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№ 9278

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A C Ramachandra, V Viswanatha, K Kishor, H Suhas and E Pannir Selvam

November 8, 2022

International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 10 Issue: 8
DOI: https://doi.org/10.17762/ijritcc.v10i8.5682
***Article Received**: 10 June 2022 **Revised**: 15 July 2022 **Accepted**: 30 July 2022 **Publication**: 31 August 2022*

In-Cabin Radar Monitoring System: Detection and Localization of People Inside Vehicle using Vital Sign Sensing Algorithm

Ramachandra A C [1]
Department of ECE
Nitte meenakshi Institute of technology
Bengaluru, India
Email- ramachandra.ac@nmit.ac.in

Viswanatha V [2]
Department of ECE
Nitte Meenakshi Institute of Technology
Bengauru, India
Email – viswas779@gmail.com

Kishor K [3]
Department of ECE
Nitte Meenakshi Institute of Technology
Bengaluru, India
kishorreddy045@gmail.com

Suhas H [4]
Department of ECE
Nitte Meenakshi Institute of Technology
Bengaluru, India
suhasgowd006@gmail.com

Pannir Selvam E [5]
Department of RADAR
Veoneer India Pvt,Ltd
Bengaluru, India
pannir.selvam@gmail.com

Abstract— Radars are used in automobiles for various functionalities, starting from the obstacle alarm during vehicle reversing to advanced functionalities like autonomous driving. A practical method for monitoring people inside a vehicle for various applications (surveillance, safety, etc.) could be built using Radar. This paper presents the embedded implementation of a vital sign sensing algorithm using the radar signal processing (RSP) technique. MEX (MATLAB executable) interface is performed with the embedded C code of the vital sign sensing algorithm generated for validating the results with the RSP technique. Finally, Unit testing is performed on the developed embedded C code of the vital sign sensing algorithm to remove the dead codes and to verify whether all branches and statements in a developed algorithm are working accordingly. The embedded C code results were found to be matching precisely with the RSP technique. With the help of obtained results, we can differentiate between an adult and a baby inside a vehicle.

Keywords— CAN, Automotive, Embedded implementation, In-Cabin sensing, Lidar.

I. INTRODUCTION

Motor industry is the primary target of mmWave-0Wave radar applications [1]. Furthermore, there are also a number of different applications being studied in the business and healthcare sectors. For a number of therapeutic and diagnostic uses, such as disease diagnosis and oximetry, millimeter-0wave radars are being explored [2].

Human vital signs are tracked invisibly and remotely is one of the emerging application areas [3]. This is useful in a variety of situations, including going to monitor a large number of sleep seniors to accurately identify family conditions. In healthcare settings for toddlers and accident victims, in addition to use in driver observing to catch forgetfulness and fatigue in drivers to prevent accidents, the equipment is used for chronically sick patients if non-contact evaluations are preferred. Over last four decades, microwave remote scanning of physiological signals with proof of concepts for applications including sleep deprivation [5, 6], simultaneous infant and child mortality syndrome (SIDS), and person identification using radar capture respiratory patterns [7], Doppler radar has been shown useful in application domains [4, 5].

In this paper, Embedded C code of vital sign algorithm is implemented for estimating the vital sign to differentiate between the Adult and a baby, using radar signal processing techniques. Furthermore, an MEX (MATLAB executable) interface is examined to validate the embedded C code, with the RSP algorithm developed in MATLAB as a reference. Finally, unit testing is performed for the developed embedded code.

II. THEORITICAL BACKGROUND

A. Signal Model

The basic premise of physiological radar is that a magnetic transmission is thrown at a human subject but also reflected off the adult's chest surface, causing phase shift [8-10]. The small

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displacement of the chest surface related to cardio-respiratory activity is a direct function of phase shift of the reflected signal [11]-[13]. The frequency modulated transmitted signal is provided by the subsequent equation: [14]-[16]:

$$x_T(t) = A_T \cos(2\pi f_c t + \pi \frac{B}{T_c} t^2 + \emptyset(t)) \quad \ldots \qquad (1)$$

Where, the phase noise from the transmitter is given by $\emptyset(t)$

The indication of chirp beginning frequency is f_c

The chirp's bandwidth is represented by B

Every width of a chirp is expressed by T_c

Every period of chirp repetitions is specified by f_r

The outgoing signal is taken in by the radar in something like a scaled-down and time-shifted (by and t d) form via:

$$x_R(t) = \alpha A_T \{\cos(2\pi f_c(t - t_d) + \pi \frac{B}{T_c}(t - t_d)^2 + \emptyset(t - t_d))\} \quad \ldots. \qquad (2)$$

Where, time-delayed form of the reflected signal is calledt_d.

$$t_d = \frac{2R(t)}{C} \quad \ldots \quad (3)$$

And $R(t) = r_0 + A_{br} \cos(2\pi f_{br} t) \quad \ldots \quad (4)$

Where,

R (t) is the object radial range as shown in equation 4

Amplitude of the breathing rate is given by A_{br}

Breathing frequency is denoted by f_{br}

Speed of light is denoted by C

A further temporal shift (r) will happen in a radar with many receivers because of the relative distances between the different receiver components. Equation 5 displays the signal that each receiver element has received.

$$x_R(t)_i = \alpha A_t(\cos(2\pi f_c(t - t_d - ir) + \pi B f_r(t - t_d - ir)^2 + \phi(t - t_d - ir))) \quad \ldots \quad (5)$$

Where $r = \frac{d\sin\theta}{C}$

I is the receiver element count, and is the angle of arrival. The transmitted phase and received phase from 1 and 2 are presented below, respectively.

$$A = 2\pi f_c t + \pi B f_r t^2 + \phi(t) \qquad \ldots \qquad (6)$$

$$B_i = 2\pi f_c(t - t_d - ir) + \pi B f_r(t - t_d - ir)^2 + \phi(t - t_d - ir) \quad \ldots. \quad (7)$$

After I/Q mixing, the signal is provided below. The received signal is combined with a copy of the broadcast signal.

$$y_i(t) = A_r e^{j(A - Bi)} \quad \ldots \quad (8)$$

Where, the received signal power is indicated by A_r

When a signal is received at the first antenna element, it is combined with a copy of the sent signal to create a single channel signal. This "In-phase" (I) signal is shown as follows simplification:

$$y(t) = A_r e^{j(2\pi f_c t + \pi B f_r t^2 + \phi(t) - 2\pi f_c(t - t_d) + \pi B f_r(t - t_d)^2 + \phi(t - t_d))} \quad \ldots (9)$$

On solving for the phase, we get

$$y(t) = A_r e^{j((-\frac{4\pi f_c A_{br}}{C} - \frac{4\pi f_r A_{br} t}{C})\cos(2\pi f_{br} t) - \frac{4\pi f_c A_{br}}{C} - \frac{4\pi B f_r A_{br} t}{C})} \quad \ldots.. (10)$$

Concentrating on phase change in the slow time axis is adequate to extract breathing rate since the chest movement has a relatively modest amplitude (10 mm) and a low vibrational frequency (4 Hz) [8].

B. Advantages of Millimeter Wave Sensing

The sensitivity is substantially higher than microwave radar because the little move of the middle of the chest is in the millimeter scale and closely matches the radar wavelengths [9].

III. DESIGN AND METHODOLOGY

This portion of the article will focus on the implementation of vital sign algorithm in embedded C. Figure1 shows the block diagram of vital sign estimation. The signal model is explained in Section 2. The phase extraction block extracts the phase information from the signal model. Once the phase extraction is done phase unwrapping is performed to obtain the actual displacement profile [18]-[19].

The DC or trend removal of the differential phase is carried out by computing ((t)-mean (t))) on every t. (t). Then, the impulse-like noise is then removed by computing a forward (t)-t+1) and backward (t)-t-1) phase difference for each t. If these are greater than a defined standard, t is then replaced with a reconstructed value [20]-[21].

The breathing spectrum ranges between [0.1 – 0.5] Hz. By using the bandpass filter, we can limit the frequency values between those ranges.

FFT applied on the autocorrelated signal. The frequency corresponding to the maximum peak gives the corresponding breathing rate frequency. From this frequency, the

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corresponding breathing rate is calculated in breaths per minute (bpm) [22]-[23].

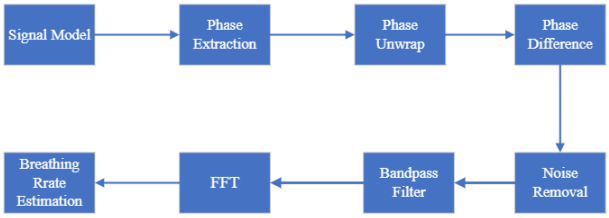

Figure 1 Block Diagram of Vital Sign Estimation

A. Embedded C implementation

Figure 2 shows the Embedded C code Implementation Flow Chart.

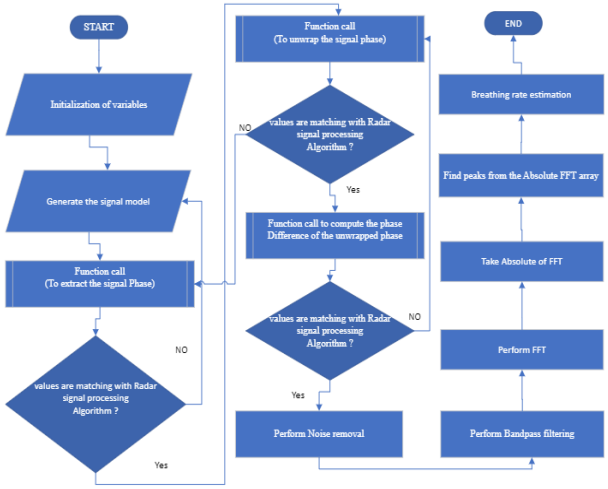

Figure 2 C code generation Flowchart

Above figure shows the flowchart for implementing an algorithm in Embedded C. Here main aim is to validate the results which we are implementing in Embedded C code, with the help of the Radar signal processing Algorithm. If results of Embedded C code are exactly matching with the Radar signal processing Algorithm, we can proceed the implementation otherwise we can correct it by travelling back to the previous step.

B. C Code and MEX Interface :Functional Implementation

This section deals with the interfacing the Embedded C Code with MATLAB Executable (MEX), MEX is an abbreviation for MATLAB Executable. We can use MATLAB to invoke custom C routines as if they were built-in functions thanks to MEX-files. Mex-files are referred to as M-functions in MATLAB. In this part, all code examples will be provided in C. the capability of immediately calling large-scale C or FORTRAN functions from MATLAB without having to rewrite things as M-files. Users may recreate restrictive calculations, such for-loops, as a MEX-file to increase efficiency. Parallelism- For operations that can't be vectorized, you can develop multi-threaded C code.

Figure 3 shows the C MEX interface, where MATLAB (RSP algorithm) input is given to Embedded C logic. At the end both the RSP algorithm and Embedded C code produces the same output.

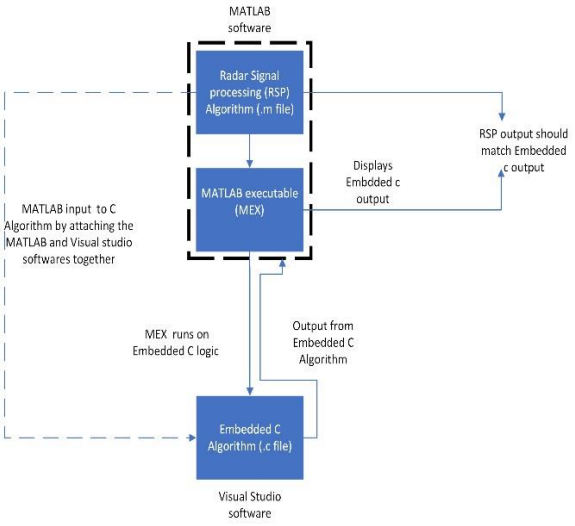

Figure 3 C MEX interface functional block diagram

IV. RESULTS AND DISCUSSION

In this section, we are discussing about the results obtained after validating the Embedded C code.

Before going to the results let us understand how respiratory rate varies across age [10]. Breathing information across Newborn to Adult is given in below table.

TABLE I. Acceptable Ranges for Respiratory Rates [14]

Acceptable Range OF Respiratorn Rates for Age	
Age	**Rate (Breaths per Minuter)**
New Born	30 – 40
Infant (6 Monts)	20 – 40
Toddler (2 years)	25 – 32
Child	20 – 30
Adolescent	16–19
Adult	12 – 20

By observing the above table, we can say that common breathing rate in adults are 12-20 BPM. Normal Breathing rate across the Newborn babies and children's is 30 BPM.

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Received phase: - figure 4 shown is the extracted phase from the original signal. This phase is obtained by performing arc tangent operation for the generated signal. By referring figure 4 we can say that both the RSP and Embedded C graph are matching each other.

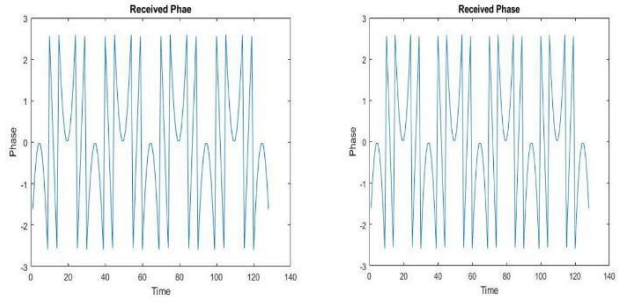

Figure 4 Received Phase for 20 BPM

Unwrapped Phase: - figure 5 shows the unwrapped phase, this unwrapped phase is obtained by performing unwrap operation on the received phase. This operation is performed to obtain the actual displacement profile. By referring figure 5 we can say that both the RSP and Embedded C graphs are matching each other.

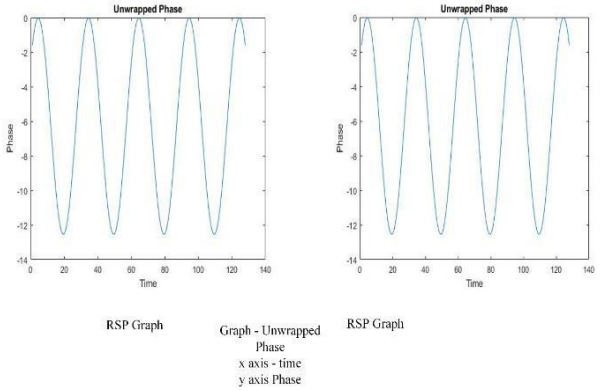

Figure 5 Unwrapped *Phase for 20 BPM*

Phase Difference: - Figure 6 shows the phase difference plot, which is extracted from the unwrapped phase. By performing phase difference operation for the unwrapped phase, we can obtain the phase-difference plot. By referring the RSP graph and Embedded C graph we can say that both the graphs are matching each other.

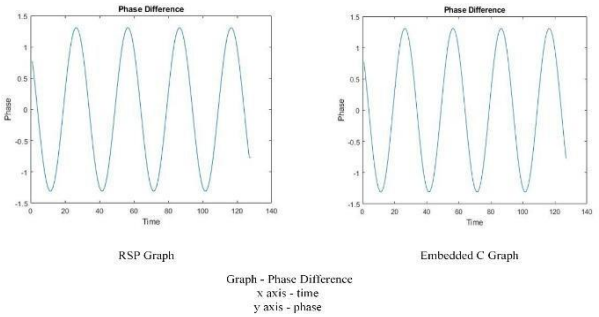

Figure 6 Phase difference for 20BPM

FFT and Peak picking: - FFT is performed. By looking into the peaks in the FFT spectrum we can estimate the breathing rate. FFT graph is shown in the figure 8. Figure 9 shows a peak picking from the FFT array.

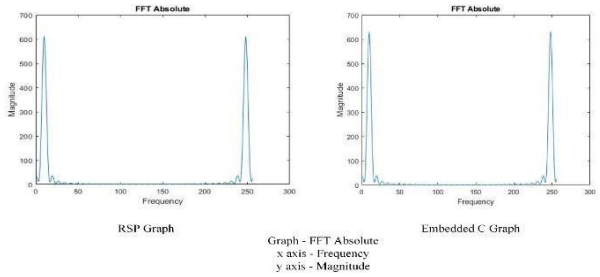

Figure 7Absolute FFT

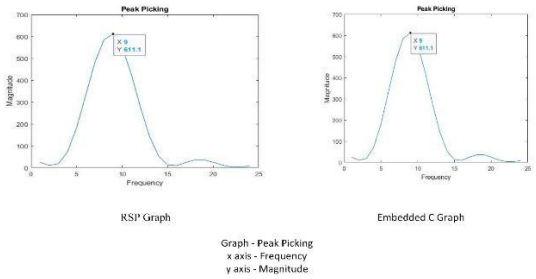

Figure 8peak picking from FFT spectrum

V. CONCLUSION AND FUTURE SCOPE

In this project Embedded C code is implemented with the help of Radar signal Processing technique. Algorithm which is developed in embedded C is matching exactly with the Radar signal processing (RSP) Algorithm. we can differentiate between the adult and a baby by calculating the exact breaths per minute (BPM) value.

The developed embedded C code can estimate the respiration rate based on the chest displacement.

Future scope for the current project is defines below.

We can extend this tecnhique for extraction of heart beat.

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We can port the developd algorithm to the hardware, where this hardware board can be interfaced in a car for the purpose of breathing rate measurement, to differentiate between adult and a baby.

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