An Improved Method for the Determination of Airplane Radial Velocity Using Doppler Shift

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Abstract

In this research velocity of moving airplane from its recorded digital sound is introduced. The data of sound file is sliced into several frames using overlapping partitions. Then the array of each frame is transformed from time domain to frequency domain using Fourier Transform (FT). To determine the characteristic frequency of the sound, a moving window mechanics is used, the size of that window is made linearly proportional with the value of the tracked frequency. This proportionality is due to the existing linear relationship between the frequency and its Doppler shift. An algorithm was introduced to select the characteristic frequencies, this algorithm allocates the frequencies which satisfy the Doppler relation, beside that the tracked frequencies was chosen to be the most occurred frequencies in the power spectrum. Several sizes of the overlap windows have been tested to study the effect of window size on the accuracy of the determined radial velocity of the moving airplane. The obtained results have been compared with the corresponding results of non overlapped window. The accuracy of the results was assessed using two criteria, the first is the closeness of the curves of the determined radial velocities versus time for the case of overlapped and non-overlapped window; the closer curves indicate better results. The second used criteria is the Root Mean Square Error (RMSE), it is used to determine the degree a method for determining the radial of linearity of the relationship between Doppler shift and characteristic frequencies, the least values of (RMSE) signify better results are obtained.

Keywords
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طريقة مطورة لتحديد السرعة النصف قطرية للطائرة بأستخدام أزاحة دوبلر

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الخلاصة

في هذا البحث تم أستخدام طريقة لأيجاد السرعة النصف قطرية لطائرة متحركة من تسجيلها الصوتي الرقمي. المعلومات للفايل الصوتي تم تقطيعها الى مقاطع متعددة باستخدام التقطيع المتشابك، ثم المصفوفة لكل مقطع تم تحويلها من الجال الزمني الى المجال الترددي باستخدام تحويل فورير. لأيجاد التردد المميز للصوت تم أستخدام ميكانيكية النافذة المتحركة، حيث جعل حجم النافذة يتناسب طرديا مع قيمة التردد الذي يتم ملاحقته. ذلك التناسب يعود الى العلاقة الخطية بين التردد وازاحة دوبلر له. تم أستخدام خوارزمية لأنتقاء الترددات المميزة، هذةالخوارزمية تحدد الترددات التي تحقق اضافة لذلك الترددات الملاحقة تم أختيارها علىاساس أنها الترددات الأكثر حصولا في طيف القدرة. عدة قيم للنوافذ المتشابكة تم أختبارها لدراسة تأثير حجم النافذة على دقة ايجاد السرعة النصف قطرية للطائرةالمتحركة. تم مقارنة النتائج المستحصلة مع نتائج النافذة غير المتشابكة. قيمت دقة النتائج على أساس عاملين، ألأول تقارب المنحنيات للسرع النصف قطرية كدالة للزمن في حالة النوافذ المتشابكة وغيرالمتشابكة؛ المنحنيات المتقاربة أفضل. العامل الثاني هو جذر معدل مربع الخطأ؛ حيث أستخدم لأيجاد درجة الخطية بين العلاقة بين أزاحة دوبلر والترددات المميزة، كلما كانت قيم جذر معدل مربع الخطأ أقل دلت على أن النتائج أفضل.

Introduction

A common method of obtaining information about remote object is to bounce a wave signature from it. The sound based methods are divided into two categories, active and passive. In this research the passive system was used because it emits no energy; therefore it is ideal for covert operations. The most important applications of passive systems are in military surveillance, they can detect and track the moving wave sources [1]. One of the techniques that depend on Doppler shift phenomena is the passive Doppler tracking; they are catalogued into two dual classes: ***(i)*** positioning and velocity computing of the tracked source and ***(ii)*** navigation (if the source, of known position and dynamics, is a navigational aid) [2].

It is benefit to list some of the related work in this field like: Al.Hyali which had used Histogram Summation Method to determine the characteristics frequencies. This method is based on the stability attribute of the characteristic frequencies. The degree of the characteristic frequency stability was considered as "the percentage of the occurrence of some frequency within certain tolerance; (i.e., shift window)" [3]. Kuang & Morris have shown that an ultrasonic tracking system using the Doppler effect can potentially track high-speed robot motion very accurately [4]. Goto & Sato have reported the results of conducted analysis for the motion characteristics (distance, bearing, velocity, and course) and sound source frequency determined after the eliminate by Doppler effect from sounds radiated by the propulsion system of unknown object in sea [5].

In this research we make use of the Doppler shift by developing an algorithm that recognizes the characteristic frequencies versus their shift and use it to calculate the radial velocity of airplane.

Theoretical Model

The relationship describes the Doppler effect is given as follows:

$$\Delta f = f\,\frac{\pm V_R}{V_{sd} \mp V_R} \qquad (1)$$

Where, Δf is difference between the frequency of a certain time frame relative to the previous one, f is the fundamental frequency of source in (Hz), V_{sd} is the velocity of the sound, and V_R the radial velocity component of the moving airplane.

When a sound source move toward the detector, the apparent frequency increases, which requires a minus sign in the denominator, otherwise a plus sign should be used.

It is clear from equation (1) that the relationship between Δf and f is a linear relationship. So, if the factor $\frac{\pm V_R}{V_{sd} \mp V_R}$ is assumed equal to α then equation (1) should be rewritten to be as follows

$$\Delta f = \alpha f \qquad (2)$$

Two cases have to be taken into consideration according to α parameter:

1. When the source moving toward the observer, then

$$\alpha = \frac{V_R}{V_{sd} - V_R} \qquad (3a)$$

Or

$$V_R = V_{sd}\left(\frac{\alpha}{1+\alpha}\right) \qquad (3b)$$

2. When the source moving away from the observer, then

$$\alpha = \frac{-V_R}{V_{sd} + V_R} \qquad (4a)$$

$$V_R = V_{sd}\left(\frac{-\alpha}{1+\alpha}\right) \qquad (4b)$$

So, by determining α the radial velocity V_R can be found.

The total velocity of the airplane related to the radial velocity component by the equation

$$V_R = V\cos\theta \qquad (5)$$

Where θ is the angle between the horizon and the position vector of the airplane relative to the observer.

The value of α can be determined by tracking the changes in characteristic frequency (which is one of the most apparent frequencies in the power spectrum of the sound signal of the airplane). The value of each characteristic frequency is tracked from one frame to other, and according to equation (2) the shifts in the values of each frequency is proportional with the original value of the characteristic frequency. This condition was utilized in the present work to find out the suitable characteristic frequency.

The Syggested System

The structure of the proposed system for determining the radial velocity from digital sound records is illustrated in figure (1). It is consist of many modules each one is applied either to map the processed data from a domain or to extract some features parameters. The first step in the first model is reading the wave header; and then loading the sound data. In the second module the data is partitioned into overlapped frames, the length of each of these frames depends on the chosen value of time interval parameter. The partitioning is done by applying the Time Slicing Method. In this method two types of moving windows could be applied:

1. Non-overlap window
2. Overlap window

This method partitions the wave data, in time domain, into frames of equal lengths. Essentially the method involves sectioning the data record into overlapping sections. The length of each frame is called block length (L), it is determined as the product of sampling rate (R) (the number of samples per second), by the frame time (T) which is the time interval of each audio data block:

$$L = T \times R \tag{6}$$

The jump step, (S) represents the value of jump length from a certain frame to the next following frame, is determined from the value of block length (L) and overlapping ratio (V), using the following equation:

$$S = L \times (1 - V) \tag{7}$$

The number of frames (n) is found from the frame length (L), jump step (S), and the total number of samples (N), which is registered in the wave header:

$$n = \left\lfloor \frac{N - L}{S} \right\rfloor \tag{8}$$

The third module in the introduced system is concerned with the conversion of the block audio data from time domain to frequency domain using one of the known transformation methods; in this research project the discrete Fourier Transformation (DFT) was used. This module is important to get the characteristic frequencies. Also, in this module the power spectrum of each transformed audio frame was computed.

The fourth module includes the following:

a. Rearrangement of the power spectrum elements according to their power value in descending order, and determine the threshold values which includes the maximum and minimum values of the power spectrum frequencies, taken under processing.

b. Finding the frequencies of the peaks using a peak detection method.

In the fifth module the characteristic frequencies are found using the power spectrum. These characteristic frequencies with their associated shifts are used in Doppler equation (2). The shifts in characteristic frequencies are determined using a variable window to track the most frequently occurred frequencies. In the last module the radial velocity is determined from the slope of f versus Δf.

Results

The studied airplanes sounds, in this study, are belong to the Mig-21, Sekhoy-25 and Sekhoy-22 airplanes. The information of the sound records are listed in table (1).The presented results in this section are of two types, they are: *Δf* versus *f* and the radial velocity versus time.

The reliability of the results was assessed according to the closeness of the curves of the determined radial velocity. Also the value of Root Mean Square Error (RMSE) of the determined Doppler shift, for different characteristic frequencies, is used as reliability indicator. The results of the Doppler shift versus characteristic frequency is determined for different time is calculated using the overlapped and non-overlapped window. Samples of the obtained results are shown in figures (2) and (3). The results of the radial velocity versus time, for some records, are shown in figures (4) (5) and (6). The results of the RMSE are listed in table (2).

Discussion and Conclusion

1.The curves of radial velocity versus time for the overlapped and non overlapped window should be close to each other, because relation should be same whatever the system parameters values are taken, so it doesn't depend on the type of window whether it is (overlapped or non-overlapped). The moving window is just a technique used
to find the radial velocity. Matching this fact with the obtained results lead us to a conclusion that "whenever the curves of determined radial velocity are closer to each other regardless the type of used window the determined results will be more acceptable".

1. From the shape of the curves, the radial velocity of approaching airplane increases fast when the airplane is far away from the sensor site. When it become closer the increase in radial velocity slows down, this happened because near the sensor site the component of the radial velocity varies relatively slow.

3. It has been noticed that the magnitude xof relative Doppler shift ($\frac{\Delta f}{f}$) is small at low magnitudes of the radial velocity (i.e., when airplane is near the sensor site), and it becomes higher when the airplane is far away from the sensor site. This behavior occurs because when the airplane is near the sensor site the value of the radial velocity approaches zero, and it is increased as the airplane moves away from the sensor site.

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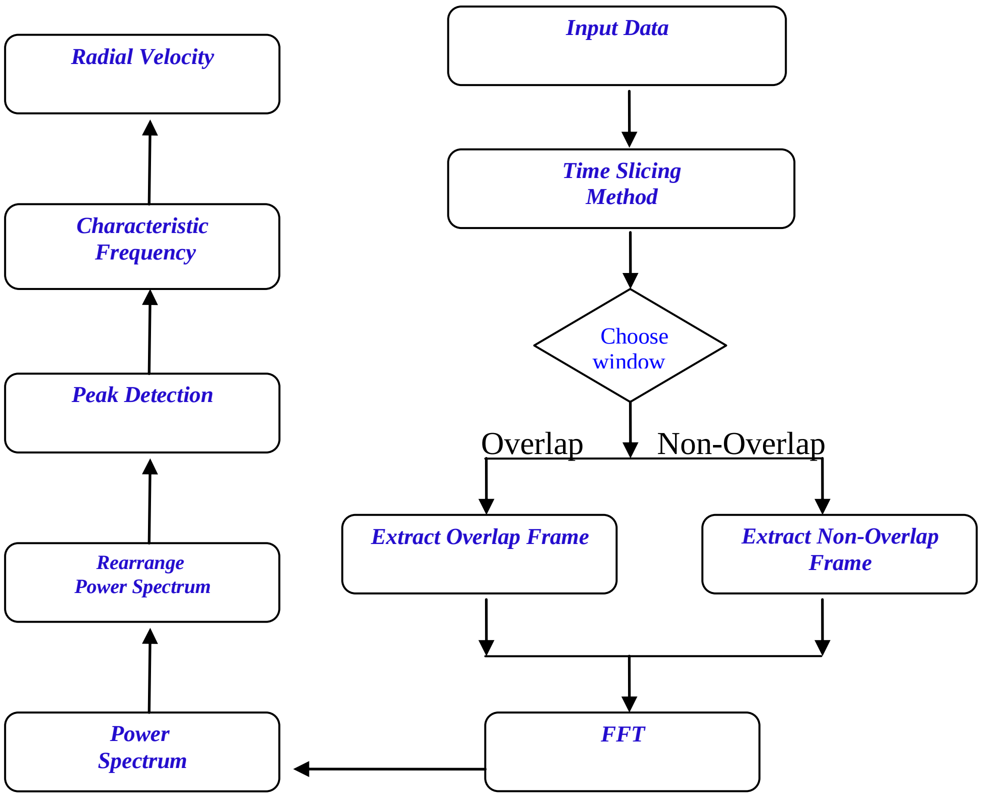

Fig. (1) The steps of the suggested radial velocity determination methods

Table (1) Information about the studied airplanes

Type	Sampling Rate (sample/Sec)	File Size (Byte)	Record Time (Sec)
M1-1	22050	418204	9.48308
S1-1	22050	672270	15.2442
S2-1	22050	541764	12.2849

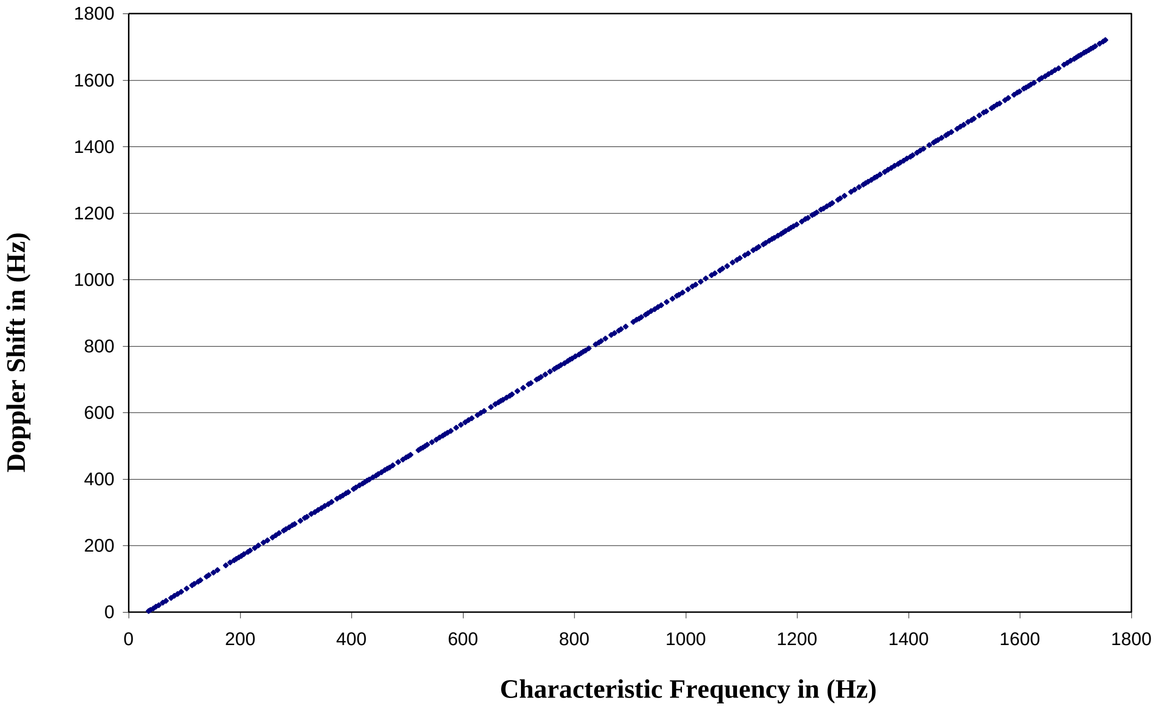

Fig. (2) Doppler shift versus the characteristic frequency for S1-1 airplane for a non-overlapped window and frame size equal to 200ms.

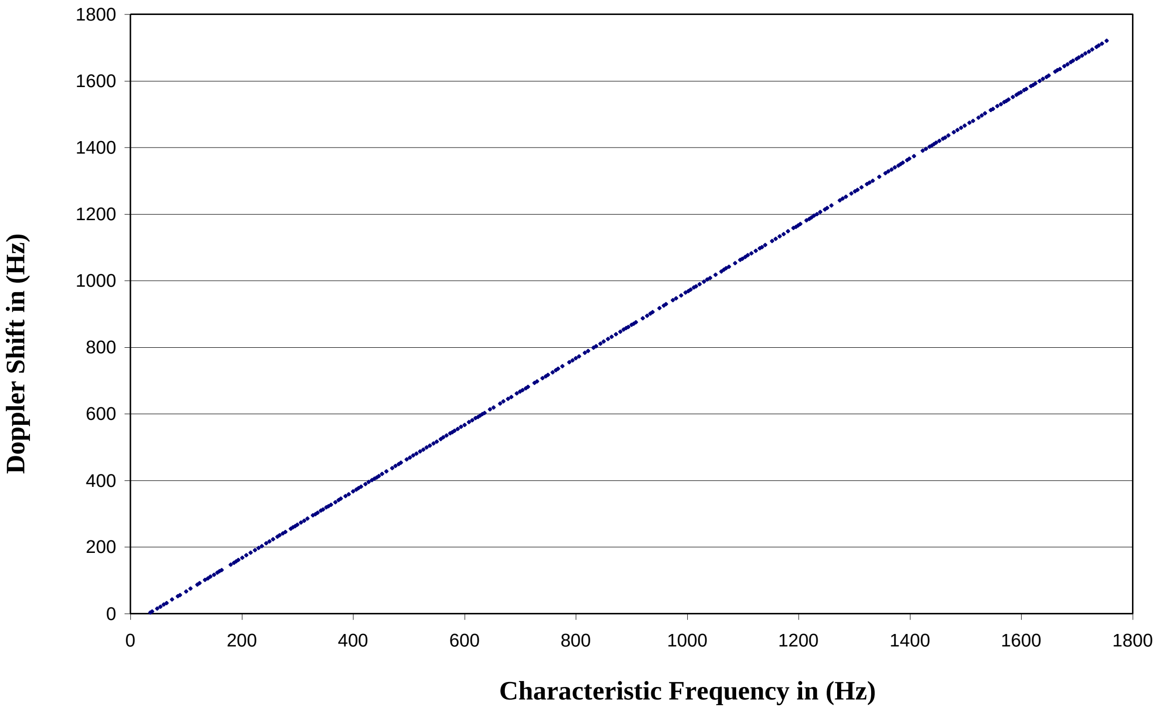

Fig. (3) Doppler shift versus the characteristic frequency for M1-1 airplane for a non-overlapped window and frame size equal to 200ms.

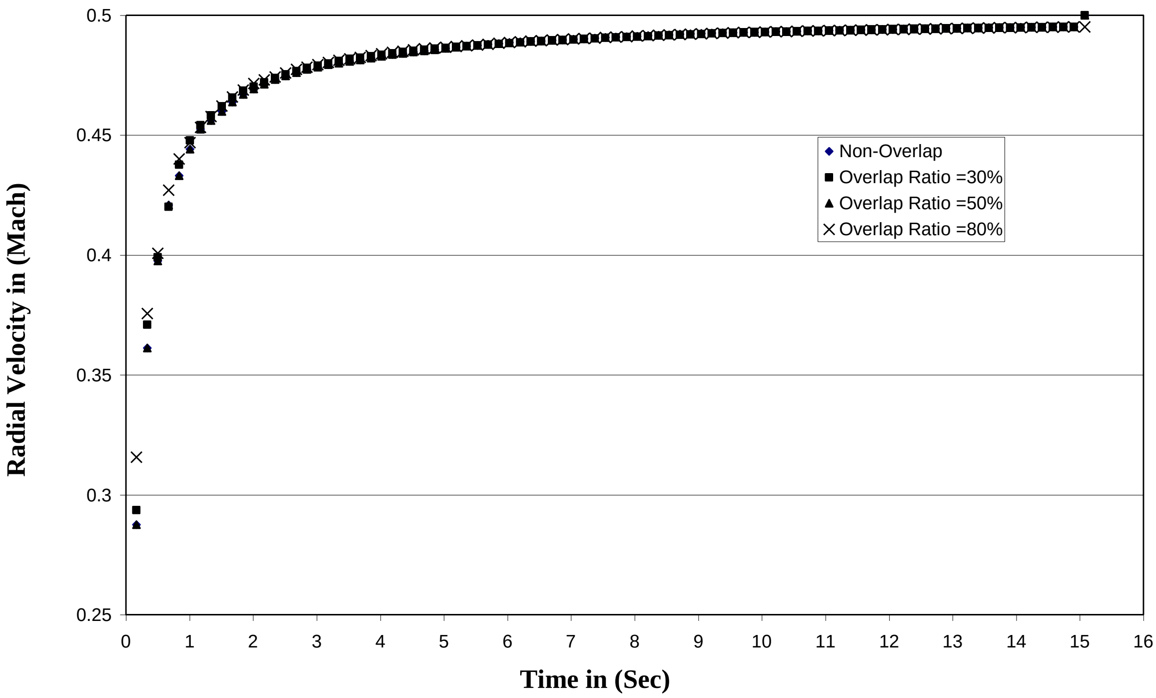

Fig. (4) The radial velocity versus time for S1-1 airplane with frame size equal to 200ms

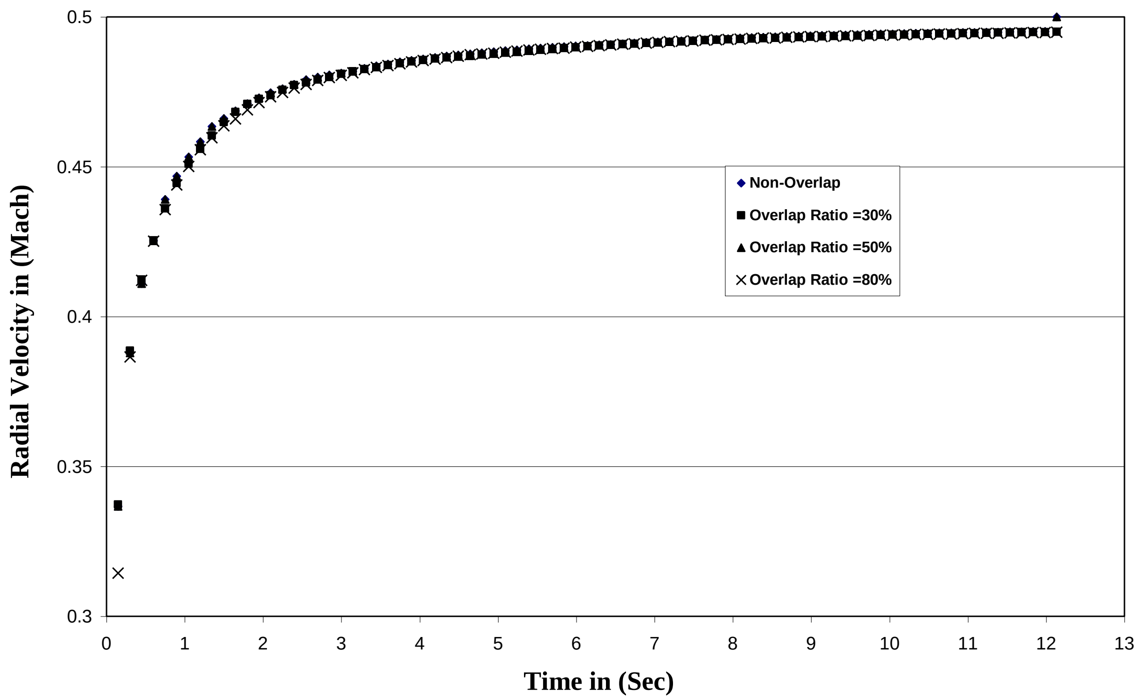

Fig. (5) The radial velocity versus time for S2-1 airplane with frame size equal to 200ms

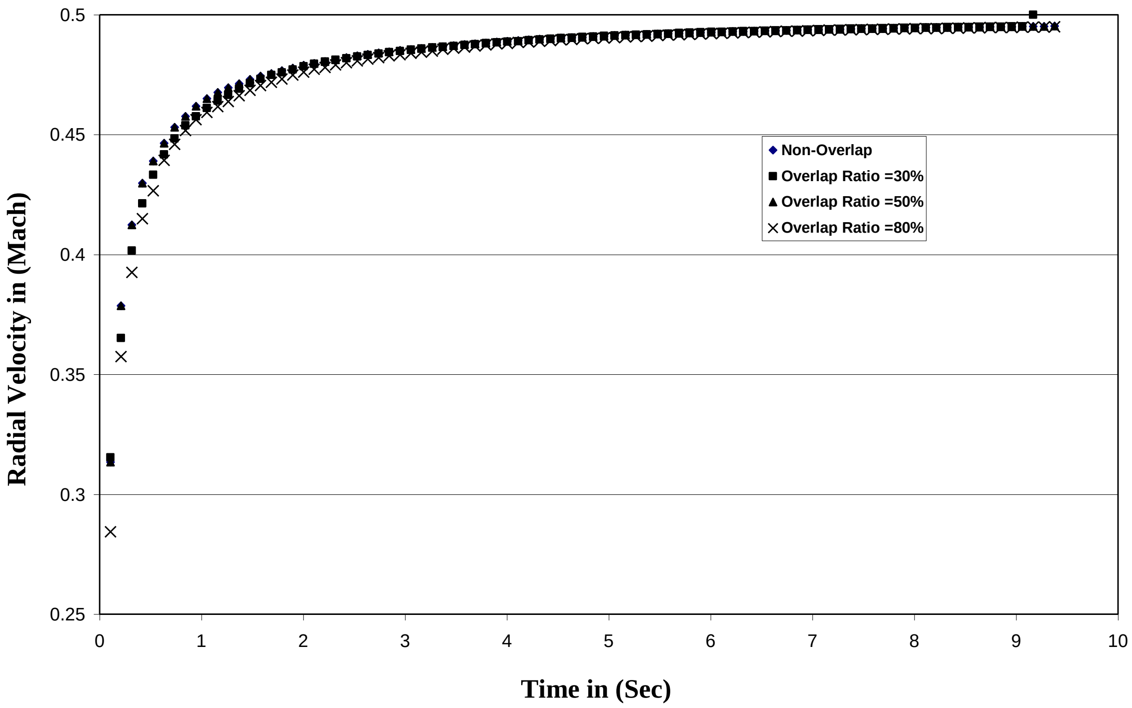

Fig. (6) The radial velocity versus time for M1-1 airplane with frame size equal to 200ms

Table(2) The values of RMSE of (Δf) for different airplanes with window size equal to 0.05 and frame size equal to 200 ms

Type of Windows	Type of Airplanes		
	S1-1	S2-1	M1-1
Non-Overlap	1.195	1.142	1.160
Overlap Ratio=30%	1.246	1.118	1.109
Overlap Ratio= 50%	1.195	1.142	1.160
Overlap Ratio=80%	1.112	1.250	1.105