QUANTITATIVE MODEL-BASED ANALYSIS OF F_0 CONTOURS OF EMOTIONAL SPEECH

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ABSTRACT

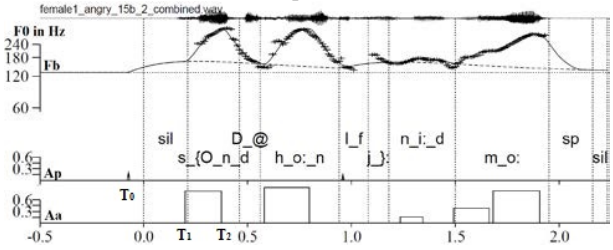
Emotional speech recognition and synthesis are currently in focus due to emerging applications in Human-Computer Interaction. Past studies found the need to include secondary emotions (e.g. worried, apologetic) along with primary emotions (e.g. sad, happy), as social interactions exhibit subtle nuances. The F_0 contours of utterances spoken with five primary and five secondary emotions produced by two male and two female New Zealand English speakers were parameterized using the Fujisaki model. Automatic extraction followed by manual adjustments yielded amplitude and timing parameters on the utterance, phrase and syllable levels. Results show that the ten emotions significantly influence amplitude parameters on all levels, especially as a function of speaker-activation, being high in 'excited' as compared to 'sad', for instance. Also, the frequencies of accents and distributions of tonal transitions were analysed. As the Fujisaki model offers continuous F_0 contours, these results are directly applicable to emotional speech synthesis.

Keywords: Secondary emotions, Fujisaki Model, Fundamental frequency, Accent

1. INTRODUCTION

High-quality emotional speech synthesisers are key components of state-of-the-art Human-Computer Interaction (HCI) applications. In social interactions, [1] has reported that emotions to be processed by such systems are not only the primary ones, such as happy, angry, sad, but also secondary emotions, e.g. worried, apologetic and anxious that are more subtle in nature. There have been studies that analyse the acoustic parameters of emotional speech to understand which features distinguish one emotion from another, and facilitate modelling these emotions for synthesis purposes (e.g.: [2–6]). In many studies Fundamental frequency (F_0) has been found to be a significant emotion-distinguishing factor (e.g.:[2–4]). The descriptive features of F_0 like mean and range provide useful information about emotion separation. But in speech synthesis the complete F_0 contour needs to be carefully modelled, as it conveys concurrent linguistic information - e.g. sentence modality and word prominences, as well as paralinguistic information (e.g. emotional variations). Hence, there is a need to parameterise the F_0 contour via a quantitative model. The Fujisaki model [9] parameterises the F_0 contour superimposing (1) the base frequency F_b, indicated by the horizontal line at the floor of the F_0 pattern of the utterance as shown in Figure 1, (2) the phrase component, the slowly drooping phrasal contours accompanying each prosodic phrase, and (3) the accent component, reflecting fast F_0 movements on accented syllables and boundary tones. The input functions of the model are impulse-wise so called phrase commands and rectangular accent commands which are displayed in the two lower tracks of Figure 1. These commands are specified by the following parameters: (1) Phrase command onset time T_0: Onset time of the phrasal contour, typically before the segmental onset of the phrase of the ensuing prosodic phrase. (2) Phrase command amplitude A_p: Magnitude of the phrase command that precedes each new prosodic phrase, quantifying the amount of reset in the declination line. (3) Accent Command Amplitude A_a: Accent command amplitude associated with every pitch accent. (4) Accent command onset time T_1 and offset time T_2: The timing of the accent command that can be related to the timing of

Figure 1: Fujisaki model parameters for *'Sound the horn if you need more'* (SAMPA phonetic symbol). T_0, T_1, T_2 are marked for first phrase and accent commands



the underlying segments. The model approximates the natural F_0 contour and interpolates through unvoiced sounds. The Fujisaki model is event-based, i.e. every command is related to the onset of a new phrase, accented syllable or boundary tone. It is parsimonious as large parts of the contour can be captured using few parameters and the parameters can be directly used to synthesise the F_0 contour. Due to these reasons this model has been used in this study. Past studies used the model in various prosodic contexts, e.g.: analysing tonal contrasts in Vietnamese [8], the influence of underlying attitudes and emotions in German [9] and Mandarin [10], as well as arousal in a psychotherapeutic setting [11] and perceived syllable prominence in German [12]. The use of the Fujisaki model to analyse emotional speech is a less explored area. [14] has analysed six emotions based on the Fujisaki model and [13] has employed the Fujisaki model for voice conversion for emotional speech. With growing needs in HCI, there is a need to also study some secondary emotions along with the primary emotions and quantitatively analyse them using the Fujisaki model. This is with the goal of synthesizing F_0 contours reflecting the emotion differences.

2. EMOTIONAL SPEECH CORPUS

To analyse the emotions needed for HCI, an open-source emotional speech corpus (available at : github.com/tli725/JL-Corpus) was developed [15], containing five primary (angry, happy, neutral, sad, excited) and five secondary emotions (anxious, pensive, apologetic, enthusiastic, worried) elicited by two male and two female professional New Zealand English speakers. It has strictly-guided simulated emotions with 15 sentences for each emotion. Fujisaki model fitting of the F_0 contour involves manual corrections, hence a subset of the corpus (50%) covering all emotions and all speakers equally was used. The corpus contains 2400 short utterances and 1200 were used. Hence, 120 sentences were analysed for each emotion. The sentences in the corpus are semantically neutral, except two emotionally coloured ones for each of the secondary emotions with semantics conveying that emotion (e.g. 'I owe you an apology.' for *apologetic*). The corpus was segmented at the syllable-level using HTK-based [16] American English forced alignment system and hand-corrected where needed.

3. FUJISAKI MODEL ANALYSIS

First, the F_0 contour was extracted using the Praat standard method [17] using a time step of 0.01s. Then the Fujisaki model parameters were estimated from the natural F_0 contour using an automatic algorithm [18]. In the analysis of reading-style speech typically every content word is characterized by at least one accent command associated with the primary pitch accent and the base frequency F_b is kept constant for each speaker [19]. In the context of emotional speech, however, in principle every syllable can exhibit an accent command, especially when the emotion entails strong arousal. Sometimes even a single syllable that is strongly emphasized can contain two accent commands as seen in the syllable 'm_o:' of Figure 1. Among the total number of accent commands analysed 14.8% are cases where 2 accent commands are associated with a single syllable. We also observed that for certain speakers the F_b has to be adjusted ($\pm$ 10Hz) as a function of the emotion portrayed. The Fujisaki model parameters for each utterance were checked to ensure that potential errors in F_0 tracking did not affect them, leading to additional accent commands in unvoiced segments. Finally, an automatic time alignment of the Fujisaki parameters with each of the syllables in the corpus was performed, i.e., accent commands are associated with the syllables in which they begin and end, and phrase commands with the initial syllables of phrases that they precede. The resulting database contains the Fujisaki model parameters (A_a, A_p, F_b, T_0, T_1, T_2) for each of the syllables. In total the Fujisaki model-based parameterised data contains 4777 accent commands and 1701 phrase commands almost equally distributed among the ten emotions. As the F_0 contour can be described as a sequence of linguistically motivated tone switches, major rises and falls [19], the tone switches have also been marked based on the accent command alignment with respect to the syllable. Table 1 displays a list of accent command alignment options derived from [20] and their associated codes henceforth used in this paper. As a result, each syllable exhibits a switching code associated with it. In cases where there are two accent commands in one syllable (like 'm_o:' of Figure 1), combination tone switch codes were produced by concatenating the two codes associated with the two accent commands using a '+' sign.

4. RESULTS AND DISCUSSION

Figure 2 shows parameterised F_0 contour results of the sentence 'Find your boot is in this shoot' produced with four emotions. The panels show from top

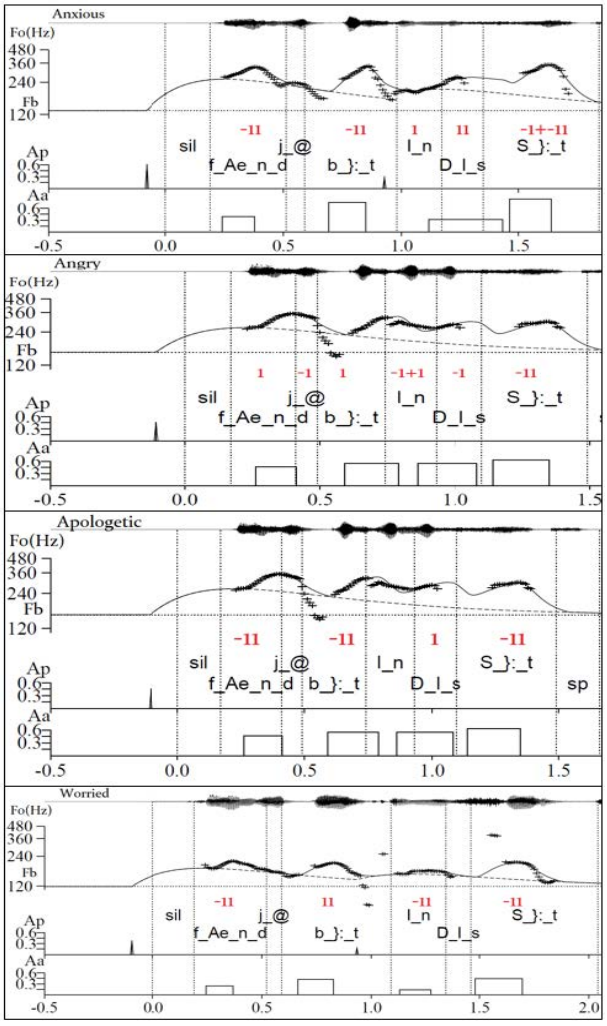
Table 1: Tone switch codes used in this paper

Tone Switch condition in current syllable	Code
Rising tone switch	1
Falling tone switch	-1
Rising, then falling tone switch	-11
Falling, then rising tone switch	12
Accent command across syllable	11

Table 2: Features that distinguish the emotion pairs based on ANOVA and t-test results. D: Sentence-level mean duration of accent commands, R: Number of accent commands per second.)

	angry	**anxious**	**apologetic**	**enthusiastic**	**excited**	**happy**	**neutral**	**pensive**	**sad**
anxious	A_p, R	-	-	-	-	-	-	-	-
apologetic	A_p, A_a	A_p, A_a, R	-	-	-	-	-	-	-
enthusiastic	A_a	A_a	A_p, A_a, R	-	-	-	-	-	-
excited	A_a	A_a	A_p, A_a, R	A_p, A_a	-	-	-	-	-
happy	A_a	-	A_p, A_a, R	A_p, A_a	A_p, A_a	-	-	-	-
neutral	A_p, A_a, R	A_p, A_a, D	R	A_p, A_a, D, R	A_p, A_a, D, R	-	-	-	-
pensive	A_p, A_a, R	A_p, A_a	A_p, A_a, R	A_a, R	A_p, A_a, R	A_p, A_a, R	A_p, A_a	-	-
sad	A_p, A_a, R	A_p, A_a, R	-	A_p, A_a, D, R	A_p, A_a, R	A_p, A_a, R	A_a	A_a, R	-
worried	A_p, A_a, R	A_a	A_p, A_a, R	A_a, R	A_p, A_a, R	A_a, R	A_p, A_a, D	-	A_p, A_a, R

Figure 2: Fujisaki model parameterisation of F_0 contours for *'Find your boot in this shoot'* in four emotions.

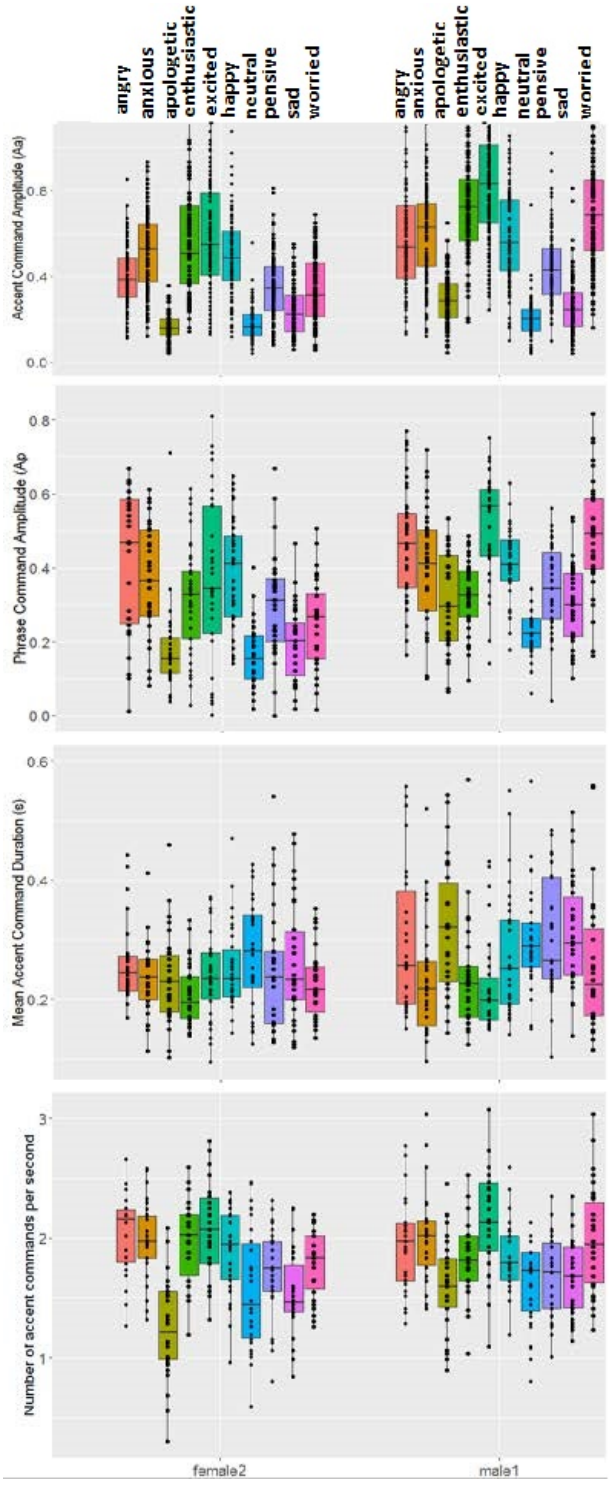


to the bottom (1) speech waveform, (2) extracted F_0 contour (Hz) indicated by + signs and the Fujisaki model-based contour as a smooth continuous line, (3) underlying phrase command amplitudes (A_p) and (4) accent command amplitudes (A_a). The results of the Fujisaki parameters obtained for each emotion and their relation to emotion production are discussed here. It can be seen that high arousal emotions like *angry* and *anxious* exhibit larger accent commands compared to low arousal *apologetic*. The trends for A_a and A_p for all the emotions can be seen in the boxplots in Figure 3 for speakers *female2* and *male1*. As the F_0 baseline at F_b was kept constant within each speaker, A_p and A_a are good indicators of the emotion influence on the phrase and accent levels, respectively. *Apologetic* and *sad* exhibit the lowest A_a and A_p, while excited has the highest values. A_a is the best discriminator among the four features (seen in Table 2) which lists all emotion pairs and features that distinguish them based on ANOVA and pair-wise t-tests (both at significance level of 0.05). The utterance-wise mean duration of accent commands (D) was the least distinguishing feature. The D of *female2* does not vary as much as that of *male1*. This may be due to *female2's* higher speech rate (0.31 syllables/sec). A weak, but significant correlation between A_a and D [Pearson's r = *-.146, n = 4738, p < .01***] was found. This suggests that higher accent command amplitudes are associated with shorter accent command durations. The number of accent commands per second (R) was calculated by counting the number of accent commands in one sentence and dividing it by the total duration (in secs) of the sentence. R also distinguishes between emotions, with *apologetic* having the lowest number per second, and *excited* having the highest. For lower arousal emotions like *apologetic* the speakers tend to produce a smaller number of accented syllables as observable in the examples in Figure 2. This will in turn affect R. The number of accented syllables does not match exactly the number of accent commands, as mentioned previously there were cases where an accented syllable was associated with two accent commands (14.8 %). None of the features were able to distinguish *apologetic* vs. *sad* and *happy* vs. *anxious*.

The secondary emotion closest to primary emotions *excited* and *happy* on the valence-arousal (VA) plane is *enthusiastic* (Valence level indicates the

pleasantness of the voice ranging from unpleasant (e.g.: sad, fear) to pleasant (e.g.: happy, calm). Arousal level specifies the level of reaction to stimuli and range from inactive (e.g.: sleepy, sad) to active (e.g.: anger, surprise) [23]). The secondary emotion closest to *angry* is *anxious* and the secondary emotions closest to *sad* are *neutral* and *apologetic*. From Figure 3 it can be noted that the feature values for the emotions that are close to a primary emotion cover a similar area under the boxplot, with differences in the median line and overall range. So, feature values of the secondary emotions fall in between the extreme values of the primary emotions as expected due to their non-extreme positions on a VA plane [1].

Figure 3: Box plots of Fujisaki Model parameters A_a, A_p, mean accent command duration (D), number of accent commands per second (R) vs emotions.



Analysing the tone switches, the most frequent were falling tones (-1). All the initial syllable tone switches were falling. For the final syllable position, the falling tone (-1) and the rising then falling tone switch (-11) were the most common. Also, the higher arousal emotions are characterized by more occurrences of -11 (accent starts and ends in the same syllable) whereas lower activation ones exhibit more 11, i.e., more syllables are covered by one and the same accent command. This means that accents commands in high arousal emotions are shorter and accents more prominent, not only with respect to the F_0 interval reflected by A_a, but also the concentration of the peak. In contrast, in lower arousal emotions more syllables are strung together between two accents, forming the hat-pattern [21]. An inspection of the tone switch codes (marked in red in Figure 2) reveals that despite the underlying linguistic information being maintained the same for all the emotions, the combinations of the tone switches may vary. Hence the sequence of code switches is useful information in F_0 contour synthesis.

5. CONCLUSION

In this study five primary and five secondary emotions were analysed using the Fujisaki model. We were able to show that model parameters and two derived features are significantly influenced by the emotions. Using the superpositional approach we can now quantify this influence on the utterance, phrase and accent levels. Also, the accent command alignment with the syllable was analyzed and found to vary depending on the emotion type. Alignment codes are similar to tone labels in ToBI [22]. However, as the Fujisaki model captures the entire F_0 contour and not just certain landmarks, it also facilitates direct synthesis of F_0 contours which is one of the objectives of our study. Parameters can be predicted based on linguistic and paralinguistic context, such as positions of accented syllables and emotion type, to regenerate the contour during speech synthesis. We are aware that emotions cannot be discriminated exclusively by F_0, but other acoustic features need to be taken into account as shown in [7]. Future work will therefore be dedicated to the development of a prediction model combining the F_0 contours with other prosodic features.

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