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<th>Prediction Problem of Discrete Multiple Time Series (Mathematical Decision Making under uncertainty and ambiguity)</th>
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<td>Iwamura, Kakuzo</td>
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Kyoto University
Prediction Problem of Discrete Multiple Time Series

by

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Abstract

Here we present the way to make a prediction of discrete multiple time series. Our prediction method is easy to implement on Personal Computers and has a flexibility in applying to the real world data. It admit us to take into consideration some circumstances which can't be incorporated in ordinary discrete multiple time series prediction.

Subject areas: Prediction, Planning and Forecasting

1 Introduction

In Odanaka and Iwamura[9], we developed Prediction Theory of Discrete Multiple Time Series. We rewrite here definitions. Let $a_{k}^{(i)} (1 \leq i \leq n)$ be the given $n$ messages with a discrete time index $k$, let $b_{k}^{(i)} (1 \leq i \leq n)$ be the signals and $(b_{k}^{(i)} - a_{k}^{(i)}) (1 \leq i \leq n)$ be noises. Define the auto-correlation functions

$$
\varphi_{ij}^{dd}(v) = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{n=-N}^{N} b_{n}^{(i)} b_{n+v}^{(j)},
$$

$$
\varphi_{ij}^{md}(v) = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{n=-N}^{N} a_{n}^{(i)} b_{n+v}^{(j)},
$$

$$
\varphi_{ij}^{mm}(v) = \lim_{N \to \infty} \frac{1}{2N+1} \sum_{n=-N}^{N} a_{n}^{(i)} a_{n+v}^{(j)},
$$

We assumed here that all these auto-correlation functions exist and that

$$
\varphi_{ij}^{dd}(v) = \varphi_{ji}^{dd}(v)
$$

holds for any $v, i, j$ to derive a DP type algorithm to solve the minimization problem

$$
\min \lim_{N \to \infty} \frac{1}{2N+1} \sum_{k=-N}^{N} \left( a_{k+s}^{(1)} - \sum_{i=1}^{n} \sum_{\tau=0}^{M} A_{i}(\tau)b_{k-\tau}^{(i)} \right)^{2}
$$
where \( A_i(\tau)(1 \leq i \leq n, 0 \leq \tau \leq M) \) are variables to be determined. We easily see that for a stationary multiple time series assumptions (1),(2), (3) hold, whereas assumption (4) doesn't always.

Although there are some algorithms as for the prediction of a single time series in the books such as J.D.Hamilton[5], H.Tong[11], we don't have so much ones as for a multiple time series. Yet, we think that the existence of the functions in (1),(2),(3) and the symmetric condition (4) are not so trivial. If we use Carayannis, Kalouptsidis and Manolakis Algorithm[3] then we can drop condition(4). Still we are restricted to treat just only discrete multiple time series satisfying assumptions (1),(2),(3). We think that the DP algorithm in [9] will be useful for predicting in a long range for almost stationary multiple time series with symmetric condition.

Here we consider a multiple time series which is neither stationary nor symmetric. Hence, generally speaking, we can't make a prediction in a long range, because such a long range predicton will be proved incorrect in the future by a real data. For a bad natured multiple time series, we think that our Prediction Method is more useful in practice. So, we are dealing with a multiple time series for which AIC[1] is not applicable. We can find that there are some other results which were obtained in a similar spirit like ours. The reader can consult Kitagawa and Akaike[6], Chang and Lee[4], Zhao and Iwamura and Liu[13] for this purpose.

## 2 Prediction Problem of Discrete Multiple Time Series

On the contrary to Odanaka and Iwamura[9], we don't assume the existence of the autocorrelation functions. So, we deal with signals \( b_k^{(i)}(1 \leq i \leq n) \) only. We don't care for \( a_k^{(i)}(1 \leq i \leq n) \). Let's predict signal \( j \) at time \( t + 1 \) and so let's write the predicted value \( \hat{b}_{t+1}^{(j)}. \) Consider a linear combination of \( b_k^{(i)}(1 \leq i \leq n, s \leq k \leq t, 1 \leq \tau \leq M) \), i.e.,

\[
\sum_{i=1}^{n} \sum_{\tau=1}^{M} a_{i\tau} b_{k-\tau}^{(j)}
\]

for a positive integer \( M. \) Then let

\[
I(M) = \sum_{k=s}^{t} \left( b_k^{(j)} - \sum_{i=1}^{n} \sum_{\tau=1}^{M} a_{i\tau} b_{k-\tau}^{(i)} \right)^2
\]

, where \( s < t \) and we have signal observations \( b_k^{(i)}(1 \leq i \leq n, s-M \leq k \leq t) \). Let \( M_0 \) be a given positive integer. For each \( M = 1, 2, \cdots, M_0 \), calculate \( a_{i\tau} = \hat{a}_{i\tau}(1 \leq i \leq n, 1 \leq \tau \leq M) \) at which \( I(M) \) takes its minimum. Then plot the predicted value \( \hat{b}_{t+1}^{(j)}(M) \) for each \( M, 1 \leq M \leq M_0 \). We call this prediction model Short Range Fuzzy Prediction Model-Combined Model of Autoregressive type Prediction Model and Bellman Model, because we get \( M_0 \) predicted values for \( \hat{b}_{t+1}^{(j)} \) using full information of \( b_k^{(i)}(1 \leq i \leq n, s-M_0 \leq k \leq t) \). We use the term Fuzzy because we get \( M_0 \) predicted values with different residuuals \( I(M), M = 1, 2, \cdots, M_0 \).

If we take a linear combination of \( b_k^{(i)}(1 \leq i \leq n, i \neq j, s \leq k \leq t, 1 \leq \tau \leq M) \), then we get a Bellman Model in Bellman[2]. Lastly, if we take a linear combination of \( b_k^{(j)}(1 \leq \tau \leq M) \), then we get a traditional Autoregression type Model, which uses only information of itself. Let's consider the situation where two persons are disputing
each other what will be the most likely value for $b_{t+1}^{(1)}$ at time $t$. One predicts $b_{t+1}^{(1)}$ based on the observation $b_{k}^{(1)}$, while the other predicts $b_{t+1}^{(1)}$ based on the observation $b_{k}^{(2)}$ because he thinks that $b_{k}^{(2)}$ dominates $b_{k}^{(1)}$ and so insists that his predicted value be better with different predicted value. In case their values differ largely nobody can determine the predicted value. Furthermore, as is the case for time series data which come from economy, it is sometimes very difficult to determine from which time point to which time point should we take information in multiple time series data. In such situation, the two are advised to make compromise first on time interval from which the two should take information. Then go into the Short Range Fuzzy Prediction-Combined Model of Autoregressive type Prediction Model and Bellman Model.

3 An Example

We take two Japanese land price indexes $b_{k}^{(1)}$ and $b_{k}^{(2)}$ for 20 years ($1 \leq k \leq 20$). $b_{k}^{(1)}$ is a land price index of down town Utsunomiya(merchant use), where $b_{k}^{(2)}$ is a land price indexof Suginami ward Tokyo(residential use). Hence $n=2$. Set $1 < s < t \leq 20$ and $M_{0}$ so that $1 \leq s-M_{0}$ holds.In this case, Mayor of Utsunomiya city and its resident living in down town Utsunomiya are disputing on the predicted land price index. Then what model would be the best and what is its predicted value? Writing

$$
\chi_{i\tau} = \sum_{k=s}^{t} b_{k}^{(1)} b_{k-\tau}^{(i)},
$$

$$
\varphi_{ij}(\tau, \sigma) = \sum_{k=s}^{t} b_{k-\tau}^{(1)} b_{k-\sigma}^{(j)} (1 \leq i, j \leq 2; 1 \leq \tau, \sigma \leq M)
$$

we have to maximize

$$
\hat{E}_{M} = 2 \sum_{i=1}^{2} \sum_{\tau=1}^{M} a_{i\tau} \chi_{i\tau} - \sum_{i,j=1}^{2} \sum_{\tau,\sigma=1}^{M} a_{i\tau} a_{j\sigma} \varphi_{ij}(\tau, \sigma)
$$

, where $a_{i\tau}$ ($1 \leq i \leq 2; 1 \leq \tau \leq M$) are variables whose values should be determined. Differetiating (10) by $a_{i\tau}$, we get

$$
\sum_{\tau=1}^{M} ((\varphi_{11}(\tau, \tau_{0}) + \varphi_{11}(\tau_{0}, \tau)) a_{1\tau} + (\varphi_{21}(\tau, \tau_{0}) + \varphi_{12}(\tau_{0}, \tau)) a_{2\tau}) = 2\chi_{1\tau_{0}}
$$

$$
\sum_{\tau=1}^{M} ((\varphi_{12}(\tau, \tau_{0}) + \varphi_{21}(\tau_{0}, \tau)) a_{1\tau} + (\varphi_{22}(\tau, \tau_{0}) + \varphi_{22}(\tau_{0}, \tau)) a_{2\tau}) = 2\chi_{2\tau_{0}}
$$

Here, we have $2M$ equations with $2M$ unkowns ($(a_{1\tau}, a_{2\tau})^{t}, 1 \leq \tau \leq M$. In order to successively predict $b_{t+1}^{(1)}$ for $M = 1, 2, \ldots, M_{0}$, i.e., in a fuzzy sense, we use Carayannis,Kalouptsidis and Manolakis algorithm[3]. Computational results would be shown at the end of the paper.
4 Acknowledgment

This research was financially supported by President of Josai University. Computational works was carried out by the author’s student Mr.T.Shibahara. Although the author invented Short Range Fuzzy Prediction Model by his own thinking, Prof. Odanaka of Hokkaido Information University let me know the result of R.Bellman[2]. The author would like to express his hearty thanks to all of them.

References

Autoregression type Model

Input data $s = 16$ $t = 19$ $m0 = 4$

$b(1, 1) = 1.3$ $b(2, 1) = 1$

$b(1, 2) = 1.3$ $b(2, 2) = 1.1$

$b(1, 3) = 1.3$ $b(2, 3) = 1.3$

$b(1, 4) = 1.3$ $b(2, 4) = 1.5$

$b(1, 5) = 1.4$ $b(2, 5) = 1.8$

$b(1, 6) = 1.5$ $b(2, 6) = 2.5$

$b(1, 7) = 1.6$ $b(2, 7) = 2.7$

$b(1, 8) = 1.7$ $b(2, 8) = 2.8$

$b(1, 9) = 1.75$ $b(2, 9) = 2.9$

$b(1, 10) = 1.75$ $b(2, 10) = 3.2$

$b(1, 11) = 1.8$ $b(2, 11) = 7.7$

$b(1, 12) = 2.4$ $b(2, 12) = 9.5$

$b(1, 13) = 2.45$ $b(2, 13) = 8.6$

$b(1, 14) = 3.4$ $b(2, 14) = 8.3$

$b(1, 15) = 4.4$ $b(2, 15) = 8.2$

$b(1, 16) = 4.4$ $b(2, 16) = 7.2$

$b(1, 17) = 4$ $b(2, 17) = 5.4$

$b(1, 18) = 3.7$ $b(2, 18) = 4.6$

$b(1, 19) = 3.4$ $b(2, 19) = 4.2$

\[ BHAT[M], \ i[M], \ for \ m = 1: \ 3.19772 \ 0.0978585 \]

\[ a[1] : 1.19118 \]

\[ a[2] : -0.257021 \]

\[ BHAT[M], \ i[M], \ for \ m = 2: \ 3.09903 \ 0.018042 \]

\[ a[1] : 1.30016 \]

\[ a[2] : -0.486885 \]

\[ a[3] : 0.13196 \]

\[ BHAT[M], \ i[M], \ for \ m = 3: \ 3.14766 \ 0.00649255 \]

\[ a[1] : 1.49012 \]

\[ a[2] : -0.843548 \]

\[ a[3] : 0.476912 \]

\[ a[4] : -0.190382 \]

\[ BHAT[M], \ i[M], \ for \ m = 4: \ 3.01526 \ 2.73295e-26 \]
Bellman Model
Input data $S = 16$ $T = 19$ $MO = 4$ $\tau_1 = 1$

\[
\begin{align*}
B(1, 1) &= 0.3 \quad B(2, 1) = 1 \\
B(1, 2) &= 1.3 \quad B(2, 2) = 1.1 \\
B(1, 3) &= 1.3 \quad B(2, 3) = 1.3 \\
B(1, 4) &= 1.3 \quad B(2, 4) = 1.5 \\
B(1, 5) &= 1.4 \quad B(2, 5) = 1.8 \\
B(1, 6) &= 1.5 \quad B(2, 6) = 2.5 \\
B(1, 7) &= 1.6 \quad B(2, 7) = 2.7 \\
B(1, 8) &= 1.7 \quad B(2, 8) = 2.8 \\
B(1, 9) &= 1.75 \quad B(2, 9) = 3.2 \\
B(1, 10) &= 1.75 \quad B(2, 10) = 3.2 \\
B(1, 11) &= 1.8 \quad B(2, 11) = 7.7 \\
B(1, 12) &= 2.4 \quad B(2, 12) = 9.5 \\
B(1, 13) &= 2.45 \quad B(2, 13) = 8.6 \\
B(1, 14) &= 3.4 \quad B(2, 14) = 8.3 \\
B(1, 15) &= 4.4 \quad B(2, 15) = 8.2 \\
B(1, 16) &= 4.4 \quad B(2, 16) = 7.2 \\
B(1, 17) &= 4.4 \quad B(2, 17) = 5.4 \\
B(1, 18) &= 3.7 \quad B(2, 18) = 4.6 \\
B(1, 19) &= 3.4 \quad B(2, 19) = 4.2 \\
B(1, 20) &= 0 \quad B(2, 20) = 0 \\
\end{align*}
\]

\[R =
\begin{align*}
169.4 & \quad 190.82 & \quad 207.68 & \quad 222.36 \\
190.82 & \quad 217.13 & \quad 237.36 & \quad 253.41 \\
207.68 & \quad 237.36 & \quad 261.93 & \quad 280.18 \\
222.36 & \quad 253.41 & \quad 280.18 & \quad 300.34 \\
\end{align*}
\]

\[D =
\begin{align*}
-100.5 & \quad -114.32 & \quad -125.86 & \quad -134.79 \\
\end{align*}
\]

\begin{align*}
\text{BHAT}_M, \text{i}[M]\text{ for } M = 1 & : 2.49174 \quad 0.986328 \\
\text{BHAT}_M, \text{i}[M]\text{ for } M = 2 & : 2.42491 \quad 0.419351 \\
\text{BHAT}_M, \text{i}[M]\text{ for } M = 3 & : 2.69081 \quad 0.000155738 \\
\text{BHAT}_M, \text{i}[M]\text{ for } M = 4 & : 2.39801 \quad 8.21925e-22 \\
\end{align*}

\textbf{Figure 2}
Proposed Method

<table>
<thead>
<tr>
<th>Input data</th>
<th>S= 18</th>
<th>T= 19</th>
<th>MC= 4</th>
</tr>
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<tr>
<td>B(1, 1)</td>
<td>1.3</td>
<td>B(2, 3)</td>
<td>1.0</td>
</tr>
<tr>
<td>B(1, 2)</td>
<td>1.3</td>
<td>B(2, 2)</td>
<td>1.1</td>
</tr>
<tr>
<td>B(1, 3)</td>
<td>1.3</td>
<td>B(2, 3)</td>
<td>1.3</td>
</tr>
<tr>
<td>B(1, 4)</td>
<td>1.4</td>
<td>B(2, 4)</td>
<td>1.5</td>
</tr>
<tr>
<td>B(1, 5)</td>
<td>1.4</td>
<td>B(2, 5)</td>
<td>1.8</td>
</tr>
<tr>
<td>B(1, 6)</td>
<td>1.5</td>
<td>B(2, 6)</td>
<td>2.5</td>
</tr>
<tr>
<td>B(1, 7)</td>
<td>1.6</td>
<td>B(2, 7)</td>
<td>2.7</td>
</tr>
<tr>
<td>B(1, 8)</td>
<td>1.7</td>
<td>B(2, 8)</td>
<td>2.8</td>
</tr>
<tr>
<td>B(1, 9)</td>
<td>1.8</td>
<td>B(2, 8)</td>
<td>2.9</td>
</tr>
<tr>
<td>B(1, 10)</td>
<td>1.8</td>
<td>B(2, 10)</td>
<td>3.2</td>
</tr>
<tr>
<td>B(1, 11)</td>
<td>1.8</td>
<td>B(2, 11)</td>
<td>7.7</td>
</tr>
<tr>
<td>B(1, 12)</td>
<td>2.4</td>
<td>B(2, 12)</td>
<td>9.5</td>
</tr>
<tr>
<td>B(1, 13)</td>
<td>2.5</td>
<td>B(2, 13)</td>
<td>8.6</td>
</tr>
<tr>
<td>B(1, 14)</td>
<td>3.4</td>
<td>B(2, 14)</td>
<td>8.3</td>
</tr>
<tr>
<td>B(1, 15)</td>
<td>4.4</td>
<td>B(2, 15)</td>
<td>8.2</td>
</tr>
<tr>
<td>B(1, 16)</td>
<td>4.4</td>
<td>B(2, 16)</td>
<td>7.2</td>
</tr>
<tr>
<td>B(1, 17)</td>
<td>4.0</td>
<td>B(2, 17)</td>
<td>5.4</td>
</tr>
<tr>
<td>B(1, 18)</td>
<td>3.7</td>
<td>B(2, 18)</td>
<td>4.6</td>
</tr>
<tr>
<td>B(1, 19)</td>
<td>3.4</td>
<td>B(2, 19)</td>
<td>4.2</td>
</tr>
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\[ R = 0.13862000 + 03 \times 0.21276000 + 03 \times 0.13344000 + 03 \times 0.24276000 + 03 \]

\[ R = 0.11924000 + 03 \times 0.26760000 + 03 \times 0.10244000 + 03 \times 0.28836000 + 03 \]

\[ R = 0.21276000 + 03 \times 0.33880000 + 03 \times 0.20344000 + 03 \times 0.38164000 + 03 \]

\[ R = 0.17714000 + 03 \times 0.41536000 + 03 \times 0.15184000 + 03 \times 0.44472000 + 03 \]

\[ R = 0.13344000 + 03 \times 0.20344000 + 03 \times 0.13256000 + 03 \times 0.23516000 + 03 \]

\[ R = 0.12100000 + 03 \times 0.20128000 + 03 \times 0.10500000 + 03 \times 0.27892000 + 03 \]

\[ R = 0.24276000 + 03 \times 0.30184000 + 03 \times 0.23516000 + 03 \times 0.43426000 + 03 \]

\[ R = 0.20731000 + 03 \times 0.47472000 + 03 \times 0.17850000 + 03 \times 0.50682000 + 03 \]

\[ R = 0.17714000 + 03 \times 0.17714000 + 03 \times 0.12050000 + 03 \times 0.20731000 + 03 \]

\[ R = 0.12585000 + 03 \times 0.23410000 + 03 \times 0.97060000 + 02 \times 0.25023000 + 03 \]

\[ R = 0.20731000 + 03 \times 0.41536000 + 03 \times 0.26128000 + 03 \times 0.47472000 + 03 \]

\[ R = 0.23410000 + 03 \times 0.50238000 + 03 \times 0.20107000 + 03 \times 0.56036000 + 03 \]

\[ R = 0.10244000 + 03 \times 0.15184000 + 03 \times 0.10300000 + 03 \times 0.17650000 + 03 \]

\[ R = 0.97060000 + 02 \times 0.20107000 + 03 \times 0.85385000 + 02 \times 0.21834000 + 03 \]

\[ R = 0.28836000 + 03 \times 0.44472000 + 03 \times 0.27892000 + 03 \times 0.50682000 + 03 \]

\[ R = 0.25023000 + 03 \times 0.56036000 + 03 \times 0.21834000 + 03 \times 0.60098000 + 03 \]

\[ d=0.1290+03-0.2100+03-0.1250+03-0.2290+03 \]

\[ d=0.1110+03-0.2520+03-0.9580+02-0.2700+03 \]

BHAT (M), I (M) FOR M= 1 0.30749D+01 0.47146D-01

BHAT (M), I (M) FOR M= 2 0.30552D+01 0.42970D-23

BHAT (M), I (M) FOR M= 3 0.30552D+01 0.43409D-23

BHAT (M), I (M) FOR M= 4 0.30552D+01 0.43370D-23

**Figure 3**