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A Frame-Based Combining Method for Telemetry Data

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Abstract:
Ground stations in multiple receiver telemetry systems receive flight data independently in different locations. In these systems, flight data from different sources should be selected in the most accurate combination. There has been word-based telemetry data combining methods in the literature. These methods select each word in telemetry frame independently. In this paper we introduce a frame-based selection method, considering that errors in telemetry systems affect many words in a frame at once. The method we introduce selects all the words in a frame from one source. We compare the effectiveness of the two combining methods using real flight data and demonstrate the superiority of our method.

Key words: flight data processing, data combining, multiple receiver telemetry, post-process, flight test

Introduction

Telemetry systems are used in launch vehicles, missiles and unmanned air vehicles to gather flight information regarding the vehicle such as position and velocity, and to gather scientific data such as temperature, pressure and vibration in order to use in flight analyses [1]. In telemetry systems, data that is collected from sensors and electronic equipment is modulated and transmitted from on-board antennas. In the ground station, telemetry data is received, demodulated and recorded to be analyzed later in the post-process. In cases where flight trajectory goes out of the coverage area of the ground station, more than one ground station at different locations should be used in order to cover the entire flight trajectory and to establish a telemetry link without communication loss.

In multiple receiver telemetry systems each ground station record telemetry data independently. Thus, telemetry data from different ground stations should be selected in the most accurate combination. Combining methods can be divided into two categories regarding when the process is applied: pre-detection combining methods that combine telemetry data in the RF level, post-detection combining methods that selects the strongest signal in the digital level. Pre-detection methods use weighting factor system by assigning a gain to each ground station and averaging according to the gain factors. The gain factors can be assigned according to the Automatic Gain Control (AGC) values of the receivers [2] or simple averaging can be applied by assigning the same gain factor to each ground station. Urech suggests a pre-detection combining method by assigning gain factors according to the Signal to Noise Ratio (SNR) of the telemetry signals [3]. In order to realize pre-detection combining method, a network that can collect real-time data of each ground station into one place should be established between ground stations. The network should handle synchronization problems in real time where the distance between ground stations is large. In addition to that, mobile telemetry ground stations make it difficult to use network infrastructure of the area. Therefore, pre-detection combining method is generally used in applications where ground stations / antennas are close to each other. Furthermore, there are Commercial of the Shelf (COTS) products that combine different telemetry signals to improve signal quality by using spatial diversity.

It is more practical to use post-detection methods where the distance between ground stations is large. There has been word-based post-detection telemetry data combining methods in the literature. Wilson proposed a word-based data combining method that uses correlation between successive samples [4]. Since most of the telemetry data is expected not to change radically between successive samples, the combining method selects the station that gives the least difference. In this study, Wilson's method is improved by performing combining frame-based instead of word-based.

Combining Methods

In order to improve the combining method efficiency, a pre-knowledge about the telemetry link or ground stations should be used as a priori. SNR values of the telemetry signals or AGC values of the ground stations can be used as a priori. In this paper, correlation between successive samples, and the information that errors in telemetry links tend to last longer than a word are used as a priori.

A typical telemetry data is composed of avionic information such as current, voltage and software mode indicator, and sensor data such as temperature, acceleration, vibration and pressure. These data ordinarily have high autocorrelation function output. For example a temperature sensor that measures air temperature is supposed to give output that does not involve high peaks. Therefore if large difference in the temperature output is observed in telemetry data it is accepted as an error. In addition to that, oversampled sensor outputs increase correlation between successive samples. Moreover, some of the data in the telemetry frame remain constant through the flight for reasons such as bit-synchronization and frame-synchronization. Therefore, changes in such constant words indicate errors. For the very reason, there should only be small differences between successive samples. Hence, Minimum Mean Square Error (MMSE) between successive samples can be used as the selection criteria.

Let N be the number of ground station and Φ_1, Φ_2, ..., Φ_N be telemetry data series. Then $\Phi_i(f, w)$ denotes the w.th word of f.th frame belonging to station i. At first, mod of the word is selected as follows:

$$Q(f, w) = mod(\, \Phi_1(f, w), \Phi_2(f, w), \ldots, \Phi_N(f, w)\,) \quad (1)$$

$$q(f, w) = Q(f, w) \quad (2)$$

$Q(f, w)$ denotes the mod of the word and $q(f, w)$ denotes the selected word. If there is only one mod for the word, the word obtained from eq. (1) is selected as indicated in eq. (2). In the case that there are multiple mods of the word, another method should be used. For example, if 3 out of 4 ground stations have the same word, then the predominant word can be selected. However, in the event of 2 stations have same word and other 2 stations have another word, stations give 2 mods and another method should be applied. In such cases word-based selection methods based on MMSE are used in the literature. The method takes into account that telemetry data does not vary in a large extend between successive samples and selects the word from the station that gives the least MMSE. Word-based method employs the selection to each word independently.

In this paper, the selection method is implemented as frame-based. Different from the word-based method, the proposed algorithm selects all the words in a frame from only one ground station. In order to clarify differences of the two methods, word-based method in the literature is reviewed and the proposed frame-based method is analyzed.

Word-Based Method

The method Wilson suggests selects each word in a frame independently. Let d_m be the distance of a word to its neighboring samples, the method applies each mod obtained from eq. (1) to eq. (3).

$$q(f, w) = \underset{m}{\arg min}\{\, d_m\!: \mathrm{m} \in Q(f, w)\,\} \quad (3)$$

Distance of a word to its neighboring samples is calculated as follows:

$$d_m = [\Phi_m(f, w) - \Phi_m(f\text{-}1, w)]^2 + [\Phi_m(f, w) - \Phi_m(f+1, w)]^2 \quad (4)$$

For each ground station, distances obtained from eq. (4) are compared as indicated in eq. (3), and the word whose station has minimum distance is selected. Word-based method can select each word in a frame from different stations. For example,

$$q(f, w\text{-}1), q(f, w), q(f, w+1)$$

word series can be selected as

$$\Phi_2(f, w\text{-}1), \Phi_1(f, w), \Phi_2(f, w+1).$$

On the contrary, frame-based method selects each word in a frame from only one station. Considering the previous example, the word series

$$q(f, w\text{-}1), q(f, w), q(f, w+1)$$

should be selected as

$$\Phi_1(f, w\text{-}1), \Phi_1(f, w), \Phi_1(f, w+1)$$

or

$$\Phi_2(f, w\text{-}1), \Phi_2(f, w), \Phi_2(f, w+1).$$

Frame-Based Method

Proposed frame-based method calculates distances of the words to their neighboring samples in a same way as word-based method applies using eq. (4). Then, cumulative distance of the frame for each station is calculated as in eq. (5).

$$q(f,\, w) = \underset{m}{\arg min}\{\, \textstyle\sum_k\, d_m\colon \mathrm{m} \in Q(f,\, w)\,\} \qquad (5)$$

The station that produces the minimum cumulative distance is selected for all of the words in the considered frame.

The motivation behind the cumulative distance approach is that if an error occurs in a frame, probability of another error occurring in the same frame is high. This is because error sources in the telemetry links do not consist of only Gaussian noise. Error sources such as multipath fading and synchronization loss cause multiple word errors in the frame. Since such error causes are commonly observed in telemetry systems, it can be used as a priori in the combining method to increase performance.

Flight Test Results

In order to demonstrate efficiency, both of the methods are implemented on 6 different flight test data. In the analysis, errors are detected by Cyclic Redundancy Check (CRC) codes of the frames.

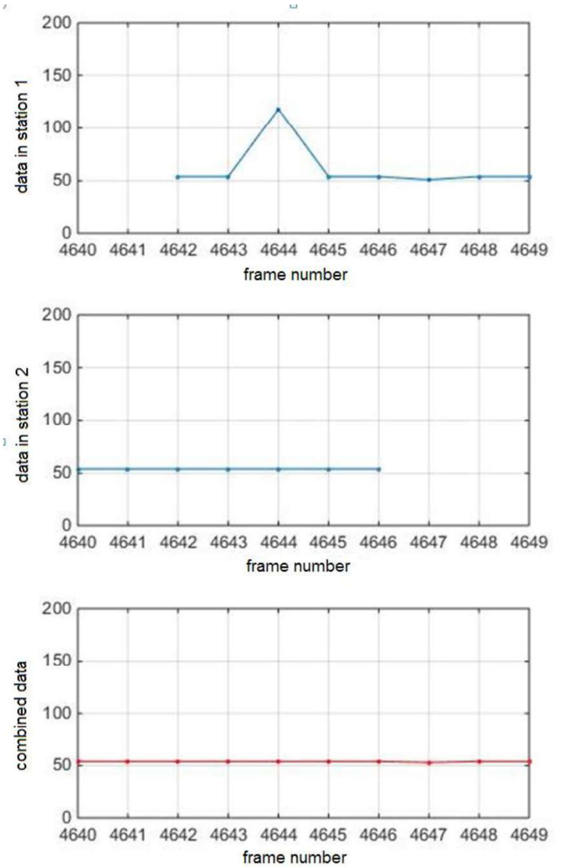

Fig.1: Temperature sensor output in two ground stations and word-based combining method output

Figure 1 illustrates a temperature sensor output for several frames in 2 stations and also word-based combining method output. As the figure shows, 2 stations have different values for temperature data in 4644. frame. Therefore a selection method should be applied to the word, either word-based or frame-based. If the word-based selection method is used, d_m for the stations is calculated from eq. (4) as follows:

Station1: $(54\text{-}118)^2 + (54\text{-}118)^2 = 8192$

Station2: $(54\text{-}54)^2 + (54\text{-}54)^2 = 0$

As a result, station that gives the minimum distance, second station, should be selected. However, for the frame-based selection method, all of the words in the frame should be considered. For the words that two stations do not agree on in the 4644. frame, d_m should be calculated and cumulative distance should be compared for 2 stations.

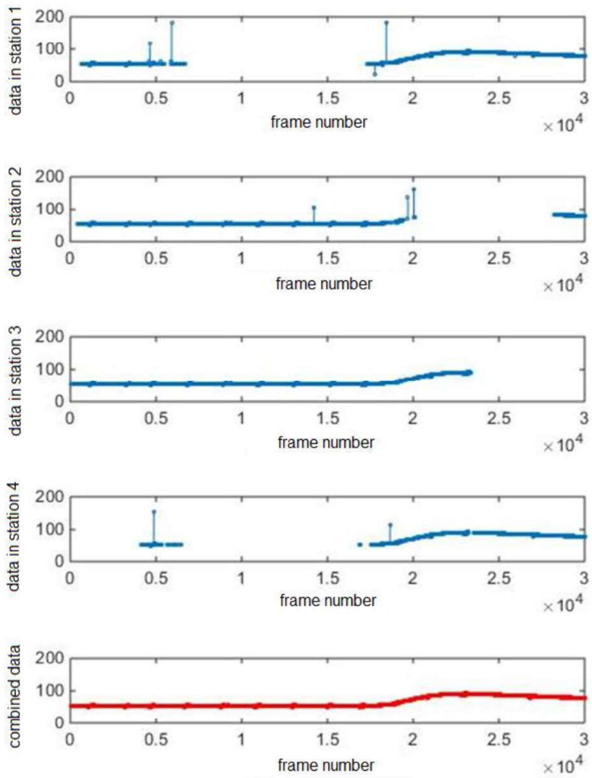

Fig.2: Temperature sensor output throughout the flight in 4 stations and frame-based combining method output

Figure 2 demonstrates a temperature sensor output throughout the flight in 4 stations and final data after frame-based combining method is applied. Since the ground stations do not cover the entire flight trajectory, telemetry link loss occurs occasionally. In addition to that, errors take place in individual stations. However in the combined data, a smooth and continuous sensor data is obtained.

Flight data from 4 ground stations that are located at 4 different locations are collected and combined with both word-based according to eq. (3) and frame-based according to eq. (5). Since the combining methods are post-processes, processing time is not considered in this study.

For all of the 6 flight tests the same frame format is used (e.g. frame length, synchronization word, CRC equation). Error occasion in the frame is checked by CRC code and number of frames that contains errors is calculated for each flight test. Frame Error Rate (FER), the ratio of errored frame to total number of frames, is used as criteria for the comparison of methods.

Tab.1: Frame error rates of combining methods

Flight Test No	**Word-Based FER (%)**	**Frame-Based FER (%)**
Test-1	5.5×10^{-3}	1.7×10^{-3}
Test-2	10^{-2}	3.7×10^{-3}
Test-3	1.3×10^{-2}	4.7×10^{-3}
Test-4	4×10^{-3}	8.1×10^{-4}
Test-5	2.4×10^{-2}	4.8×10^{-3}
Test-6	10^{-2}	2.2×10^{-3}

In all flight tests the proposed frame-based combining method produces better performance, resulting in 2.7 to 5.1 times lower frame error rates. It is turn out that the proposed frame-based combining method is a strong data combining method candidate for multiple receiver telemetry systems.

Conclusions

In this study, data combining methods that are used in telemetry applications are investigated and a new frame-based method is proposed instead of the word-based combining methods in the literature, considering that errors in telemetry systems affect many words in a frame at once. The two methods are compared using real flight data, and the results demonstrate the superiority of the proposed method.

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