,'b-o',meas,avg_mbright,'k-*','LineWidth'
    ,1.50,...
    'Markersize',8);
grid; axis([0 28 0 5])
```

```
len = legend(descr,'Location','SouthEast');
set(len,'Fontsize',24);
xlabel('Measure','Fontsize',24);
text(28,5,'More bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)
%ypos = ylabel('Time (s)','Fontsize',24); %set(ypos,'Position',[-1.3 4 0])
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 avg_mbright 3 3.5 4 4.5 5])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' round(100*avg_mbright)/100 3 '' 4 ''
    5})

saveas(gca,fullfile(folder,'int_meas_intervals_bright_mbright'));

%% SOFT
%%%%%%%%%% ———————————— Soft ——————————————— %%%%%%%%%%%%%

% From Audacity:
time_soft = [0 4.422 6.781 9.445 11.571 14.041 16.300 18.534 21.021 ...
    22.903 25.269 27.489 30.218 32.856 36.430 40.148 44.047 48.641 ...
    51.412 54.980 59.250 62.438 65.561 68.635 72.445 76.096 79.776
    85.081];

avg_soft = time_soft(28)/nb_meas; % avg. duration of each measure

% 27 intervals:
interval_soft = zeros(1,27);
for i = 1:27
    interval_soft(i) = time_soft(i+1) - time_soft(i);
end

%%%%%%% ——————————————— More soft ——————————————————— %%%%%%%%%
% From Audacity:
time_msoft = [0 4.043 7.027 9.881 12.414 14.493 17.079 19.825 22.551 ...
    24.716 27.298 29.556 32.359 34.961 38.333 41.763 46.076 49.508 52.455
    ...
    55.605 60.604 64.071 67.347 71.046 75.126 79.449 83.962 89.975];

avg_msoft = time_msoft(28)/nb_meas; % avg. duration per measure

% 27 intervals:
interval_msoft = zeros(1,27);
for i = 1:27
    interval_msoft(i) = time_msoft(i+1) - time_msoft(i);
end


%% SOFT PLOTS

close all; figure; subplot(2,1,1);
plot(meas,interval_soft,'r-o',meas,avg_soft,'k-*','LineWidth',1.50,...
    'MarkerSize',8);
grid on; axis([0 28 0 5.5]);
leg = legend(descr,'Location','SouthEast'); set(leg,'Fontsize',24)
xlabel('Measure','Fontsize',24);
text(28,5.5,'Soft','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)
%ypos = ylabel('Time (s)','Fontsize',24); %set(ypos,'Position',[-1.4 4.75
```

```
     0])
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 3 avg_soft 3.5 4 4.5 5])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' '' round(100*avg_soft)/100 '' 4 ''
     5});

subplot(2,1,2);
plot(meas,interval_msoft,'r-o',meas,avg_msoft,'k-*','LineWidth',1.50,...
     'MarkerSize',8);
%set(gca,'xgrid','on','GridLineStyle','--');
axis([0 28 0 6.5]); grid on;
leg = legend(descr,'Location','SouthEast');
set(leg,'Fontsize',24)
xlabel('Measure','Fontsize',24);
text(28,6.5,'More soft','HorizontalAlignment','right',...
     'VerticalAlignment','bottom','Fontsize',24);
%ypos = ylabel('Time (s)','Fontsize',24);% set(ypos,'Position',[-1.3 5.5
     0])
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 3 avg_msoft 3.5 4 4.5 5 5.5 6])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' '' round(100*avg_msoft)/100 '' 4 '' 5
      '' 6});

saveas(gca,fullfile(folder,'int_meas_intervals_soft_msoft'));



%% FULL
%%%%%%% --------------- Full -------------------- %%%%%%%%%%%
% First beat played arpeggio, top note is decided to define the downbeat.
% Audicity:
time_full = [0.190 4.962 7.969 10.949 13.497 16.160 18.412 21.300 ...
     23.850 25.801 27.997 29.959 31.979 34.428 37.587 41.441 45.464 ...
     48.900 51.747 55.295 60.027 63.530 66.968 70.430 73.830 ...
     77.606 81.740 86.958];

avg_full = time_full(28)/nb_meas; %avg duration per measure

% 27 intervals:
interval_full = zeros(1,27);
for i = 1:27
     interval_full(i) = time_full(i+1) - time_full(i);

end

%%%%%% --------------- More full ------------- %%%%%%%%%%%%%
% From Audacity:
time_mfull = [0.192 3.056 4.956 7.868 9.930 12.478 14.670 17.323 19.312
      ...
     21.559 23.762 25.919 28.034 30.548 33.885 37.866 41.977 45.380 47.943
      ...
     51.323 55.774 59.222 62.575 65.932 69.324 73.034 77.175 82.579];

avg_mfull = time_mfull(28)/nb_meas; % avg duration per measure

% 27 intervals between each downbeat:
interval_mfull = zeros(1,27);
```

```
for i = 1:27
    interval_mfull(i) = time_mfull(i+1) - time_mfull(i);

end

%% FULL PLOTS

close all; figure; subplot(2,1,1)
plot(meas,interval_full,'g-o',meas,avg_full,'k-*','LineWidth',1.50,...
    'Markersize',8);
grid on; axis([0 28 0 5.5]);
leg = legend(descr,'Location','SouthEast'); set(leg,'Fontsize',24);
xlabel('Measure','Fontsize',24);
text(28,5.5,'Full','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)
%ypos = ylabel('Time (s)','Fontsize',24);% set(ypos,'Position',[-1.4 4.75 0]);
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 3 avg_full 3.5 4 4.5 5])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' '' round(100*avg_full)/100 '' 4 '' 5})

subplot(2,1,2);
plot(meas,interval_mfull,'g-o',meas,avg_mfull,'k-*','LineWidth',1.50,...
    'Markersize',8);
%set(gca,'xgrid','on','GridLineStyle','--');
grid on; axis([0 28 0 5.5]);
leg = legend(descr,'Location','SouthEast');
set(leg,'Fontsize',24);
xlabel('Measure','Fontsize',24);
text(28,5.5,'More full','VerticalAlignment','bottom',...
  'HorizontalAlignment','right','FontSize',24);
%ypos = ylabel('Time (s)','Fontsize',24);% set(ypos,'Position',[-1.1 5 0]);
set(gca,'XTick',0:5:30,'Fontsize',22);
set(gca,'YTick',[0 0.5 1 1.5 2 2.5 3 avg_mfull 3.5 4 4.5 5 5.5])
set(gca,'YTickLabel',{0 '' 1 '' 2 '' '' round(100*avg_mfull)/100 '' 4 '' 5 ''});

saveas(gca,fullfile(folder,'int_meas_intervals_full_mfull'));
```

Inter-Onset Intervals (IOIs)

```
%%%%%%%% INTER-ONSET INTERVALS %%%%%%%%%
%% FIRST THREE CHORDS OF MEASURE 27
% three onsets -> two inter-onset intervals
x = 1:2;
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

% time of onset 1, 2 and 3:
b = [75.654 77.183 77.383]; % bright
s = [79.776 81.475 81.767]; % soft
f = [81.740 83.589 83.870]; % full
mb = [65.979 67.267 67.561]; % more bright
ms = [83.962 85.956 86.249]; % more soft
mf = [77.175 79.103 79.317]; % more full

```

```
% intervals:
b_int = [b(2)-b(1) b(3)-b(2)];
s_int = [s(2)-s(1) s(3)-s(2)];
f_int = [f(2)-f(1) f(3)-f(2)];
mb_int = [mb(2)-mb(1) mb(3)-mb(2)];
ms_int = [ms(2)-ms(1) ms(3)-ms(2)];
mf_int = [mf(2)-mf(1) mf(3)-mf(2)];

%% PLOTTING IOI FOR BSF (bar plot)

A = [b_int' s_int' f_int'];

close all; figure;
p = bar(A,0.1,'grouped'); axis([0.5 2.5 0 2]); grid on;
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Interval','Fontsize',24); ylabel('Time (s)','Fontsize',24);
labels = {'Dotted 8th note to 16th note','16th note to half note'};
set(gca,'XTick',1:3,'Fontsize',22,'XTickLabel',labels)
set(gca,'YTick',0:0.25:2,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.5 '' 1 '' 1.5 '' 2})
set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g');

saveas(gca,fullfile(folder,'int_onset_int_barplot_meas27_bsf'))

%% PLOTTING IOI FOR MBRIGHT MSOFT MFULL (bar plot)
B = [mb_int' ms_int' mf_int'];

close all; figure;
p = bar(x,B,0.1,'hist'); axis([0.5 2.5 0 2.25]); grid on;
leg = legend('More bright','More soft','More full');
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Interval','Fontsize',24); ylabel('Time (s)','Fontsize',24);
labels = {'Dotted 8th note to 16th note','16th note to half note'};
set(gca,'XTick',1:3,'Fontsize',22,'XTickLabel',labels)
set(gca,'YTick',0:0.25:2.25,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.5 '' 1 '' 1.5 '' 2 ''})
set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g');

saveas(gca,fullfile(folder,'int_onset_int_barplot_meas27_mbmsmf'))
```

```
%% INTER-ONSET INTERVALS MEASURES 22 AND 23
% Onsets of first and second beats of measures 22 and 23:
t22b = [59.216 60.475];
t23b = [62.061 63.559];
t22s = [62.443 63.720];
t23s = [65.561 66.916];
t22f = [62.530 64.963];
t23f = [66.968 68.637];
t22mb = [50.026 51.305];
t23mb = [52.778 54.140];
t22ms = [64.071 65.549];
t23ms = [67.347 68.906];
t22mf = [59.223 60.474];
t23mf = [62.575 64.025];
```

```
% intervals:
b22 = t22b(2) - t22b(1); b23 = t23b(2) - t23b(1);
s22 = t22s(2) - t22s(1); s23 = t23s(2) - t23s(1);
f22 = t22f(2) - t22f(1); f23 = t23f(2) - t23f(1);
mb22 = t22mb(2) - t22mb(1); mb23 = t23mb(2) - t23mb(1);
ms22 = t22ms(2) - t22ms(1); ms23 = t23ms(2) - t23ms(1);
mf22 = t22mf(2) - t22mf(1); mf23 = t23mf(2) - t23mf(1);

%% PLOTTING IOIs MEAS22 (bar plot)
x = 1:6;
A = [b22 mb22 s22 ms22 f22 mf22];
B = [b23 mb23 s23 ms23 f23 mf23];
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

close all; figure;
p1 = bar(x,A,0.1); grid on;
% leg = legend('Bright','Soft','Full');
% set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Timbre','Fontsize',24); ylabel('Time (s)','Fontsize',24);
labels = {'Bright' 'More bright' 'Soft' 'More soft' 'Full' 'More full'};
set(gca,'XTick',1:6,'Fontsize',24,'XTickLabel',labels)
set(gca,'YTick',0:0.25:2.5,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.5 '' 1 '' 1.5 '' 2 '' 2.5})

saveas(gca,fullfile(folder,'int_onset_int_meas22'))

%% PLOTTING IOIs MEAS23

close all; figure;
p2 = bar(x,B,0.1); grid on; %axis([0.5 2.5 0 2]); grid on;
% leg = legend('Bright','Soft','Full');
% set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Timbre','Fontsize',24); ylabel('Time (s)','Fontsize',24);
labels = {'Bright' 'More bright' 'Soft' 'More soft' 'Full' 'More full'};
set(gca,'XTick',1:6,'Fontsize',24,'XTickLabel',labels)
set(gca,'YTick',0:0.25:1.5,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.5 '' 1 '' 1.5})

saveas(gca,fullfile(folder,'int_onset_int_meas23'))
```

```
%% INTER-ONSET INTERVALS MEASURE 24
% Onsets of first and second beats of measure 24:
t24b = [65.170 66.773];
t24s = [68.634 70.156];
t24f = [70.430 72.030];
t24mb = [55.713 57.119];
t24ms = [71.045 72.564];
t24mf = [65.932 67.341];

% IOIs
b24 = t24b(2) - t24b(1);
s24 = t24s(2) - t24s(1);
f24 = t24f(2) - t24f(1);
mb24 = t24mb(2) - t24mb(1);
ms24 = t24ms(2) - t24ms(1);
mf24 = t24mf(2) - t24mf(1);
```

```
%% PLOTTING IOI (bar plot)
x = 1:6;
A = [b24 mb24 s24 ms24 f24 mf24];

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

close all; figure;
p1 = bar(x,A,0.1); grid on;
% leg = legend('Bright','Soft','Full');
% set(leg,'Location','EastOutside','Fontsize',24)
ylim([0 1.75])
xlabel('Timbre','Fontsize',24); ylabel('Time (s)','Fontsize',24);
labels = {'Bright' 'More bright' 'Soft' 'More soft' 'Full' 'More full'};
set(gca,'XTick',1:6,'Fontsize',24,'XTickLabel',labels)
set(gca,'YTick',0:0.125:1.75,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.25 '' 0.5 '' 0.75 '' 1 '' 1.25 '' 1.5 ''
    1.75})

saveas(gca,fullfile(folder,'int_onset_int_meas24'))
```

Time Analysis

```
%%% ------- Finding exact duration of all 6 recordings ------- %%%
brightaudio = miraudio('bright with cuts.wav');
le = mirlength(brightaudio);

%%
morebright = miraudio('more bright with cuts.wav');
br = mirlength(morebright)

%%
fullaudio = miraudio('full with cuts.wav');
fullength = mirlength(fullaudio)

%%
morefull = miraudio('more full with cuts.wav');
mf = mirlength(morefull)

%%
softaudio = miraudio('soft with cuts.wav');
softlength = mirlength(softaudio)

%%
msoftaudio = miraudio('more soft with cuts');
msoftlength = mirlength(msoftaudio)
```

Peak Detection

```
%%% ------- Peak detection on envelopes ------- %%%

%% BRIGHT RECORDINGS

abright = miraudio('bright with cuts.wav'); % audio signal curve
bbright = mirenvelope(abright); % envelope
% detecting peaks, storing them in the order they are detected, with
% corresponding abscissa axis location. Threshold 0.40 of audio signal
```

```
% amplitudes to only detect the highest peaks in the envelope:
cbright = mirpeaks(bbright,'Threshold',0.40,'Order','Abscissa');
[bx,by] = mirgetdata(cbright); % extracting data

qbright = miraudio('more bright with cuts.wav');
rbright = mirenvelope(qbright);
sbright = mirpeaks(rbright,'Threshold',0.40,'Order','Abscissa');
[mbx,mby] = mirgetdata(sbright);

%% SOFT RECORDINGS

asoft = miraudio('soft with cuts.wav')
bsoft = mirenvelope(asoft)
csoft = mirpeaks(bsoft,'Threshold',0.40,'Order','Abscissa')
[sx,sy] = mirgetdata(csoft);


qsoft = miraudio('more soft with cuts.wav');
rsoft = mirenvelope(qsoft);
ssoft = mirpeaks(rsoft,'Threshold',0.40,'Order','Abscissa');
[msx,msy] = mirgetdata(ssoft);

%% FULL RECORDINGS

afull = miraudio('full with cuts.wav');
bfull = mirenvelope(afull);
cfull = mirpeaks(bfull,'Threshold',0.40,'Order','Abscissa') % peaks listed chronologically
[fx,fy] = mirgetdata(cfull);

qfull = miraudio('more full with cuts.wav');
rfull = mirenvelope(qfull);
sfull = mirpeaks(rfull,'Threshold',0.40,'Order','Abscissa');
[mfx,mfy] = mirgetdata(sfull);

%% PLOTTING RESULTS FROM FIRST ROUND OF RECORDINGS
close all;
figure; plot(bx,by,'*-',sx,sy,'r*-',fx,fy,'g*-','Linewidth',2);
xlabel('Time (s)','Fontsize',24); ylabel('Amplitude','Fontsize',24);
set(gca,'Fontsize',22); grid on; ylim([0.1 0.4])
leg = legend('Bright','Soft','Full');
set(leg,'Fontsize',24,'Location','EastOutside');

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gcf,fullfile(folder,'bright_full_soft_amplitudes_sfa_tid'));

%% PLOTTING RESULTS FROM SECOND ROUND OF RECORDINGS

figure; plot(mbx,mby,'*-',msx,msy,'r*-',mfx,mfy,'g*-','LineWidth',2);
xlabel('Time (s)','Fontsize',24); ylabel('Amplitude','Fontsize',24);
set(gca,'Fontsize',22); grid; ylim([0.1 0.4])
leg = legend('More bright','More soft','More full');
set(leg,'Fontsize',24,'Location','EastOutside')

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gcf,fullfile(folder,'mbright_mfull_msoft_amplitudes_sfa_tid'));
```

Centroids

```
%%% ———— CALCULATING CENTROIDS ————— %%%
b = mircentroid('bright with cuts')
mb = mircentroid('more bright with cuts');
s = mircentroid('soft with cuts');
ms = mircentroid('more soft with cuts');
f = mircentroid('full with cuts');
mf = mircentroid('more full with cuts');

values = [b,mb,s,ms,f,mf];
x = 1:6;
yverdier = zeros(1,6);

for i = 1:6
    yverdier(i) = mirgetdata(values(i)); % extracting centroid values
end
%% PLOTTING CENTROIDS (bar plot)

close all; figure;
p = bar(x,yverdier,0.1,'LineWidth',1.5); grid on;
labels = {'Bright','More bright','Soft','More soft','Full','More full'};
set(gca,'XTick',1:6,'XTickLabel',labels,'Fontsize',22);
set(gca,'YTick',0:150:1500);
set(gca,'YTickLabel',{0 '' 300 '' 600 '' 900 '' 1200 '' 1500});
xlabel('Timbre','Fontsize',24);
ylabel('Spectral centroid (Hz)','Fontsize',24);


folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'spectral_centroids_barplot'));
```

Rolloff frequencies

```
%%% ——— ROLLOFF FREQUENCIES ———— %%%

%% BRIGHT MEASURE 24

s_b24 = mirspectrum('meas24_bright')
% when spectrum is calculated: computing miraudio, computing mirsum,
% computing mirspectrum. Sampling rate 44100 Hz.
k_b24 = mirrolloff(s_b24) % gives output-freq = 2063.8229 Hz

n_b24 = get(s_b24,'Data'); % yvalues
o_b24 = get(s_b24,'Pos'); % xvalues

yvals_b24 = n_b24{1,1}{1,1};
xvals_b24 = o_b24{1,1}{1,1};
% Extracting rolloff frequency:
r_b24 = get(k_b24,'Data'); rfreq_b24 = r_b24{1,1}{1,1};

%% BRIGHT MEAS24 - plotting the spectrum with drawn in line for rolloff
    frequency
close all;
figure; plot(xvals_b24,yvals_b24); hold on;
xb24=[rfreq_b24,rfreq_b24];
yb24=[0,400];
```

```matlab
plot(xb24,yb24,'r-','LineWidth',3); xlim([0 5000])
xlabel('Frequency (Hz)','FontSize',24); ylabel('Magnitude','Fontsize',24);
set(gca,'YTick',0:100:900,'Fontsize',22)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'spectrum_with_rolloff_bright_meas24'));

%% SOFT MEAS24

s_s24 = mirspectrum('meas24_soft');
k_s24 = mirrolloff(s_s24);
r_s24 = get(k_s24,'Data'); rfreq_s24 = r_s24{1,1}{1,1};

%% FULL MEAS24

s_f24 = mirspectrum('meas24_full');
k_f24 = mirrolloff(s_f24);
r_f24 = get(k_f24,'Data'); rfreq_f24 = r_f24{1,1}{1,1};

%% MORE BRIGHT MEAS24

s_mb24 = mirspectrum('meas24_mbright');
k_mb24 = mirrolloff(s_mb24);
r_mb24 = get(k_mb24,'Data'); rfreq_mb24 = r_mb24{1,1}{1,1};

%% MORE SOFT MEAS24

s_ms24 = mirspectrum('meas24_msoft');
k_ms24 = mirrolloff(s_ms24);
r_ms24 = get(k_ms24,'Data'); rfreq_ms24 = r_ms24{1,1}{1,1};

%% MORE FULL MEAS24

s_mf24 = mirspectrum('meas24_mfull');
k_mf24 = mirrolloff(s_mf24);
r_mf24 = get(k_mf24,'Data'); rfreq_mf24 = r_mf24{1,1}{1,1};

%% PLOTTING ROLLOFF-FREQUENCIES MEAS24
x = 1:6;
freq = [rfreq_b24 rfreq_mb24 rfreq_s24 rfreq_ms24 rfreq_f24 rfreq_mf24];
close all; figure;
st = stem(x,freq,'LineWidth',4); grid on; xlim([0.5 6.5])
labels = {'Bright','More bright','Soft','More soft','Full','More full'};
set(gca,'XTick',1:6,'XTickLabel',labels,'Fontsize',22); ylim([0 2150])
set(gca,'YTick',0:250:2150);
% set(gca,'YTickLabel',{0 '' 300 '' 600 '' 900 '' 1200 '' 1500});
xlabel('Timbre','Fontsize',24);
ylabel('Rolloff frequency (Hz)','Fontsize',24);


folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rolloff_meas24_stemplot'));

%% BRIGHT (whole recording)

s_b = mirspectrum('bright with cuts');
k_b = mirrolloff(s_b);
```

```
r_b = get(k_b,'Data'); rfreq_b = r_b{1,1}{1,1};

%% SOFT (whole recording)

s_s = mirspectrum('soft with cuts');
k_s = mirrolloff(s_s);
r_s = get(k_s,'Data'); rfreq_s = r_s{1,1}{1,1};

%% FULL (whole recording)

s_f = mirspectrum('full with cuts')
k_f = mirrolloff(s_f);
r_f = get(k_f,'Data'); rfreq_f = r_f{1,1}{1,1};

%% MORE BRIGHT (whole recording)

s_mb = mirspectrum('more bright with cuts');
k_mb = mirrolloff(s_mb);
r_mb = get(k_mb,'Data'); rfreq_mb = r_mb{1,1}{1,1};

%% MORE SOFT (whole recording)

s_ms = mirspectrum('more soft with cuts');
k_ms = mirrolloff(s_ms);
r_ms = get(k_ms,'Data'); rfreq_ms = r_ms{1,1}{1,1};

%% MORE FULL (whole recording)

s_mf = mirspectrum('more full with cuts');
k_mf = mirrolloff(s_mf);
r_mf = get(k_mf,'Data'); rfreq_mf = r_mf{1,1}{1,1};

%% PLOTTING ROLLOFF–FREQUENCIES, STEM PLOT
x = 1:6;
freq = [rfreq_b rfreq_mb rfreq_s rfreq_ms rfreq_f rfreq_mf];
close all; figure;
s = stem(x,freq,'LineWidth',4); grid on; xlim([0.5 6.5])
labels = {'Bright','More bright','Soft','More soft','Full','More full'};
set(gca,'XTick',1:6,'XTickLabel',labels,'Fontsize',22); ylim([0 2500])
set(gca,'YTick',0:250:2500);
% set(gca,'YTickLabel',{0 '' 300 '' 600 '' 900 '' 1200 '' 1500});
xlabel('Timbre','Fontsize',24);
ylabel('Rolloff frequency (Hz)','Fontsize',24);


folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rolloff_stemplot'));
```

Spectra and Histograms

```
%%% ------------------ HISTOGRAMS -------------------- %%%
freq_min = 20;
freq_max = 10000;
folderpath = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
%%%%%%%%%%%%%%%%%%%%%%%%
% The first three takes:
%% BRIGHT SPECTRUM
```

```
p = mirspectrum('bright with cuts','dB','Min',freq_min,'Max',freq_max)

freq_bright = get(p,'Frequency');
magn_bright = get(p,'Magnitude');

f_bright = freq_bright{1,1}{1,1};
m_bright = magn_bright{1,1}{1,1};

close all; figure;
semilogx(f_bright,m_bright);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize'
    ,24);
set(gca,'YTick',-20:20:80,'Fontsize',22);
xlim([20 11000]);

saveas(gcf,fullfile(folderpath,'spectrumdB_logf_bright'));

%% BRIGHT HISTOGRAM
q = mirhisto(p,'Number',200)
% using 'Weight'(amplitudes/nb of occurences) to extract
% data from histogram

hist_y = get(q,'Weight'); yval = hist_y{1,1};
hist_x = get(q,'Bins'); % upper and lower value of bars

values_low = hist_x{1,1}(:,:,1); % lower values
values_high = hist_x{1,1}(:,:,2); % upper
values_mid = (values_high + values_low)/2; % mid values

%% SOFT

r = mirspectrum('soft with cuts','dB','Min',freq_min,'Max',freq_max);
freq_soft = get(r,'Frequency');
magn_soft = get(r,'Magnitude');

f_soft = freq_soft{1,1}{1,1};
m_soft = magn_soft{1,1}{1,1};

close all; figure;
semilogx(f_soft,m_soft);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize'
    ,24);
set(gca,'YTick',-20:20:80,'Fontsize',22);
xlim([20 11000]);
saveas(gcf,fullfile(folderpath,'spectrum_dB_logf_soft'));

s = mirhisto(r,'Number',200);
% using 'Weight'(amplitudes/nb of occurences) to extract
% data from histogram

hist_y2 = get(s,'Weight'); yval2 = hist_y2{1,1};
hist_x2 = get(s,'Bins'); % upper and lower value of bar

values_low2 = hist_x2{1,1}(:,:,1); % lower values
values_high2 = hist_x2{1,1}(:,:,2); % upper
values_mid2 = (values_high2 + values_low2)/2; % mid values

```

```
%% FULL

t = mirspectrum('full with cuts','dB','Min',freq_min,'Max',freq_max);
freq_full = get(t,'Frequency');
magn_full = get(t,'Magnitude');

f_full = freq_full{1,1}{1,1};
m_full = magn_full{1,1}{1,1};

close all; figure;
semilogx(f_full,m_full);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize',24);
set(gca,'YTick',-20:20:80,'Fontsize',20);
xlim([20 11000]);
saveas(gcf,fullfile(folderpath,'spectrum_dB_logf_full'));

% Histogram:
u = mirhisto(t,'Number',200);
% using 'Weight'(amplitudes/nb of occurences) to
% extract data from histogram

hist_y3 = get(u,'Weight'); yval3 = hist_y3{1,1};
hist_x3 = get(u,'Bins'); % upper and lower value of bar

values_low3 = hist_x3{1,1}(:,:,1); % lower value
values_high3 = hist_x3{1,1}(:,:,2); % upper
values_mid3 = (values_high3 + values_low3)/2; % mid value

%%
%%%%%%%%%%%%%%%%%%%%%%
% the second take:
%% MORE BRIGHT

a = mirspectrum('more bright with cuts','dB','Min',freq_min,'Max',freq_max);
freq_mbright = get(a,'Frequency');
magn_mbright = get(a,'Magnitude');

f_mbright = freq_mbright{1,1}{1,1};
m_mbright = magn_mbright{1,1}{1,1};

close all; figure;
semilogx(f_mbright,m_mbright);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize',24);
set(gca,'YTick',-20:20:80,'Fontsize',22);
xlim([20 11000]);
saveas(gcf,fullfile(folderpath,'spectrum_dB_logf_morebright'));

% Histogram:
b = mirhisto(a,'Number',200);
% using 'Weight'(amplitudes/nb of occurences) to extract
% data from histogram

hist_y4 = get(b,'Weight'); yval4 = hist_y4{1,1};
hist_x4 = get(b,'Bins'); % upper and lower value of bar
```

```
values_low4 = hist_x4{1,1}(:,:,1); % lower value of bar
values_high4 = hist_x4{1,1}(:,:,2); % upper value
values_mid4 = (values_high4 + values_low4)/2; % middle value of bar

%% PLOTTING B + MB IN A SUBPLOT:
% STAIRS:
close all;
figure; st1 = subplot(2,1,1)
stairs(values_mid,yval,'linewidth',3); ylim([0 1750]) % BRIGHT
xlabel('Magnitude (dB)','Fontsize',24); grid on;
ylabel({'Number of','occurrences'},'Fontsize',24);
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,1750,'Bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);

st2 = subplot(2,1,2)
stairs(values_mid4,yval4,'linewidth',3); ylim([0 1750]) % MORE BRIGHT
xlabel('Magnitude (dB)','Fontsize',24); grid
ylabel({'Number of','occurrences'},'Fontsize',24);
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,1750,'More bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);

saveas(gcf,fullfile(folderpath,'histo_nbvsdB_bmb_stairsplot'));

%% MORE SOFT

c = mirspectrum('more soft with cuts','dB','Min',freq_min,'Max',freq_max);
freq_msoft = get(c,'Frequency');
magn_msoft = get(c,'Magnitude');

f_msoft = freq_msoft{1,1}{1,1};
m_msoft = magn_msoft{1,1}{1,1};

close all; figure;
semilogx(f_msoft,m_msoft);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize'
    ,24);
set(gca,'YTick',-20:20:80,'Fontsize',22);
xlim([20 11000]);
saveas(gcf,fullfile(folderpath,'spectrum_dB_logf_moresoft'));

% Histogram:
d = mirhisto(c,'Number',200);
% uses 'Weight'(amplitudes/nb of occurences) to extract
% data from histogram

hist_y5 = get(d,'Weight'); yval5 = hist_y5{1,1};
hist_x5 = get(d,'Bins'); % upper and lower value of bar

values_low5 = hist_x5{1,1}(:,:,1); % lower value of bar
values_high5 = hist_x5{1,1}(:,:,2); % upper value of bar
values_mid5 = (values_high5 + values_low5)/2; % middle value of bar

%% PLOTTING S + MS IN SUBPLOT, STAIRSPLOT:
close all; figure; subplot(2,1,1)
```

```
stairs(values_mid2,yval2,'Linewidth',3); xlim([-22 80]) % SOFT
xlabel('Magnitude (dB)','Fontsize',24); grid on; ylim([0 4500])
ylabel({'Number of','occurrences'},'Fontsize',24);
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,4500,'Soft','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);

subplot(2,1,2)
stairs(values_mid5,yval5,'Linewidth',3); grid on; % MORE SOFT
xlabel('Magnitude (dB)','Fontsize',24); ylim([0 4500])
ylabel({'Number of','occurrences'},'Fontsize',24);
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,4500,'More soft','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);

saveas(gcf,fullfile(folderpath,'histo_nbvsdB_sms_stairsplot'));

%% MORE FULL

g = mirspectrum('more full with cuts','dB','Min',freq_min,'Max',freq_max);
freq_mfull = get(g,'Frequency');
magn_mfull = get(g,'Magnitude');

f_mfull = freq_mfull{1,1}{1,1};
m_mfull = magn_mfull{1,1}{1,1};

close all; figure;
semilogx(f_mfull,m_mfull);
xlabel('Frequency (Hz)','Fontsize',24); ylabel('Magnitude (dB)','Fontsize'
    ,24);
set(gca,'YTick',-20:20:80,'Fontsize',22);
xlim([20 11000]);
saveas(gcf,fullfile(folderpath,'spectrum_dB_logf_morefull'));


% Histogram:
h = mirhisto(g,'Number',200);
% using 'Weight'(amplitudes/nb of occurences) to
% extract data from histogram

hist_y6 = get(h,'Weight'); yval6 = hist_y6{1,1};
hist_x6 = get(h,'Bins'); % upper and lower value of each bar

values_low6 = hist_x6{1,1}(:,:,1); % lower value of bar
values_high6 = hist_x6{1,1}(:,:,2); % upper value of bare
values_mid6 = (values_high6 + values_low6)/2; % middle value of bar

%% PLOTTING F + MF IN SUBPLOT

close all;
figure; subplot(2,1,1)
stairs(values_mid3,yval3,'Linewidth',3); ylim([0 1700]) % FULL
xlabel('Magnitude (dB)','Fontsize',24); grid on;
ylabel({'Number of','occurrences'},'Fontsize',24);
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,1700,'Full','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);
```

```
subplot(2,1,2)
stairs(values_mid6,yval6,'Linewidth',3); xlim([-20 80]) % MORE FULL
xlabel('Magnitude (dB)','Fontsize',24); grid
ylabel({'Number of','occurrences'},'Fontsize',24); ylim([0 1700])
set(gca,'XTick',-20:20:80,'Fontsize',22);
text(80,1700,'More full','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24);

saveas(gcf,fullfile(folderpath,'histo_nbvsdB_fmf_stairsplot'));
```

Low Energy Ratio and Temporal Evolution of Energy

```
%% MIRLOWENERGY AND RMS ENERGY + AVERAGE RMS ENERGY PLOTS

%% BRIGHT

b1 = mirrms('bright with cuts','Frame',0.05,0.5) % rms calculated for each frame,
% resulting in a plot showing coeff. value vs temporal location of events
% (in seconds). mirrms command without the 'Frame' argument results in a
% single dimensionless number for the rms energy of the signal.
b1_low = mirlowenergy(b1) % 0.6057
b1_xval = get(b1,'Data');
yb1 = b1_xval{1,1}{1,1};

b1_rmsvalue = mirrms('bright with cuts') % output RMS energy is 0.069533
% so low energy ratio is not based on output from the code above, but
% for an average of rms-values of each frame

% Checking if b1_rmsvalue gives same result as taking the average of all
% frames:
rms_sum = 0;
for i = 1:length(yb1)
    rms_sum = rms_sum + yb1(i);
end

b1_average = rms_sum/length(yb1); % gives 0.0532

% testing to check if 0.0532 is used as rms average for calculation of low
% energy ratio:

nb_frames_below_av = 0;

for i = 1:length(yb1)
    if yb1(i) < b1_average
        nb_frames_below_av = nb_frames_below_av + 1;

    end
end

leratio = nb_frames_below_av/length(yb1); % outputs 0.6057
% Hence, b1_average is used as rms average of signal, used when the low
% energy ratio is computed.

% Calculations every 0.025 sec, due to the 'Frame' option in the argument
% of mirrms function. Want to have time (s) on abscissae axis in the plot,
```

```
% not frame:
t = 0.025;
nb_frames = length(yb1);
length_signal = t*nb_frames; % gives 83.3750
%len = mirlength('bright with cuts'); len_br = get(len,'Data'); % gives 83.4460 s

%% MORE BRIGHT

b2 = mirrms('more bright with cuts','Frame')
b2_low = mirlowenergy(b2); % 0.60711

b2_xval = get(b2,'Data');
yb2 = b2_xval{1,1}{1,1};

b2_rmsvalue = mirrms('bright with cuts') % output RMS energy is 0.069533

% summing rms of each frame
rmsb2_sum = 0;
for i = 1:length(yb2)
    rmsb2_sum = rmsb2_sum + yb1(i);
end

b2_average = rmsb2_sum/length(yb2); % gir 0.0533

%% SUBPLOTS bright + more bright

close all; figure; subplot(2,1,1)
x1 = 1:length(yb1);
%close all; figure;
plot(x1,yb1,'g-+'); hold on;
plot(x1,b1_average,'r','LineStyle','--','Linewidth',2);
axis([0 3500 0 0.45])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3500,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 ''})
text(3500,0.45,'Bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)

subplot(2,1,2)
x2 = 1:length(yb2);
plot(x2,yb2,'g-+'); hold on;
plot(x2,b2_average,'r','LineStyle','--','Linewidth',2);
axis([0 3000 0 0.5])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3000,'Fontsize',22)
set(gca,'YTick',0:0.05:0.5,'Fontsize',22)
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 '' 0.5})
text(3000,0.5,'More bright','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)


folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_bright_mbright_frame_withaverage'));

%% SOFT
```

```
s1 = mirrms('soft with cuts','Frame') % calculating rms of each frame
s1_low = mirlowenergy(s1) % gives 0.62101

s1_xval = get(s1,'Data');
ys1 = s1_xval{1,1}{1,1};

% summing rms:
rmss1_sum = 0;
for i = 1:length(ys1)
    rmss1_sum = rmss1_sum + ys1(i);
end

s1_average = rmss1_sum/length(ys1); % gives 0.0466


%% MORE SOFT

s2 = mirrms('more soft with cuts','Frame')
s2_low = mirlowenergy(s2) % gir 0.6313

s2_xval = get(s2,'Data');
ys2 = s2_xval{1,1}{1,1};

rmss2_sum = 0;
for i = 1:length(ys2)
    rmss2_sum = rmss2_sum + ys2(i);
end

s2_average = rmss2_sum/length(ys2); % gir 0.0618

%% SUBPLOTS SOFT + MORE SOFT

close all; figure; subplot(2,1,1)
x1 = 1:length(ys1);
plot(x1,ys1,'g—+'); hold on;
plot(x1,s1_average,'r','LineStyle','–','Linewidth',2);
axis([0 3800 0 0.5])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3800,'Fontsize',22)
set(gca,'YTick',0:0.05:0.5,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 '' 0.5})
text(3800,0.5,'Soft','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)

subplot(2,1,2)
x2 = 1:length(ys2);
plot(x2,ys2,'g—+'); hold on;
plot(x2,s2_average,'r','LineStyle','–','Linewidth',2);
axis([0 3800 0 0.5])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3800,'Fontsize',22)
set(gca,'YTick',0:0.05:0.5,'Fontsize',22)
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 '' 0.5})
text(3800,0.5,'More soft','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
```

```
saveas(gca,fullfile(folder,'rms_soft_msoft_frame_withaverage'));


%% FULL

f1 = mirrms('full with cuts','Frame')
f1_low = mirlowenergy(f1); % gives 0.61933

f1_xval = get(f1,'Data');
yf1 = f1_xval{1,1}{1,1};

rmsf1_sum = 0;
for i = 1:length(yf1)
    rmsf1_sum = rmsf1_sum + yf1(i);
end

f1_average = rmsf1_sum/length(yf1); % gives 0.0468

%% MORE FULL

f2 = mirrms('more full with cuts','Frame')
f2_low = mirlowenergy(f2) % gives 0.59335

f2_xval = get(f2,'Data');
yf2 = f2_xval{1,1}{1,1};

rmsf2_sum = 0;
for i = 1:length(yf2)
    rmsf2_sum = rmsf2_sum + yf2(i);
end

f2_average = rmsf2_sum/length(yf2); % gives 0.0639

%% SUBPLOTS FULL + MORE FULL

close all; figure; subplot(2,1,1)
x1 = 1:length(yf1);
plot(x1,yf1,'g--+'); hold on;
plot(x1,f1_average,'r','LineStyle','--','Linewidth',2);
axis([0 3700 0 0.5])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3700,'Fontsize',22)
set(gca,'YTick',0:0.05:0.5,'Fontsize',22);
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 '' 0.5})
text(3700,0.5,'Full','HorizontalAlignment','right',...
    'VerticalAlignment','bottom','Fontsize',24)

subplot(2,1,2)
x2 = 1:length(yf2);
plot(x2,yf2,'g--+'); hold on;
plot(x2,f2_average,'r','LineStyle','--','Linewidth',2);
axis([0 3700 0 0.5])
xlabel('Frame','Fontsize',24); ylabel('Coefficient value','Fontsize',24);
set(gca,'XTick',0:500:3700,'Fontsize',22)
set(gca,'YTick',0:0.05:0.5,'Fontsize',22)
set(gca,'YTickLabel',{0 '' 0.1 '' 0.2 '' 0.3 '' 0.4 '' 0.5})
text(3700,0.5,'More full','HorizontalAlignment','right',...
```

```
    'VerticalAlignment','bottom','Fontsize',24)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_full_mfull_frame_withaverage'));

%% EXTRACTING MIR-VALUES FOR LOW ENERGY RATIOS

low_e_mirvalues = [b1_low,b2_low,s1_low,s2_low,f1_low,f2_low];

low_e = zeros(1,6);
for i = 1:6
    low_e(i) = mirgetdata(low_e_mirvalues(i));
end

%% PLOTTING LOW ENERGY RATIOS (bar plot)
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

xval = 1:6;
labels = {'Bright', 'More bright','Soft', 'More soft', 'Full', 'More full'};
% figure; plot(xval,low_e,'*-');
close all; figure;
p = bar(xval,low_e,0.1,'g','Linewidth',1.5); grid on;
ylim([0.585 0.635])
set(gca,'YTick',0.585:0.005:0.635)
set(gca,'XTick',1:6,'XTickLabel',labels,'Fontsize',22);
xlabel('Timbre','Fontsize',24); ylabel('Low energy ratio','Fontsize',24);

saveas(gca,fullfile(folder,'lowenergyratio_barplot'));
```

Attack Time

```
%%%%%%% ATTACK-TIME OF THREE FIRST ONSETS OF MEAS 27 %%%%%%%%%%%%%%

%% BRIGHT
% THE SAME RHYTHM USED FOR IOI CALCULATIONS
% Default setting of miraudio and 'Extract' is the time settings t1 and t2
% are counted from the beginning of the audio file. All cuts are made
% 0.200 sec before and after the first and last onset, respectively.
% Seconds 's' is also default setting.

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
%
t1 = 75.454;
t2 = 77.583;
% extracting relevant segment:
b = miraudio('bright with cuts', 'Extract', t1, t2,'s');% sampl.rate 44110 Hz
mirsave(b,'meas27_bright')

%ons2 = mironsets('meas27_bright','Contrast',0.1);

%% BRIGHT

% METHOD: plot mironsets('meas27_bright','Contrast',0.1,'Attacks') in order
% to know which attacktimes are being considered. Then perform attacktime
```

```
% on the onset-curve before extracting attacktime data using get(...,'Data')

% Contrast removes smaller detected onsets
ons_bright = mironsets('meas27_bright','Contrast',0.1,'Attacks');
attime_bright = mirattacktime(ons_bright,'Lin');
data_bright = get(attime_bright,'Data');
% From manual inspection of plots:
attacktime_bright = [data_bright{1,1}{1,1}(:)];

%% SOFT ATTACKTIME
close all; clear;
t1 = 79.576;  % 0.2 s before and after first and last onset, respectively
t2 = 81.967;

s = miraudio('soft with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110 Hz
mirsave(s,'meas27_soft')

ons_soft = mironsets('meas27_soft','Contrast',0.1,'Attacks');
attime_soft = mirattacktime(ons_soft);
data_soft = get(attime_soft,'Data');
% From manual inspection of plots:
attacktime_soft = [data_soft{1,1}{1,1}(:)];

%% FULL ATTACKTIME

t1 = 81.540;
t2 = 84.070;

f = miraudio('full with cuts', 'Extract',t1,t2,'s')
mirsave(f,'meas27_full');

ons_full = mironsets('meas27_full','Contrast',0.1,'Attacks');
attime_full = mirattacktime(ons_full,'Lin');
data_full = get(attime_full,'Data');
% From manual inspection of plots:
attacktime_full = [data_full{1,1}{1,1}(1,2:4)];

%% MORE BRIGHT

t1 = 65.779;
t2 = 67.761;

mb = miraudio('more bright with cuts','Extract',t1,t2,'s');
mirsave(mb,'meas27_mbright')

ons_mb = mironsets('meas27_mbright','Contrast',0.1,'Attacks');
attime_mb = mirattacktime(ons_mb,'Lin');
data_mb = get(attime_mb,'Data');
% From manual inspection of plots:
attacktime_mb = data_mb{1,1}{1,1}(1,1:3);

%% MORE SOFT
% Here different extract times are tested, both shorter and longer, because
% of the odd location of the onset attack curve. But this did not affect
% the placement of the curve. 0.2 s before and after first and last onset
```

```
% is then still used:
t1 = 83.762;
t2 = 86.449;

ms = miraudio('more soft with cuts','Extract',t1,t2,'s');
mirsave(ms,'meas27_msoft')

% The plot from detected onset attack time is included in the report as it
% illustrates the odd start of attack.

ons_ms = mironsets('meas27_msoft','Contrast',0.1,'Attacks')
attime_ms = mirattacktime(ons_ms,'Lin')
data_ms = get(attime_ms,'Data');
% From manual inspection of plots:
attacktime_ms = data_ms{1,1}{1,1}(1,2:4);

%% MORE FULL

t1 = 76.975;
t2 = 79.517;

mf = miraudio('more full with cuts','Extract',t1,t2,'s');
mirsave(mf,'meas27_mfull')

ons_mf = mironsets('meas27_mfull','Contrast',0.1,'Attacks');
attime_mf = mirattacktime(ons_mf,'Lin');
data_mf = get(attime_mf,'Data');
% From manual inspection of plots:
attacktime_mf = data_mf{1,1}{1,1}([1 3 4]);

%% SUBPLOT ATTACK TIME MEASURE 27
x = 1:3;
A = [attacktime_bright attacktime_soft attacktime_full'];

close all; figure
s1 = subplot(2,1,1)

% putting together the three vector into one matrix in order to make a bar
% plot. The bar plot function plots one group for each row in the matrix
%
% bars are plotted for each column.

p1 = bar(x,A,0.15,'hist'); ylim([0 0.075]); grid;
leg1 = legend('Bright','Soft','Full');
set(leg1,'Location','EastOutside','Fontsize',24);
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:3,'Fontsize',22)

set(p1(1),'FaceColor','b'); set(p1(2),'FaceColor','r');
set(p1(3),'FaceColor','g'); hold on;
% Adding errorbars to each bar:
er = 0.005; % max error is \pm 0.005 s
errors = [er er er; er er er; er er er];

xvals1 = get(p1,'XData'); % xvalues for each bar
% Finding mid-x-values for each bright bar, storing them in variable
% b_bars. Here the first row gives xval starting point of all three bright
```

```
% bars, second row gives xval end points of bright bars:
b_bars1 = [xvals1{1,1}(1,:); xvals1{1,1}(3,:)]; % first and third row
b_bars_mid1 = zeros(1,3);
for i = 1:length(b_bars1)
    b_bars_mid1(i) = (b_bars1(2,i) + b_bars1(1,i))/2;

end

% Soft bars:
s_bars1 = [xvals1{2,1}(1,:); xvals1{2,1}(3,:)];
s_bars_mid1 = zeros(1,3);
for i = 1:length(s_bars1)
    s_bars_mid1(i) = (s_bars1(1,i) + s_bars1(2,i))/2;
end

%Full bars:
f_bars1 = [xvals1{3,1}(1,:); xvals1{3,1}(3,:)];
f_bars_mid1 = zeros(1,3);
for i = 1:length(f_bars1)
    f_bars_mid1(i) = (f_bars1(1,i) + f_bars1(2,i))/2;
end


ebright1 = errorbar(b_bars_mid1(1,:),A(:,1),errors(:,1),'LineStyle','none'
    );
set(ebright1,'LineWidth',2,'Color','k');
esoft1 = errorbar(s_bars_mid1(1,:),A(:,2),errors(:,2),'LineStyle','none');
set(esoft1,'LineWidth',2,'Color','k');
efull1 = errorbar(f_bars_mid1(1,:),A(:,3),errors(:,3),'LineStyle','none');
set(efull1,'LineWidth',2,'Color','k');
%text(2.025,0.055,'Error \pm 0.010 s','HorizontalAlignment','left',...
 %   'VerticalAlignment','bottom','Fontsize',18);

s2 = subplot(2,1,2)
B = [attacktime_mb' attacktime_ms' attacktime_mf'];

p2 = bar(x,B,0.15,'hist'); ylim([0 0.075]); grid;
leg2 = legend('More bright','More soft','More full');
set(leg2,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:3,'Fontsize',22)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g'); hold on;
% Adding errorbars to each bar:
er = 0.005; % max error is \pm 0.005 s
errors = [er er er; er er er; er er er];

xvals2 = get(p2,'XData'); % xvalues for each bar
% Finding mid-x-values for each bright bar, storing them in variable
% b_bars. Here the first row gives xval starting point of all three bright
% bars, second row gives xval end points of bright bars:
b_bars2 = [xvals2{1,1}(1,:); xvals2{1,1}(3,:)]; % first and third row
b_bars_mid2 = zeros(1,3);
for i = 1:length(b_bars2)
    b_bars_mid2(i) = (b_bars2(2,i) + b_bars2(1,i))/2;

end
```

```
% Soft bars:
s_bars2 = [xvals2{2,1}(1,:); xvals2{2,1}(3,:)];
s_bars_mid2 = zeros(1,3);
for i = 1:length(s_bars2)
    s_bars_mid2(i) = (s_bars2(1,i) + s_bars2(2,i))/2;
end

%Full bars:
f_bars2 = [xvals2{3,1}(1,:); xvals2{3,1}(3,:)];
f_bars_mid2 = zeros(1,3);
for i = 1:length(f_bars2)
    f_bars_mid2(i) = (f_bars2(1,i) + f_bars2(2,i))/2;
end




ebright2 = errorbar(b_bars_mid2(1,:),B(:,1),errors(:,1),'LineStyle','none'
    );
set(ebright2,'LineWidth',2,'Color','k');
esoft2 = errorbar(s_bars_mid2(1,:),B(:,2),errors(:,2),'LineStyle','none');
set(esoft2,'LineWidth',2,'Color','k');
efull2 = errorbar(f_bars_mid2(1,:),B(:,3),errors(:,3),'LineStyle','none');
set(efull2,'LineWidth',2,'Color','k');
% text(2.025,0.055,'Error \pm 0.010 s','HorizontalAlignment','left',...
%      'VerticalAlignment','bottom','Fontsize',18);

% Making the subplots of equal width:
s1pos = get(s1,'Position');
s2pos = get(s2,'Position');
s2pos(3:4) = [s1pos(3:4)];
set(s2,'Position',s2pos);

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attacktime_barplot_meas27'))
```

```
%% ATTACK TIME FOR 1st AND 2nd BEATS OF MEASURE 22
%% BRIGHT - MEASURE 22
ons_bright = mironsets('meas22_bright','Contrast',0.1,'Attacks');
attime_bright = mirattacktime(ons_bright,'Lin');
data_bright = get(attime_bright,'Data');
% From manual inspection of plots:
attacktime_bright = data_bright{1,1}{1,1}(:);

%% SOFT - MEASURE 22

ons_soft = mironsets('meas22_soft','Contrast',0.1,'Attacks');
attime_soft = mirattacktime(ons_soft);
data_soft = get(attime_soft,'Data');
% From manual inspection of plots:
attacktime_soft = data_soft{1,1}{1,1}([1 3]);

%% FULL - MEASURE 22

ons_full = mironsets('meas22_full','Contrast',0.1,'Attacks');
attime_full = mirattacktime(ons_full,'Lin');
```

```matlab
data_full = get(attime_full,'Data');
attacktime_full = data_full{1,1}{1,1}([1 3]);% From manual inspection of plots


%% MORE BRIGHT - MEASURE 22

ons_mb = mironsets('meas22_mbright','Contrast',0.1,'Attacks');
attime_mb = mirattacktime(ons_mb,'Lin');
data_mb = get(attime_mb,'Data');
% From manual inspection of plots:
attacktime_mb = data_mb{1,1}{1,1}([2 8]); % NB! Unclear onsets. And odd
% location of attack slope of second onset giving a smaller output value

%% MORE SOFT - MEASURE 22

ons_ms = mironsets('meas22_msoft','Contrast',0.1,'Attacks');
attime_ms = mirattacktime(ons_ms,'Lin');
data_ms = get(attime_ms,'Data');

attacktime_ms = data_ms{1,1}{1,1}([1 5]);% From manual inspection of plots

%% MORE FULL - MEASURE 22

ons_mf = mironsets('meas22_mfull','Contrast',0.1,'Attacks');
attime_mf = mirattacktime(ons_mf,'Lin');
data_mf = get(attime_mf,'Data');
% From manual inspection of plots:
attacktime_mf = data_mf{1,1}{1,1}([1 4]);

%% PLOTTING BSF & MBMSMF, SUBPLOT

x = 1:2;
A = [attacktime_bright attacktime_soft' attacktime_full'];
B = [attacktime_mb' attacktime_ms' attacktime_mf'];

close all; figure; s1 = subplot(2,1,1)
p = bar(x,A,0.15,'hist'); axis([0.5 2.5 0 0.08]); grid on;
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24);
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',0:0.02:0.09)

set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g'); hold on;
% Adding errorbars to each bar:
er = 0.005; % max error is \pm 0.005
errors = [er er er; er er er];

xvals = get(p,'XData'); % xvalues for each bar

b_bars = [xvals{1,1}(1,:); xvals{1,1}(3,:)]; % first and third row
b_bars_mid = zeros(1,2);
for i = 1:length(b_bars)
    b_bars_mid(i) = (b_bars(2,i) + b_bars(1,i))/2;

```

```
end

% Soft bars:
s_bars = [xvals{2,1}(1,:); xvals{2,1}(3,:)];
s_bars_mid = zeros(1,2);
for i = 1:length(s_bars)
    s_bars_mid(i) = (s_bars(1,i) + s_bars(2,i))/2;
end

%Full bars:
f_bars = [xvals{3,1}(1,:); xvals{3,1}(3,:)];
f_bars_mid = zeros(1,2);
for i = 1:length(f_bars)
    f_bars_mid(i) = (f_bars(1,i) + f_bars(2,i))/2;
end

ebright = errorbar(b_bars_mid(1,:),A(:,1),errors(:,1),'LineStyle','none');
set(ebright,'LineWidth',2,'Color','k');
esoft = errorbar(s_bars_mid(1,:),A(:,2),errors(:,2),'LineStyle','none');
set(esoft,'LineWidth',2,'Color','k');
efull = errorbar(f_bars_mid(1,:),A(:,3),errors(:,3),'LineStyle','none');
set(efull,'LineWidth',2,'Color','k');

s2 = subplot(2,1,2)
p2 = bar(x,B,0.15,'hist');
axis([0.5 2.5 0 0.05]); grid;
leg = legend('More bright','More soft','More full');
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:2,'Fontsize',22)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g'); hold on;

% Making the subplots of equal width:
s1pos = get(s1,'Position');
s2pos = get(s2,'Position');
s2pos(3:4) = [s1pos(3:4)];
set(s2,'Position',s2pos);


ebright2 = errorbar(b_bars_mid(1,:),B(:,1),errors(:,1),'LineStyle','none')
    ;
set(ebright2,'LineWidth',2,'Color','k');
esoft2 = errorbar(s_bars_mid(1,:),B(:,2),errors(:,2),'LineStyle','none');
set(esoft2,'LineWidth',2,'Color','k');
efull2 = errorbar(f_bars_mid(1,:),B(:,3),errors(:,3),'LineStyle','none');
set(efull2,'LineWidth',2,'Color','k');



folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attacktime_barplot_meas22_bsf_mbmsmf'))
```

```
%% ATTACK TIME FOR 1st AND 2nd BEATS OF MEASURE 23
% Audio files already cut from calculating rms.

%% BRIGHT - MEASURE 23
```

```
ons_bright = mironsets('meas23_bright','Contrast',0.1,'Attacks');
attime_bright = mirattacktime(ons_bright,'Lin');
data_bright = get(attime_bright,'Data');
% From manual inspection of plots:
attacktime_bright = data_bright{1,1}{1,1}([1 3]);

%% SOFT - MEASURE 23

ons_soft = mironsets('meas23_soft','Contrast',0.1,'Attacks');
attime_soft = mirattacktime(ons_soft);
data_soft = get(attime_soft,'Data');
% From manual inspection of plots:
attacktime_soft = data_soft{1,1}{1,1}(:);

%% FULL - MEASURE 23

ons_full = mironsets('meas23_full','Contrast',0.1,'Attacks');
attime_full = mirattacktime(ons_full,'Lin');
data_full = get(attime_full,'Data');
attacktime_full = data_full{1,1}{1,1}(:); % From manual inspection of plots

%% MORE BRIGHT - MEASURE 23

ons_mb = mironsets('meas23_mbright','Contrast',0.1,'Attacks');
attime_mb = mirattacktime(ons_mb,'Lin');
data_mb = get(attime_mb,'Data');
% From manual inspection of plots:
attacktime_mb = data_mb{1,1}{1,1}(:);

%% MORE SOFT - MEASURE 23

ons_ms = mironsets('meas23_msoft','Contrast',0.1,'Attacks');
attime_ms = mirattacktime(ons_ms,'Lin');
data_ms = get(attime_ms,'Data');
% From manual inspection of plots:
attacktime_ms = data_ms{1,1}{1,1}(:);

%% MORE FULL - MEASURE 23

ons_mf = mironsets('meas23_mfull','Contrast',0.1,'Attacks');
attime_mf = mirattacktime(ons_mf,'Lin');
data_mf = get(attime_mf,'Data');
% From manual inspection of plots:
attacktime_mf = data_mf{1,1}{1,1}(:);

%% PLOTTING BSF & MBMSMF, SUBPLOT

x = 1:2;
A = [attacktime_bright' attacktime_soft attacktime_full];
B = [attacktime_mb attacktime_ms attacktime_mf];

close all; figure; s1 = subplot(2,1,1)
p = bar(x,A,0.15,'hist'); axis([0.5 2.5 0 0.06]); grid on;
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24);
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
```

```matlab
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',0:0.02:0.09)

set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g'); hold on;
% Adding errorbars to each bar:
er = 0.005; % max error is \pm 0.005
errors = [er er er; er er er];

xvals = get(p,'XData'); % xvalues for each bar

b_bars = [xvals{1,1}(1,:); xvals{1,1}(3,:)]; % first and third row
b_bars_mid = zeros(1,2);
for i = 1:length(b_bars)
    b_bars_mid(i) = (b_bars(2,i) + b_bars(1,i))/2;

end

% Soft bars:
s_bars = [xvals{2,1}(1,:); xvals{2,1}(3,:)];
s_bars_mid = zeros(1,2);
for i = 1:length(s_bars)
    s_bars_mid(i) = (s_bars(1,i) + s_bars(2,i))/2;
end

%Full bars:
f_bars = [xvals{3,1}(1,:); xvals{3,1}(3,:)];
f_bars_mid = zeros(1,2);
for i = 1:length(f_bars)
    f_bars_mid(i) = (f_bars(1,i) + f_bars(2,i))/2;
end

ebright = errorbar(b_bars_mid(1,:),A(:,1),errors(:,1),'LineStyle','none');
set(ebright,'LineWidth',2,'Color','k');
esoft = errorbar(s_bars_mid(1,:),A(:,2),errors(:,2),'LineStyle','none');
set(esoft,'LineWidth',2,'Color','k');
efull = errorbar(f_bars_mid(1,:),A(:,3),errors(:,3),'LineStyle','none');
set(efull,'LineWidth',2,'Color','k');

s2 = subplot(2,1,2)
p2 = bar(x,B,0.15,'hist');
axis([0.5 2.5 0 0.07]); grid;
leg = legend('More bright','More soft','More full');
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:2,'Fontsize',22)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g'); hold on;

% Making the subplots of equal width:
s1pos = get(s1,'Position');
s2pos = get(s2,'Position');
s2pos(3:4) = [s1pos(3:4)];
set(s2,'Position',s2pos);

ebright2 = errorbar(b_bars_mid(1,:),B(:,1),errors(:,1),'LineStyle','none')
    ;
```

```
set(ebright2,'LineWidth',2,'Color','k');
esoft2 = errorbar(s_bars_mid(1,:),B(:,2),errors(:,2),'LineStyle','none');
set(esoft2,'LineWidth',2,'Color','k');
efull2 = errorbar(f_bars_mid(1,:),B(:,3),errors(:,3),'LineStyle','none');
set(efull2,'LineWidth',2,'Color','k');

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attacktime_barplot_meas23_bsf_mbmsmf'))
```

```
%% ATTACK TIME FOR 1st AND 2nd BEATS OF MEASURE 24
% cut 0.1 sec before first onset and 0.2 sec after last onset

%% Bright
clear;
t1 = 65.070; % onset of first chord
t2 = 66.973; % onset of second chord

b24 = miraudio('bright with cuts', 'Extract', t1, t2,'s');% sampl.rate 44110 Hz
mirsave(b24,'meas24_bright');

%% Soft
clear;
t1 = 68.534;
t2 = 70.356;

s24 = miraudio('soft with cuts', 'Extract', t1, t2,'s');% sampl.rate 44110 Hz
mirsave(s24,'meas24_soft');

%% Full
clear;
t1 = 70.330;
t2 = 72.230;

f24 = miraudio('full with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110 Hz
mirsave(f24,'meas24_full');

%% More bright
clear;
t1 = 55.613;
t2 = 57.319;

mb24 = miraudio('more bright with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110 Hz
mirsave(mb24,'meas24_mbright')

%% More soft
t1 = 70.945;
t2 = 72.764;

ms24 = miraudio('more soft with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110 Hz
mirsave(ms24,'meas24_msoft')

%% More full
```

```
t1 = 65.832;
t2 = 67.541;

mf24 = miraudio('more full with cuts', 'Extract', t1, t2,'s')% sampl.rate
    44110 Hz
mirsave(mf24,'meas24_mfull')


%% BRIGHT - MEASURE 24
ons_bright = mironsets('meas24_bright','Contrast',0.1,'Attacks');
attime_bright = mirattacktime(ons_bright,'Lin');
data_bright = get(attime_bright,'Data');
% VERY CLEAR PEAKS/ONSETS
% From manual inspection of plots:
attacktime_bright = data_bright{1,1}{1,1}(:);

%% SOFT - MEASURE 24

ons_soft = mironsets('meas24_soft','Contrast',0.1,'Attacks');
attime_soft = mirattacktime(ons_soft);
data_soft = get(attime_soft,'Data');
% VERY CLEAR PEAKS/ONSETS
attacktime_soft = data_soft{1,1}{1,1}(:);% From manual inspection of plots

%% FULL - MEASURE 24

ons_full = mironsets('meas24_full','Contrast',0.1,'Attacks');
attime_full = mirattacktime(ons_full,'Lin');
data_full = get(attime_full,'Data');
attacktime_full = data_full{1,1}{1,1}(:);% From manual inspection of plots

%% MORE BRIGHT - MEASURE 24

ons_mb = mironsets('meas24_mbright','Contrast',0.1,'Attacks');
attime_mb = mirattacktime(ons_mb,'Lin');
data_mb = get(attime_mb,'Data');
% VERY CLEAR PEAKS/ONSETS
attacktime_mb = data_mb{1,1}{1,1}(:); % From manual inspection of plots

%% MORE SOFT - MEASURE 24

ons_ms = mironsets('meas24_msoft','Contrast',0.1,'Attacks');
attime_ms = mirattacktime(ons_ms,'Lin');
data_ms = get(attime_ms,'Data');
% VERY CLEAR PEAKS/ONSETS
attacktime_ms = data_ms{1,1}{1,1}(:);% From manual inspection of plots

%% MORE FULL - MEASURE 24

ons_mf = mironsets('meas24_mfull','Contrast',0.1,'Attacks');
attime_mf = mirattacktime(ons_mf,'Lin');
data_mf = get(attime_mf,'Data');

attacktime_mf = data_mf{1,1}{1,1}(:);% From manual inspection of plots

%% PLOTTING BSF & MBMSMF, SUBPLOT
```

```
x = 1:2;
A = [attacktime_bright attacktime_soft attacktime_full];
B = [attacktime_mb attacktime_ms attacktime_mf];

close all; figure; s1 = subplot(2,1,1)
p = bar(x,A,0.15,'hist'); axis([0.5 2.5 0 0.06]); grid on;
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24);
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',0:0.02:0.09)

set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g'); hold on;
% Adding errorbars to each bar:
er = 0.005; % max error is \pm 0.005
errors = [er er er; er er er];

xvals = get(p,'XData'); % xvalues for each bar

b_bars = [xvals{1,1}(1,:); xvals{1,1}(3,:)]; % first and third row
b_bars_mid = zeros(1,2);
for i = 1:length(b_bars)
    b_bars_mid(i) = (b_bars(2,i) + b_bars(1,i))/2;

end

% Soft bars:
s_bars = [xvals{2,1}(1,:); xvals{2,1}(3,:)];
s_bars_mid = zeros(1,2);
for i = 1:length(s_bars)
    s_bars_mid(i) = (s_bars(1,i) + s_bars(2,i))/2;
end

%Full bars:
f_bars = [xvals{3,1}(1,:); xvals{3,1}(3,:)];
f_bars_mid = zeros(1,2);
for i = 1:length(f_bars)
    f_bars_mid(i) = (f_bars(1,i) + f_bars(2,i))/2;
end

ebright = errorbar(b_bars_mid(1,:),A(:,1),errors(:,1),'LineStyle','none');
set(ebright,'LineWidth',2,'Color','k');
esoft = errorbar(s_bars_mid(1,:),A(:,2),errors(:,2),'LineStyle','none');
set(esoft,'LineWidth',2,'Color','k');
efull = errorbar(f_bars_mid(1,:),A(:,3),errors(:,3),'LineStyle','none');
set(efull,'LineWidth',2,'Color','k');

s2 = subplot(2,1,2)
p2 = bar(x,B,0.15,'hist');
axis([0.5 2.5 0 0.07]); grid;
leg = legend('More bright','More soft','More full');
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack time (s)','Fontsize',24);
set(gca,'XTick',1:2,'Fontsize',22)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g'); hold on;
```

```
% Making subplots of equal width:
s1pos = get(s1,'Position');
s2pos = get(s2,'Position');
s2pos(3:4) = [s1pos(3:4)];
set(s2,'position',s2pos);

ebright2 = errorbar(b_bars_mid(1,:),B(:,1),errors(:,1),'LineStyle','none');
set(ebright2,'LineWidth',2,'Color','k');
esoft2 = errorbar(s_bars_mid(1,:),B(:,2),errors(:,2),'LineStyle','none');
set(esoft2,'LineWidth',2,'Color','k');
efull2 = errorbar(f_bars_mid(1,:),B(:,3),errors(:,3),'LineStyle','none');
set(efull2,'LineWidth',2,'Color','k');

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attacktime_barplot_meas24_bsf_mbmsmf'))
```

Attack Slope

```
%% ATTACKSLOPE MEAS 27
% BRIGHT

[k,a] = mirattackslope('meas27_bright') % displays detected onset attacktime curves
% and attack slope values.
slope_bright = get(k,'Data')
b_slope = slope_bright{1,1}{1,1}(:);% From manual inspection of plots

%% SOFT
[s,a] = mirattackslope('meas27_soft')
slope_soft = get(s,'Data');
s_slope = slope_soft{1,1}{1,1}(:);% From manual inspection of plots

%% FULL
[f,k] = mirattackslope('meas27_full')
slope_full = get(f,'Data');
f_slope = slope_full{1,1}{1,1}(1,2:4);% From manual inspection of plots

%% MORE BRIGHT
[mb,l] = mirattackslope('meas27_mbright')
slope_mbright = get(mb,'Data');
mb_slope = slope_mbright{1,1}{1,1}(:);% From manual inspection of plots

%% MORE SOFT
[ms,n] = mirattackslope('meas27_msoft') % odd position of start of attack
% of first beat!
slope_msoft = get(ms,'Data');
ms_slope = slope_msoft{1,1}{1,1}(1,2:4);% From manual inspection of plots

%% MORE FULL
[mf,mk] = mirattackslope('meas27_mfull');
slope_mfull = get(mf,'Data');
mf_slope = slope_mfull{1,1}{1,1}(1,[1 3 4]);% From manual inspection of plots

%% SUBPLOTS
```

```

x = 1:3;
A = [b_slope s_slope f_slope'];
B = [mb_slope ms_slope' mf_slope'];

close all; figure;
s1 = subplot(2,1,1)
p = bar(x,A,0.15,'hist') %ylim([0 0.075]); grid;
leg = legend('Bright','Soft','Full'); ylim([0 2.5*10^7])
set(leg,'Location','EastOutside','Fontsize',24); grid on;
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:3,'Fontsize',22)
set(p(1),'FaceColor','b'); set(p(2),'FaceColor','r');
set(p(3),'FaceColor','g');

s2 = subplot(2,1,2)
p2 = bar(x,B,0.15,'hist') %ylim([0 0.075]); grid;
leg = legend('More bright','More soft','More full'); grid on; ylim([0
    2.5*10^7])
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:3,'Fontsize',22)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g')

% Making the subplots of equal width:
s1pos = get(s1,'Position');
s2pos = get(s2,'Position');
s2pos(3:4) = [s1pos(3:4)];
set(s2,'Position',s2pos);

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attackslope_barplot_meas27'))
```

```
%% ATTACK SLOPE MEASURE 22
%% BRIGHT
[b,a] = mirattackslope('meas22_bright') % displays detected onset
    attacktime curves
% and attack slope values.
slope_bright = get(b,'Data')
b_slope = slope_bright{1,1}{1,1}(:); % From manual inspection of plots

%% SOFT
[s,a] = mirattackslope('meas22_soft') % small peak of first onset
slope_soft = get(s,'Data');
s_slope = slope_soft{1,1}{1,1}([1 3]); % From manual inspection of plots

%% FULL
[f,k] = mirattackslope('meas22_full')
slope_full = get(f,'Data');
% From manual inspection of plots:
f_slope = slope_full{1,1}{1,1}([1 3]); % unclear onsets

%% MORE BRIGHT
[mb,l] = mirattackslope('meas22_mbright')
```

```
slope_mbright = get(mb,'Data');
% From manual inspection of plots:
mb_slope = slope_mbright{1,1}{1,1}([2 8]); % unclear onsets

%% MORE SOFT
[ms,n] = mirattackslope('meas22_msoft') % small peak of first onset
slope_msoft = get(ms,'Data');
ms_slope = slope_msoft{1,1}{1,1}([1 5]);% From manual inspection of plots

%% MORE FULL
[mf,mk] = mirattackslope('meas22_mfull')
slope_mfull = get(mf,'Data');
% From manual inspection of plots:
mf_slope = slope_mfull{1,1}{1,1}([1 4]); % unclear first onset.

%% SUBPLOTS
x = 1:2;
A = [b_slope s_slope' f_slope'];
B = [mb_slope' ms_slope' mf_slope'];

close all; figure; pl1 = subplot(2,1,1)
p1 = bar(x,A,0.1,'hist') %ylim([0 0.075]); grid;
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24); grid on;
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:0.5:2)*10^7,'Fontsize',22)
set(p1(1),'FaceColor','b'); set(p1(2),'FaceColor','r');
set(p1(3),'FaceColor','g');

pl2 = subplot(2,1,2)
p2 = bar(x,B,0.1,'hist') %ylim([0 0.075]); grid;
leg = legend('More bright','More soft','More full'); grid on;
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:2.5:10)*10^6)
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g');

% Plots of equal size:
pl1pos = get(pl1,'Position');
pl2pos = get(pl2,'Position');
pl2pos(3:4) = pl1pos(3:4);
set(pl2,'Position',pl2pos);

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attackslope_barplot_meas22_bsf_mbmsmf'))
```

```
%% ATTACK SLOPE MEASURE 23
%% BRIGHT
[b,a] = mirattackslope('meas23_bright')
slope_bright = get(b,'Data')
b_slope = slope_bright{1,1}{1,1}([1 3]);% From manual inspection of plots

```

```
%% SOFT
[s,a] = mirattackslope('meas23_soft');
slope_soft = get(s,'Data');
s_slope = slope_soft{1,1}{1,1}(:);% From manual inspection of plots

%% FULL
[f,k] = mirattackslope('meas23_full');
slope_full = get(f,'Data');
f_slope = slope_full{1,1}{1,1}(:);% From manual inspection of plots

%% MORE BRIGHT
[mb,l] = mirattackslope('meas23_mbright');
slope_mbright = get(mb,'Data');
mb_slope = slope_mbright{1,1}{1,1}(:);% From manual inspection of plots

%% MORE SOFT
[ms,n] = mirattackslope('meas23_msoft');
slope_msoft = get(ms,'Data');
ms_slope = slope_msoft{1,1}{1,1}(:); % From manual inspection of plots

%% MORE FULL
[mf,mk] = mirattackslope('meas23_mfull');
slope_mfull = get(mf,'Data');
mf_slope = slope_mfull{1,1}{1,1}(:);% From manual inspection of plots

%% PLOTTING ATTACK SLOPES IN SUBPLOT

x = 1:2;
A = [b_slope' s_slope f_slope];
B = [mb_slope ms_slope mf_slope];

close all; figure; pl1 = subplot(2,1,1)
p1 = bar(x,A,0.1,'hist'); ylim([0 4.5]*10^7)
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24); grid on;
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:1:4.5)*10^7,'Fontsize',22)
%set(gca,'YTickLabel',{0 '' 1 '' 2 '' 3 '' 4 ''})
set(p1(1),'FaceColor','b'); set(p1(2),'FaceColor','r');
set(p1(3),'FaceColor','g');

pl2 = subplot(2,1,2)
p2 = bar(x,B,0.1,'hist'); ylim([0 2.5]*10^7);
leg = legend('More bright','More soft','More full'); grid on;
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:0.5:2.5)*10^7)%,'YTickLabel',{0 '' 1 '' 2 ''})
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g');

% Plots of equal size:
pl1pos = get(pl1,'Position');
pl2pos = get(pl2,'Position');
```

```
pl2pos(3:4) = pl1pos(3:4);
set(pl2,'Position',pl2pos);

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attackslope_barplot_meas23_bsf_mbmsmf'))
```

```
%% ATTACK SLOPE MEASURE 24
%% BRIGHT
[b,a] = mirattackslope('meas24_bright');
slope_bright = get(b,'Data');
b_slope = slope_bright{1,1}{1,1}(:);% From manual inspection of plots

%% SOFT
[s,a] = mirattackslope('meas24_soft');
slope_soft = get(s,'Data');
s_slope = slope_soft{1,1}{1,1}(:);% From manual inspection of plots

%% FULL
[f,k] = mirattackslope('meas24_full');
slope_full = get(f,'Data');
f_slope = slope_full{1,1}{1,1}(:);% From manual inspection of plots

%% MORE BRIGHT
[mb,l] = mirattackslope('meas24_mbright');
slope_mbright = get(mb,'Data');
mb_slope = slope_mbright{1,1}{1,1}(:);% From manual inspection of plots

%% MORE SOFT
[ms,n] = mirattackslope('meas24_msoft');
slope_msoft = get(ms,'Data');
ms_slope = slope_msoft{1,1}{1,1}(:); % From manual inspection of plots

%% MORE FULL
[mf,mk] = mirattackslope('meas24_mfull');
slope_mfull = get(mf,'Data');
mf_slope = slope_mfull{1,1}{1,1}(:);% From manual inspection of plots

%% PLOTTING ATTACK SLOPES IN SUBPLOT

x = 1:2;
A = [b_slope s_slope f_slope];
B = [mb_slope ms_slope mf_slope];

close all; figure; pl1 = subplot(2,1,1)
p1 = bar(x,A,0.1,'hist'); ylim([0 2.5]*10^7)
leg = legend('Bright','Soft','Full');
set(leg,'Location','EastOutside','Fontsize',24); grid on;
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:0.5:4.5)*10^7,'Fontsize',22)
%set(gca,'YTickLabel',{0 '' 1 '' 2 '' 3 '' 4 ''})
set(p1(1),'FaceColor','b'); set(p1(2),'FaceColor','r');
set(p1(3),'FaceColor','g');

pl2 = subplot(2,1,2)
p2 = bar(x,B,0.1,'hist'); ylim([0 2.5]*10^7);
```

```
leg = legend('More bright','More soft','More full'); grid on;
set(leg,'Location','EastOutside','Fontsize',24)
xlabel('Onsets','Fontsize',24); ylabel('Attack slope (s^{-1})','Fontsize'
    ,24);
set(gca,'XTick',1:2,'Fontsize',22)
set(gca,'YTick',(0:0.5:2.5)*10^7)%,'YTickLabel',{0 '' 1 '' 2 ''})
set(p2(1),'FaceColor','b'); set(p2(2),'FaceColor','r');
set(p2(3),'FaceColor','g');

% Plots of equal size:
pl1pos = get(pl1,'Position');
pl2pos = get(pl2,'Position');
pl2pos(3:4) = pl1pos(3:4);
set(pl2,'Position',pl2pos);

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'attackslope_barplot_meas24_bsf_mbmsmf'))
```

RMS Energy

```
%% RMS ENERGY FOR FIRST THREE ONSETS OF MEASURE 27

b1 = mirrms('meas27_bright','Frame');
b2 = mirrms('meas27_mbright','Frame');

s1 = mirrms('meas27_soft','Frame');
s2 = mirrms('meas27_msoft','Frame');

f1 = mirrms('meas27_full','Frame');
f2 = mirrms('meas27_mfull','Frame');

%%

b1_data = get(b1,'Data');%gives yvalue
b1_ypos = b1_data{1,1}{1,1}(:);
xb1 = 1:length(b1_ypos);

b2_data = get(b2,'Data');
b2_ypos = b2_data{1,1}{1,1}(:)
xb2 = 1:length(b2_ypos);

s1_data = get(s1,'Data');
s1_ypos = s1_data{1,1}{1,1}(:);
xs1 = 1:length(s1_ypos);

s2_data = get(s2,'Data');
s2_ypos = s2_data{1,1}{1,1}(:)
xs2 = 1:length(s2_ypos);

f1_data = get(f1,'Data');
f1_ypos = f1_data{1,1}{1,1}(:);
xf1 = 1:length(f1_ypos);

f2_data = get(f2,'Data');
f2_ypos = f2_data{1,1}{1,1}(:)
xf2 = 1:length(f2_ypos);
```

```
%% PLOT BSF

close all; figure;
plot(xb1,b1_ypos,'b-+','Linewidth',2); hold on;
plot(xs1,s1_ypos,'r-+','Linewidth',2);
plot(xf1,f1_ypos,'g-+','Linewidth',2); grid on;
% axis([0 90 0 0.45])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('Bright', 'Soft', 'Full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:100,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas27_bsf'));


%% PLOT MBMSMF

close all; figure;
plot(xb2,b2_ypos,'b-+','Linewidth',2); hold on;
plot(xs2,s2_ypos,'r-+','Linewidth',2);
plot(xf2,f2_ypos,'g-+','Linewidth',2); grid on;
axis([0 110 0 0.45])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('More bright', 'More soft', 'More full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:110,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas27_mbmsmf'));
```

```
%% RMS ENERGY 1st and 2nd BEAT OF MEASURES 22 AND 23
% same procedure as for RMS calculations for measure 27
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';

%% MEASURE 22 - BRIGHT
% t1 and t2 are set 0.1 sec before and 0.2 sec after the first and last onset,
% respectively. There is a sixteenth grace note right before the downbeat.
% Especially the soft/more soft recordings display a very blurry audio
% waveform, where it is difficult to distinguish peaks.
clear;
t1 = 59.116;
t2 = 60.675;

b22 = miraudio('bright with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110 Hz
mirsave(b22,'meas22_bright')

%% MEASURE 23 - BRIGHT
clear;
t1 = 61.961;
t2 = 63.759;

b23 = miraudio('bright with cuts', 'Extract', t1, t2,'s');% sampl.rate
```

```
    44110 Hz
mirsave(b23,'meas23_bright')

%% MEASURE 22 - SOFT
clear;
t1 = 62.343;
t2 = 63.970;

s22 = miraudio('soft with cuts', 'Extract', t1, t2,'s');% sampl.rate 44110
    Hz
mirsave(s22,'meas22_soft')

%% MEAS 23 - SOFT
clear;
t1 = 65.461;
t2 = 67.116;

s23 = miraudio('soft with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110
    Hz
mirsave(s23,'meas23_soft')

%% MEAS 22 - FULL
clear;
t1 = 63.430;
t2 = 65.163;

f22 = miraudio('full with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110
    Hz
mirsave(f22,'meas22_full')

%% MEAS 23 - FULL
clear;
t1 = 66.868;
t2 = 68.837;

f23 = miraudio('full with cuts', 'Extract', t1, t2,'s')% sampl.rate 44110
    Hz
mirsave(f23,'meas23_full')

%% MEAS 22 - MORE BRIGHT
clear;
t1 = 49.926;
t2 = 51.505;

mb22 = miraudio('more bright with cuts', 'Extract', t1, t2,'s')% sampl.
    rate 44110 Hz
mirsave(mb22,'meas22_mbright')

%% MEAS 23 - MORE BRIGHT
clear;
t1 = 52.678;
t2 = 54.340;

mb23 = miraudio('more bright with cuts', 'Extract', t1, t2,'s')% sampl.
    rate 44110 Hz
mirsave(mb23,'meas23_mbright')
```

```
%% MEASURE 22 - MORE SOFT
clear;
t1 = 63.971;
t2 = 65.749;

ms22 = miraudio('more soft with cuts', 'Extract', t1, t2,'s')% sampl.rate
    44110 Hz
mirsave(ms22,'meas22_msoft')

%% MEASURE 23 - MORE SOFT
clear;
t1 = 67.247;
t2 = 69.106;

ms23 = miraudio('more soft with cuts', 'Extract', t1, t2,'s')% sampl.rate
    44110 Hz
mirsave(ms23,'meas23_msoft')

%%  MEASURE 22 - MORE FULL
clear;
t1 = 59.123;
t2 = 60.674;

mf22 = miraudio('more full with cuts', 'Extract', t1, t2,'s')% sampl.rate
    44110 Hz
mirsave(mf22,'meas22_mfull')

 %% MEASURE 23 - MORE FULL
 clear;
t1 = 62.475;
t2 = 64.225;

mf23 = miraudio('more full with cuts', 'Extract', t1, t2,'s')% sampl.rate
    44110 Hz
mirsave(mf23,'meas23_mfull')

%% RMS FOR 1st and 2nd BEAT OF MEASURE 22
b1 = mirrms('meas22_bright','Frame');
b2 = mirrms('meas22_mbright','Frame');

s1 = mirrms('meas22_soft','Frame'); % the grace note is highly carried
    over
% to the downbeat, causing a very small peak for the 1st beat.
s2 = mirrms('meas22_msoft','Frame'); % same reasoning as for soft

f1 = mirrms('meas22_full','Frame');
f2 = mirrms('meas22_mfull','Frame');

%% Extracting data

b1_data = get(b1,'Data'); %gives yvalue
b1_ypos = b1_data{1,1}{1,1}(:);
xb1 = 1:length(b1_ypos);

b2_data = get(b2,'Data'); % gives yvalue
b2_ypos = b2_data{1,1}{1,1}(:)
xb2 = 1:length(b2_ypos);
```

```
s1_data = get(s1,'Data'); %gives yvalue
s1_ypos = s1_data{1,1}{1,1}(:);
xs1 = 1:length(s1_ypos);

s2_data = get(s2,'Data');% gives yvalue
s2_ypos = s2_data{1,1}{1,1}(:);
xs2 = 1:length(s2_ypos);

f1_data = get(f1,'Data'); %gives yvalue
f1_ypos = f1_data{1,1}{1,1}(:);
xf1 = 1:length(f1_ypos);

f2_data = get(f2,'Data');% gives yvalue
f2_ypos = f2_data{1,1}{1,1}(:);
xf2 = 1:length(f2_ypos);

%% PLOTTING BSF - MEAS 22

close all; figure;
plot(xb1,b1_ypos,'b-+','Linewidth',2); hold on;
plot(xs1,s1_ypos,'r-+','Linewidth',2);
plot(xf1,f1_ypos,'g-+','Linewidth',2); grid on;
% axis([0 90 0 0.45])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('Bright', 'Soft', 'Full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:100,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas22_bsf'));

%% PLOTTING MBMSMF - MEAS 22

close all; figure;
plot(xb2,b2_ypos,'b-+','Linewidth',2); hold on;
plot(xs2,s2_ypos,'r-+','Linewidth',2);
plot(xf2,f2_ypos,'g-+','Linewidth',2); grid on;
axis([0 75 0 0.4])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('More bright', 'More soft', 'More full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:70,'Fontsize',22)
set(gca,'YTick',0:0.05:0.40)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas22_mbmsmf'));

%% RMS FOR 1st and 2nd BEAT OF MEASURE 23
clear;

b1 = mirrms('meas23_bright','Frame');
b2 = mirrms('meas23_mbright','Frame');

s1 = mirrms('meas23_soft','Frame');
s2 = mirrms('meas23_msoft','Frame');
```

```
f1 = mirrms('meas23_full','Frame');
f2 = mirrms('meas23_mfull','Frame');

%% EXTRACTING DATA FROM RMS ENERGY PLOTS FOR MEAS 23

b1_data = get(b1,'Data'); %gives yvalue
b1_ypos = b1_data{1,1}{1,1}(:);
xb1 = 1:length(b1_ypos);

b2_data = get(b2,'Data'); % gives yvalue
b2_ypos = b2_data{1,1}{1,1}(:)
xb2 = 1:length(b2_ypos);

s1_data = get(s1,'Data'); %gives yvalue
s1_ypos = s1_data{1,1}{1,1}(:);
xs1 = 1:length(s1_ypos);

s2_data = get(s2,'Data');% gives yvalue
s2_ypos = s2_data{1,1}{1,1}(:);
xs2 = 1:length(s2_ypos);

f1_data = get(f1,'Data'); %gives yvalue
f1_ypos = f1_data{1,1}{1,1}(:);
xf1 = 1:length(f1_ypos);

f2_data = get(f2,'Data'); %gives yvalue
f2_ypos = f2_data{1,1}{1,1}(:);
xf2 = 1:length(f2_ypos);


%% PLOTTING BSF - MEAS 23

close all; figure;
plot(xb1,b1_ypos,'b-+','Linewidth',2); hold on;
plot(xs1,s1_ypos,'r-+','Linewidth',2);
plot(xf1,f1_ypos,'g-+','Linewidth',2); grid on;
axis([0 80 0 0.55])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('Bright', 'Soft', 'Full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:80,'Fontsize',22)
set(gca,'YTick',0:0.05:0.55)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas23_bsf'));

%% PLOTTING MBMSMF - MEAS 23

close all; figure;
plot(xb2,b2_ypos,'b-+','Linewidth',2); hold on;
plot(xs2,s2_ypos,'r-+','Linewidth',2);
plot(xf2,f2_ypos,'g-+','Linewidth',2); grid on;
axis([0 75 0 0.45])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('More bright', 'More soft', 'More full');
set(leg,'Fontsize',24,'Location','EastOutside')
```

```
set(gca,'XTick',0:10:70,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas23_mbmsmf'));
```

```
%% RMS FOR 1st and 2nd BEAT OF MEASURE 24
b1 = mirrms('meas24_bright','Frame')
b2 = mirrms('meas24_mbright','Frame')

s1 = mirrms('meas24_soft','Frame')
s2 = mirrms('meas24_msoft','Frame')

f1 = mirrms('meas24_full','Frame')
f2 = mirrms('meas24_mfull','Frame')

% Very clear peaks for all rms plots

%%
b1_data = get(b1,'Data'); %gives yvalue
b1_ypos = b1_data{1,1}{1,1}(:);
xb1 = 1:length(b1_ypos);

b2_data = get(b2,'Data');
b2_ypos = b2_data{1,1}{1,1}(:)
xb2 = 1:length(b2_ypos);

s1_data = get(s1,'Data');
s1_ypos = s1_data{1,1}{1,1}(:);
xs1 = 1:length(s1_ypos);

s2_data = get(s2,'Data');
s2_ypos = s2_data{1,1}{1,1}(:);
xs2 = 1:length(s2_ypos);

f1_data = get(f1,'Data');
f1_ypos = f1_data{1,1}{1,1}(:);
xf1 = 1:length(f1_ypos);

f2_data = get(f2,'Data');
f2_ypos = f2_data{1,1}{1,1}(:);
xf2 = 1:length(f2_ypos);


%% PLOTTING BSF - MEAS 24

close all; figure;
plot(xb1,b1_ypos,'b-+','Linewidth',2); hold on;
plot(xs1,s1_ypos,'r-+','Linewidth',2);
plot(xf1,f1_ypos,'g-+','Linewidth',2); grid on;
% axis([0 90 0 0.45])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('Bright', 'Soft', 'Full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:100,'Fontsize',22)
set(gca,'YTick',0:0.05:0.45)

```

```
folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas24_bsf'));

%% PLOTTING MBMSMF - MEAS 24

close all; figure;
plot(xb2,b2_ypos,'b-+','Linewidth',2); hold on;
plot(xs2,s2_ypos,'r-+','Linewidth',2);
plot(xf2,f2_ypos,'g-+','Linewidth',2); grid on;
axis([0 75 0 0.4])
xlabel('Frame','Fontsize',24);ylabel('Coefficient value','Fontsize',24);
leg = legend('More bright', 'More soft', 'More full');
set(leg,'Fontsize',24,'Location','EastOutside')
set(gca,'XTick',0:10:70,'Fontsize',22)
set(gca,'YTick',0:0.05:0.40)

folder = 'C:\Users\Stine\NTNU\Masteroppgave\PianoProject';
saveas(gca,fullfile(folder,'rms_meas24_mbmsmf'));
```