# THE USE OF F0 RELIABILITY FUNCTION FOR PROSODIC COMMAND ANALYSIS ON F0 CONTOUR GENERATION MODEL

*Mitsuru NAKAI and Hiroshi SHIMODAIRA*

Japan Advanced Institute of Science and Technology, Hokuriku
1-1 Asahidai, Tatsunokuchi, Nomi, Ishikawa, 923-1292 Japan
E-mail: mit@jaist.ac.jp

## ABSTRACT

This paper describes a method of utilizing an "$F_0$ Reliability Field" (FRF), which we have proposed in our previous work, for estimating prosodic commands on $F_0$ contour generation model. This FRF is the time-frequency representation of $F_0$ likelihood, and an advantage of FRF is that it is not necessary to consider $F_0$ errors that occur during an automatic $F_0$ determination. Therefore, it is thought that FRF can be a more useful feature for automatic prosody analyses than $F_0$ contour, and our previous paper has reported the validity of FRF on the analysis of detecting prosodic boundaries in Japanese continuous speech. Moreover, in this paper, we have examined the validity on the prosodic command estimation of superpositional model. Experimental results show that the accuracy of command estimation with FRF is well and it is close to the accuracy of command estimation with ideal $F_0$ contour that has no $F_0$ error.

## 1. INTRODUCTION

Prosody of speech is an important information for speech understanding. It is well known that high quality speech synthesis can be achieved by incorporating accurate prosodic model, and it is also expected that the prosody will be a useful information for high performed speech recognition. In particular, a fundamental frequency ($F_0$) is widely used for prosody analyses, such as prosodic phrase segmentation, prosodic structure estimation and the superpositional modeling of prosodic command, and the accuracy of these prosody analyses sometimes depends on the accuracy of $F_0$ extraction. There is a long history of development of $F_0$ analysis, and various $F_0$ determination algorithms and their improved method have been proposed, but it may be said that there is no technique that is superior in every aspect to others. Therefore, we have to choose the most suitable $F_0$ determination algorithm corresponding to each prosody analysis system.

For example, $F_0$ determination error has a bad influence on the system that employs the technique of pattern matching between the observed $F_0$ contour and the approximated $F_0$ contour that the system constructs. This is because the distortion becomes large as the number of $F_0$ error increases. Therefore, it is necessary to correct $F_0$ errors and this is one of laborious postprocessing task in any automatic $F_0$ determination. So we have proposed the "$F_0$ Reliability Field" (FRF)[1] as a desirable feature for those systems, namely this feature does not need any correction of $F_0$ errors. This FRF is expressed as a time-frequency function of $F_0$ likelihood. The frequency that gives maximum likelihood is not always a real $F_0$ value, but an advantage of FRF is that the frequency that is equivalent to the real $F_0$ value always gives high $F_0$ reliability.

In our previous paper, FRF has been applied to an automatic detection system of accent phrase boundaries, which is based on the $F_0$ contour matching technique, and the validity of FRF has been confirmed. Besides our FRF, some similar features, which are based on a kind of $F_0$ reliability function, have been proposed. For example, "periodicity diagram"[2] is the time-frequency representation of $F_0$, and it has been reported that this representation is useful for determining an accurate $F_0$ value. In addition, "voicograms"[3] method of speech periodicity representation has been used for ensuring the practical correctness of $F_0$ estimation. Moreover, in this paper, we have applied our FRF to the prosodic command estimation of the $F_0$ contour generation model[4].

## 2. *F0* RELIABILITY FIELD

The $F_0$ reliability field is a temporal sequence of $F_0$ reliability function, which represents a likelihood of fundamental frequency at each time frame. This $F_0$ reliability function is based on a short-time autocorrelation function of speech wave, and the process of FRF analysis is quite similar to the $F_0$ determining process. The outline is shown in Figure.1.

The extraction algorithm is based on the lag-window method[5] that is one of $F_0$ determination algorithms. In this method, a pitch structure can be separated from the power spectrum. The desirable smoothed function of $F_0$ reliability can be obtained by incorporating a narrow spectrum band filter on this pitch structure. Here we use Hanning window as a window function on the frequency domain. This $F_0$ reliability function is analyzed per each time frame, and FRF is represented as its temporal sequence shown in the bottom of Figure.1, in which time is passed from the front to the back and horizontal axis has been converted into the logarithmic frequency domain from the time domain. It can be seen that harmonic contour of $F_0$ reliability peaks, which means half pitch contour or double pitch contour, lies in a fixed interval of $\ln 2$. Furthermore, as the number of sampling point on frequency domain is finite in this $F_0$ analysis, the $F_0$ reliability of

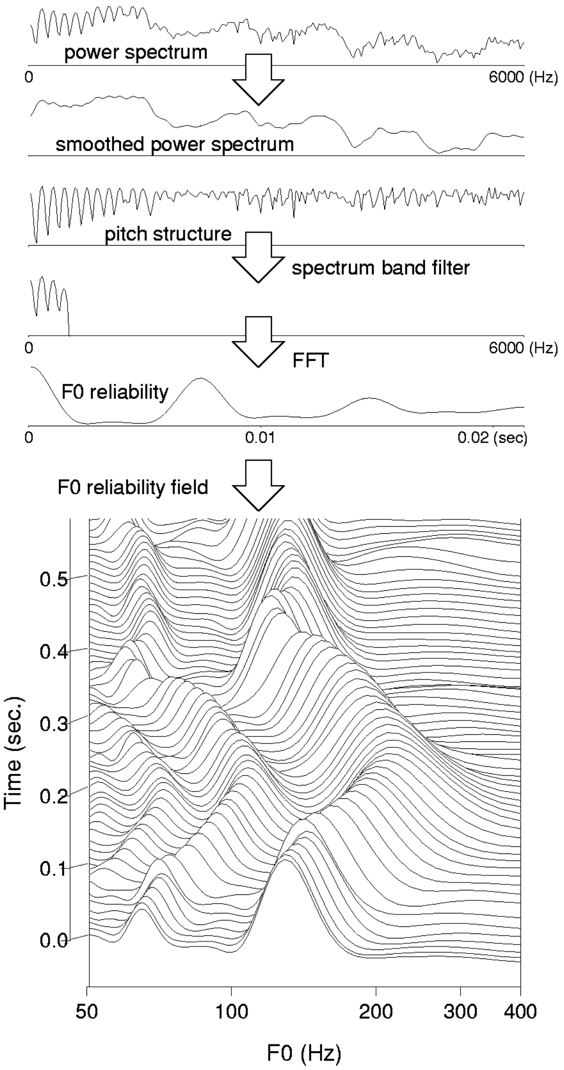


**Figure. 1**: A process of $F_0$ reliability analysis.

arbitrary frequency is determined by using Lagrange interpolation, i.e., by interpolating $N$ samples of $F_0$ reliability near the frequency which we want to obtain. In the following section, we express this FRF as a function $S(t,p)$ with time $t$ and logarithmic frequency $p$.

## 3. ESTIMATION OF PROSODIC COMMANDS ON *F0* CONTOUR GENERATION MODEL

$F_0$ contour generation model which we used in this paper is proposed by Fujisaki[4] and prosodic commands on this model can be estimated by Analysis-by-Synthesis (A-b-S) procedure, i.e., by constructing the best approximation to an observed $F_0$ feature and by examining the closeness of the approximation. A conventional method employs an $F_0$ contour as the observed $F_0$ feature, and the closeness of the approximation is measured by the mean squared error of constructed $F_0$ contour. On the other hand, using FRF as the observed feature, the optimization carried out by maximizing the mean $F_0$ reliability.

The Fujisaki's model is given by following equation:

$$\ln F_0(t) = \ln Fb + \sum_{i=1}^{I} Ap_i Gp(t - T_{0i}) + \sum_{j=1}^{J} Aa_j \left\{ Ga(t - T_{1j}) - Ga(t - T_{2j}) \right\}, \qquad (1)$$

$$Gp(t) = \begin{cases} \alpha^2 t e^{-\alpha t}, & (t \geq 0) \\ 0, & \text{(otherwise)} \end{cases} \qquad (2)$$

$$Ga(t) = \begin{cases} \min[1 - (1 + \beta t)e^{-\beta t}, \theta], & (t \geq 0) \\ 0, & \text{(otherwise)} \end{cases} \qquad (3)$$

where $Gp(t)$ represents the impulse response function of the phrase control mechanism and $Ga(t)$ represents the step response function of the accent control mechanism. The symbols in these equations indicate

| | |
|---|---|
| $Fb$ | : base value of fundamental frequency, |
| $I$ | : number of phrase commands, |
| $J$ | : number of accent commands, |
| $Ap_i$ | : magnitude of the $i$th phrase command, |
| $Aa_j$ | : amplitude of the $j$th accent command, |
| $T_{0i}$ | : timing of the $i$th phrase command, |
| $T_{1j}$ | : onset of the $j$th accent command, |
| $T_{2j}$ | : end of the $j$th accent command, |
| $\alpha$ | : natural frequency of the phrase control mechanism, |
| $\beta$ | : natural frequency of the accent control mechanism, |
| $\theta$ | : relative ceiling level of accent components. |

Here, a set of parameters, which we want to estimate, is defined as

$$\Lambda = (\lambda_1, \lambda_2, \cdots, \lambda_N), \qquad (4)$$

and each $\lambda_n$ is corresponding to some of $Ap_i$, $Aa_j$, $T_{0i}$, $T_{1j}$, $T_{2j}$, and sometimes $Fb$. The parameter $\alpha$ and $\beta$ are assumed to be constant with in an utterance, while $\theta$ is set equal to 0.9. Then, Equation (1) can be replaced with

$$f(\Lambda, t) = \ln F_0(t) \qquad (5)$$

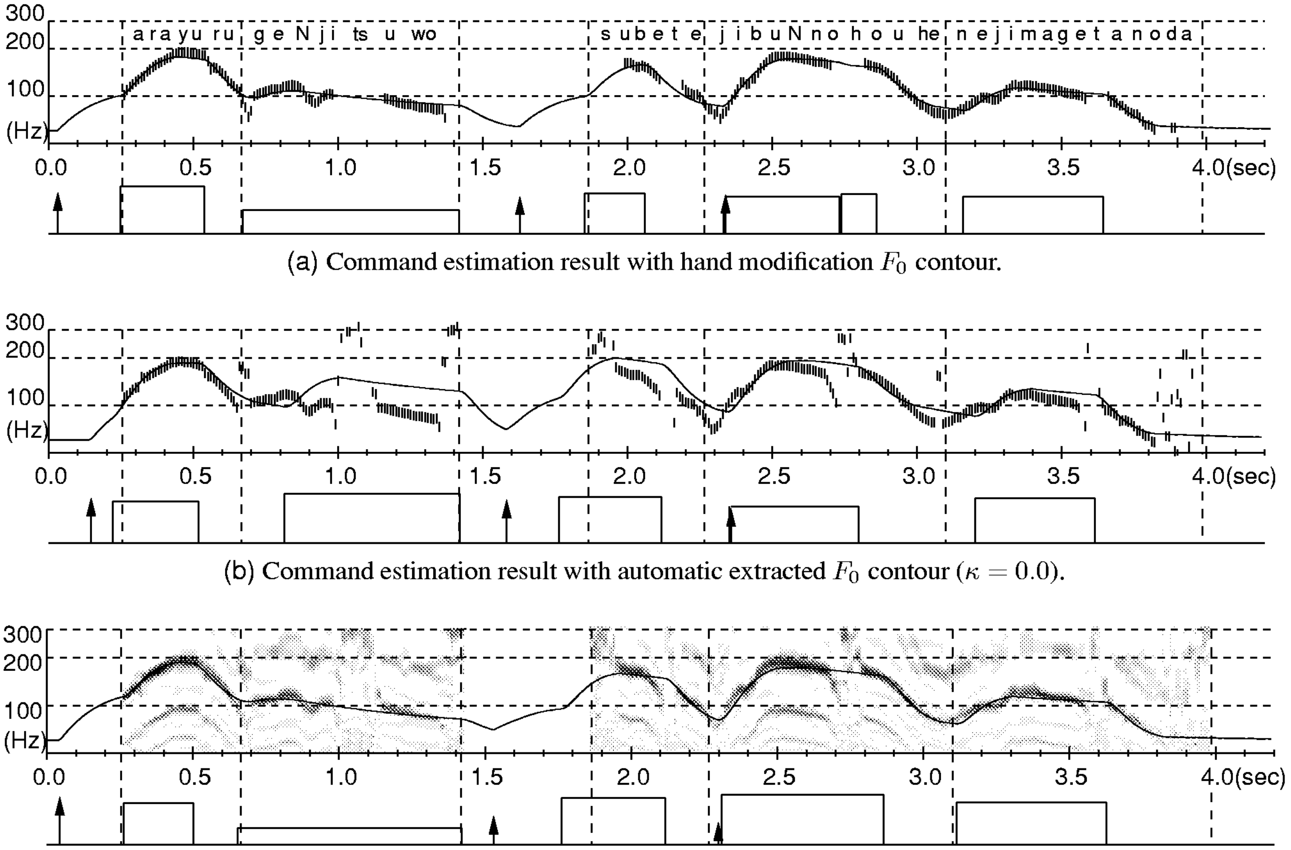
and reliability $R_\Lambda$ of this $F_0$ contour becomes

$$R_\Lambda = \sum_t S(t, f(\Lambda, t)) \qquad (6)$$

by referring to $F_0$ reliability field $S(t,p)$. If the reliability $R_\Lambda$ is not high enough, we have to modify the set of $\Lambda$ to raise the reliability. The modification value of $\lambda_n$ is defined as

$$\Delta\lambda_n = g \sum_t \frac{\partial f(\Lambda, t)}{\partial \lambda_n} \Delta S(t, f(\Lambda, t)), \qquad (7)$$

where $g$ is a step gain, and we use a gradient vector of $S(t, f(\Lambda, t))$ as $\Delta S(t, f(\Lambda, t))$. The definition of gradient vector $(v_t, v_p)$ is described in our reference [1] and we use $v_p$ for the



(a) Command estimation result with hand modification $F_0$ contour.

(b) Command estimation result with automatic extracted $F_0$ contour ($\kappa = 0.0$).

(c) Command estimation result with $F_0$ reliability field.

**Figure. 2**: Examples of estimated prosodic commands. Arrows show the magnitude and the timing of phrase commands. Rectangles show the amplitude and the timing of the accent commands. A solid line in each figure represents an approximation of $F_0$ contour that is constructed by $F_0$ contour generation model. In Fig.(a) and Fig.(b), observed $F_0$ values are plotted with vertical lines, but in Fig.(a), $F_0$ determination errors are corrected and $F_0$ values on unvoiced frames are removed by hand operation. In Fig.(c), $F_0$ reliability is expressed as a density of gray-scaled color. The content of utterance is "*arayuru geNjitsuwo subete jibuNnohouhe nejimagetanoda*" in Japanese.

modification, namely it is defined as

$$\Delta S(t_0, p_0) = \sum_{i=-M}^{M} \sum_{\substack{j=-N \\ j \neq 0}}^{N} w(t_i, p_j) \left( \frac{S(t_i, p_j) - S(t_i, p_0)}{p_j - p_0} \right), \tag{8}$$

where $w(t_i, t_j)$ is a weighting function. Finally, we can obtain the optimized parameter set by iterative computation of the above modification, when an increase of $F_0$ reliability $R_\Lambda$ becomes less than some threshold.

# 4. EVALUATION

## 4.1. Experimental conditions

Speech database used in this evaluation is the ATR's continuous speech database of phoneme balanced 503 Japanese sentences. Out of them, 50 sentences (A group) uttered by 1 male speaker (MHT) are used for the prosodic command estimation. A set of prosodic command parameters that we would estimate is $\{Ap_i, Aa_j, T_{0i}, T_{1j}, T_{2j}\}$, and initial values of those parameters are given by Hirai's technique[6], in which J_ToBI (Japanese Tone and Break Indices) labels are used. The other parameters are fixed and those values are $\ln Fb = 4.1$, $\alpha = 3.0$, $\beta = 20.0$, and $\theta = 0.9$.

As a comparative experiment, we examine a conventional estimation method, in which the observed $F_0$ contour and an optimization criterion of least squared error are used. The observed $F_0$ contour is determined automatically as a temporal sequence of frequency which gives maximum $F_0$ reliability at each time frame $t$, namely a sequence of $p_t = \arg\max_p S(t, p)$. If the $F_0$ reliability of $p_t$ becomes lower than a threshold $\kappa$, i.e., $\max_p S(t, p) < \kappa$, it is regarded that there is no $F_0$ value at that time $t$. Furthermore, we have prepared ideal $F_0$ contours to obtain desirable prosodic commands. Here, ideal $F_0$ contour means

|  | Error† | Score‡ |
|---|---|---|
| Initial set | 0.0401 | 0.089 |
| $F_0$ contour |  |  |
| $(\kappa = 0.0)$ | 0.0624 | 0.078 |
| $(\kappa = 0.1)$ | 0.0618 | 0.080 |
| $(\kappa = 0.2)$ | 0.0500 | 0.124 |
| $(\kappa = 0.3)$ | 0.0189 | 0.391 |
| $(\kappa = 0.4)$ | 0.0164 | 0.476 |
| $(\kappa = 0.5)$ | 0.0212 | 0.423 |
| (ideal) | 0.0097 | 0.437 |
| $F_0$ reliability field |  |  |
|  | 0.0209 | 0.542 |

(†) compared with ideal $F_0$ contour

(‡) $F_0$ reliability / max $F_0$ reliability

**Table. 1**: The approximation error and the $F_0$ reliability score.

the pattern that has no $F_0$ determination error, and those patterns have been created by hand operation of correcting $F_0$ errors.

## 4.2. Results

Examples of estimated prosodic commands are shown in Figure.2. In (b), the $F_0$ contour used for the estimation is automatically extracted with threshold $\kappa = 0.0$, and there are many $F_0$ determination errors, so the approximation of $F_0$ contour is extremely bad. Besides, we can see that timings of commands in (b) are greatly different from the estimation result of (a), in which the ideal $F_0$ contour is used. While, on the estimation (c) with FRF, minute approximation is possible because it is not necessary to consider the correction of $F_0$ errors and there is no lack of $F_0$ value on the observed prosodic feature.

Table.1 shows quantitative results of each estimated command set. The "Error" means the mean squared error in comparison with ideal $F_0$ contour, and the "Score" means the $F_0$ reliability score. Here, the $F_0$ reliability score is the ratio of the accumulated $F_0$ reliability to the accumulated maximum $F_0$ reliability, so it is defined as

$$\text{Reliability Score} = \frac{\sum_t S(t, f(\Lambda, t))}{\sum_t \max_p S(t, p)}. \qquad (9)$$

From the first, a squared error becomes the smallest in the case of the estimation with $F_0$ contour, because its optimization is based on a criterion of least squared error. Similarly, a reliability score becomes the biggest in the case of the estimation with FRF, because it is optimized by maximizing $F_0$ reliability. These are expected results. However, we can see that the result of FRF is relatively good with both a squared error and a reliability score, while the estimation accuracy with $F_0$ contour depends on the $F_0$ determination accuracy.

But, as a problem of command estimation using FRF, it is pointed out that an establishment of initial parameter value becomes much stricter. This is because the number of local maxima reliability score is increased by harmonic peaks of FRF. Therefore, it may be desirable to use those prosodic features properly in case by case, for example, to estimate roughly by using the $F_0$ contour at first step, and to optimize by using the FRF at second step.

## 5. CONCLUSION

We have described that prosodic feature expression like $F_0$ reliability field is more suitable for prosody analyses than $F_0$ contour. The validity is shown in both analyses of detecting prosodic boundaries in previous paper and command estimation of $F_0$ contour generation model in this report. In future works, we would apply FRF for the other prosodic information analyses.

## 6. ACKNOWLEDGMENT

We would like to thank Mr. Toshio Hirai (OGIS-RI Co.,Ltd.) for providing us with the program, which gives initial command set of $F_0$ contour generation model.

## 7. REFERENCES

1. Mitsuru Nakai and Hiroshi Shimodaira. "On representation of fundamental frequency of speech for prosody analysis using reliability function," *EUROSPEECH'97*, pp.243–246, 1997.

2. Edouard Geoffrois. "The multi-lag-window method for robust extended-range F0 determination," *ICSLP-96*, pp.2239–2242, 1996.

3. Serugei Koval, Veronika Bekasova, Michael Khitrov and Andrey Raev. : "Pitch detection reliability assessment for forensic applications," *EUROSPEECH'97*, pp.489–492, 1997.

4. Hiroya Fujisaki and Keikichi Hirose. "Analysis of voice fundamental frequency contours for declarative sentences of Japanese," *J. Acoust. Soc. Jpn (E)*, vol.5, no.4, pp.233–242, 1984.

5. Shigeki Sagayama and Sadaoki Furui. "A technique for pitch extraction by the lag-window method," *Proc. Conf. IEICE*, 1235, 1978 (in Japanese).

6. Toshio Hirai and Norio Higuchi. "Automatic extraction of the Fujisaki model parameters using the labels of Japanese Tone and Break Indices (J_ToBI) system," *Trans. IEICE*, vol.J81-D-II, no.6, pp.1058–1064, 1998 (in Japanese).