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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (22): 6589-6594, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.6589.6594

A Novel Realization of FOA Measurement for Satellite Navigation System

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Abstract: This study analyses combined estimating algorithm of FOA which can achieve high accuracy of FOA estimating at a lower SNR and can satisfy the SAR/Galileo system. It brings up an idea that combines MATLAB with DSP to design DSP system. It develops a DSP system based on TMS320C6713 using CCSLink as an assistant tool which can achieve the FOA estimate of Galileo system and designs graphics user interface. The conclusions show that developing DSP systems using MATLAB as assistant tool can exert their advantages, shorten the development period, simplify the processes of analysis, debug and test of an algorithm and improve the efficiency. Through comparison emulation result and theory request, this methodology for implementing DSP with MATLAB in approaching FOA measurement of Galileo System is proved to have wider applicability.

Key words: Galileo system, FOA, DSP, CCSLink

INTRODUCTION

In Galileo Search and Rescue (SAR/Galileo) system, distress beacons are transmitted to the MEO (Middle-altitude Earth Orbit) satellites and relayed to Medium-altitude Earth Orbit Local User Terminal (MEOLUT), which process the signals to determine the beacon location and provide distress alert messages from active 406 MHz beacons to the MEOLUT's associated Mission Control Centre (MCC). In this process, Frequency of Arrival (FOA) of beacon is one of the key parameters to the precise localization which needs real-time estimating with high accuracy (Dan *et al*., 2012).

Digital signal processors are used in a wide range of applications, such as in communications, controls, speech processing and so on (Liu, 1999). TMS320C6713 Floating- Point Digital Signal Processor is based on the high-performance, advanced Very-Long-Instruction-Word (VLIW) architecture, making this DSP an excellent choice for multichannel and multifunction applications. Operating at 225 MHz, the C6713 delivers up to 1800 MIPS, 1350 MFLOPS and with dual fixed-/floating-point multipliers up to 450 MMACS, which is considered to be TI's one of most powerful processors (Kalden *et al*., 2012; Duan and Chen, 2007).

MATLAB integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. In the early days of DSP program design, using MATLAB as assistant tool can shorten the development period and simplify the development process (Kalantzopoulos *et al*., 2012). The previous method is generally carried out by MATLAB algorithm simulation, when the simulation results are satisfactory, then compile corresponding DSP program to achieve the target. In the process of DSP debugging, the results of DSP simulation will saved by Code Composer Studio (CCS), the Texas Instruments (TI) software development environment and then transferred to MATLAB work space and compared with MATLAB simulation results in order to help to find and improve the DSP program, it is a repeated and trouble way. However, MATLAB Link for Code Composer Studio (CCSLink) provides a bidirectional interface between MATLAB and CCS, which link them together into a common simulation framework under MATLAB (Zhao *et al*., 2007). Using the CCSLink can test and verify algorithms on the C6713, exchange real-time data with development hardware and simulators and simplify software debugging and performance optimization with the advanced analysis and visualization capabilities of MATLAB (Yuan and Shen, 2012).

This study realizes FOA estimate of SAR/Galileo system based on TMS320C6713 DSP using MATLAB as programming language to aid in the designing of DSP. The rest of the study is organized into sections on, the conclude with a discussion of the results and future research.

THEORETICAL ANALYSIS

Signal format: The 406 MHz SAR distress beacons last approximately half a second, 440 m sec for a short

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message, or 520 m sec for a long message. The initial 160 m sec is pure carrier preamble, the final 280 m sec (short message) or 320 m sec (long message) contain a modulated message at a bit rate of 400 bps. There are 24-bit synchronization header in the message following the 160 m sec carrier so as to identify the message. Meanwhile bit 25 is a format flag bit used to indicate short or long message to follow and then are SAR message bits: short version 87 bits, or long version 119 bits. The distress beacon needs to make a second coding, Manchester coding, before the sending messages in order to resolving transmitting difficulties such as too long a time the information keeps 1 or 0, because the signals has only those two formations. In the processing of Manchester coding, message "1" is translated into "1,-1", while "0" into "-1,1". The bit rate is changed into 800 bps after the Manchester coding.

The SAR/Galileo system takes binary phrase modulation to process the user's messages in which the carrier shall be phase modulated positive and negative 1.1 radians peak, referenced to unmodulated carrier. Positive phase shift refers to a 1.1 radian phase advance when the message is "1", while negative phase shift refers to a 1.1 radian phase lag when the message is "0" relative to nominal phase.

FOA analysis: In the SAR/Galileo system, FOA parameter estimating is taken place in the MEOLUT of the Signal Processing Sub-system (SPS). FOA parameter is defined as the accurate frequency of the beacon signal arrival, so the estimating of FOA parameter can be considered as the estimating of carrier frequency (Li *et al*., 2003).

Considering the formation of beacon signal, the initial 160 m sec is pure carrier preamble, the following messages are modulated positive and negative 1.1 radians peak, referenced to unmodulated carrier. Spectrum of such modulated signal has a strong residual carrier component. So, the frequency can be estimated using 160 m sec pure carrier and the residual carrier component pick-up by a narrowband filter. However, the frequency of modulate signal will introduce to carrier spectrum after positive and negative 1.1 radians modulation, which cause spectral line of carrier spectrum no longer only exists in its center frequency (assuming without noise and other effects). Therefore, FOA estimate carry out by the use of the initial 160 m sec pure carrier. The problem can be transformed into estimating frequency of sine signal. This kind of problem can be easily resolved by a DFT transform or its fast calculation method FFT to meet the real-time requirements of the system.

Because there is no priority to change the form of the signal, we can only optimize our calculating method as following: Maximum Spectrum Algorithm, Rife Algorithm, Single Spectral Line And Phase Algorithm and Combined Algorithm. Assuming that f_{00} is the result of Maximum Spectrum Algorithm, f_{01} of Rife Algorithm, f_{02} of Single Spectral Line And Phase Algorithm, their main properties listed in Table 1.

We compare these four results simulating by MATLAB and choose combined algorithm for FOA parameter estimating whose architecture is shown in Fig. 1.

Assuming $f_{0e} = f_{02}$ is the final FOA, the combined algorithm is described as following:

- When $|f_{00}-f_{02}| \leq f_s/10N$, $f_{0e} = f_{02}$
- When $4_{fs}/10N<|f_{00}-f_{02}| \leq f_s/(N-M)$, $f_{0e} = f_{01}$
- When $f_s/1-N<|f_{00}-f_{02}| \leq f_s/10N$, $f_{0e} = (f_{01}+f_{02})/2$
- When $f_{0e} = (f_{01}+f_{02})/2$, phase ambiguity occurred; then judge furthermore, if $f_s/10N<|f_{00}-f_{01}|$, $f_{0e} = f_{01}$
- When $|f_{00}-f_{01}| \leq f_s/10N$ and $|f_{00}-f_{02}|>f_s/(N-M)$
  if $f_{00}>f_{02}$
  then $f_{0e} = f_{02}+2f_s/(N-M)$
  else $f_{0e} = f_{02}-2f_s/(N-M)$

Table 1: Main properties of well known spectrum estimation

Estimation method	P(f)	Comments
Maximum spectrum algorithm	$f_{00} = \frac{k_0}{N} f_s$	Choosing the maximum spectrum from DFT coefficient of sampling sequence to estimate the FOA.
Rife algorithm	$f_{01} = \frac{1}{T}\left[k_0 + \frac{r \cdot \lvert G_{k_0+r} \rvert}{\lvert G_{k_0} \rvert + \lvert G_{k_0+r} \rvert}\right]$	Using two spectral lines to estimate the FOA.When the SNR is high, it has a high performance; when the SNR is low, the performance decline.
Single spectral line and phase algorithm	$f_{02} = \frac{1}{(N-M)\Delta t} \left[\frac{N-1}{N} k_0 - \frac{M-1}{M} k_1 - \frac{\beta}{\pi}\right]$	Using one spectral line to estimate the FOA.

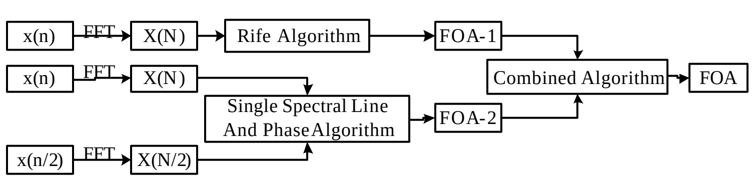

Fig. 1: Algorithms of FOA

This kind of calculation can get high qualified result through stimulation. The precision can be decreased to 0.1 Hz on the case of 0 dB SNR signal.

SYSTEM DESIGN

The processes of Matlab aidding DSP in approaching FOA measurement involve two parts: write DSP programs in CCS; generate signal data, filter coefficients and so on in MATLAB. CCSLink combines MATLAB with DSP to develop DSP system, links them together into a common simulation environment. The system makes beacon signal calculated by MATLAB and transport these signal data to DSP register through CCSLink. Then, the estimate process is completed in the DSP target and gets the FOA result. At the same time, the system can also read out the internal processing data of DSP and compare with the results from MATLAB stimulation. In addition, a unified user-friendly interface is developed which enables users to experiment with a variety of input parameters, examine graphical representations of analysis parameters. The whole parts of the system are described as following.

Programming in the CCS environment: The SNR range of the SAR/Galileo system beacon signal is from -8.8 dB to 17.2 dB, so in the process of simulating beacon signal by MATLAB, the system need to add gauss white noise in the range above after making positive and negative 1.1 radians modulation. The DSP programs firstly use a band pass filter to filtering the noise and get the initial 160 m sec carrier and then use FFT to processing the samples of 160 m sec carrier, finally get FOA estimate according to combined algorithm. The project mainly contains: main.c, init_6713.c, fir.c, fft.c and foa.c and the relationship between them is shown in Fig. 2. Moreover, the project includes a link command file(.cmd file) which

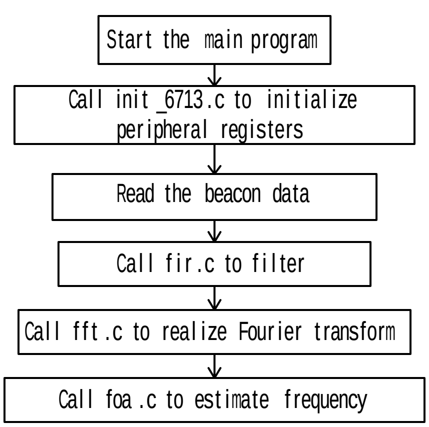

Fig. 2: Program flow chart

programmed based on the memory of the DSP target. After compiling, the linker combine all object files and object libraries to produce an executable file with extension. out, which can be loaded and run directly on the DSP target.

MATLAB aid DSP design: Firstly, the system needs beacon signals. Before arriving the signal-detecting unit of the MEOLUT, the beacon signals have already down converted to Zero Intermediate Frequency (ZIF), which are DC signals and hardly acceptable for the FOA estimation algorithm, so we need to re-modulate the ZIF signals to another nonzero frequency such as 1.5 kHz, considering the signal bandwidth is 3kHz, then make positive and negative 1.1 radians modulation for the whole beacon signals contaminated by the Additive White Gaussian Noise (AWGN) at a certain SNR. These signals transport to on-chip RAM by CCSLink for the DSP on-chip RAM is fast, which will be used by DSP program.

The system uses MATLAB function fir1() design a FIR filter, which implements the classical method of windowed linear-phase FIR digital filter design. According to the requirement of the system, MATLAB function kaiserord() specify a Kaiser window for the use with the fir1(). The designing of the filter is as following:

```
[n,Wn,beta,ftype] = kaiserord(f,a,dev,fs);
b = fir1(n,Wn,'ftype', kaiser(n+1,beta),'noscale');
```

n is the approximate filter order, Wn is normalized frequency band edges, beta is the Kaiser window parameter, ftype specifies a filter type. f is a vector of band edges and a is a vector specifying the desired amplitude on the bands defined by f, dev is a vector that specifies the maximum allowable error between the frequency response of the output filter and its desired amplitude, for each band. Fs is sampling frequency.

Filter coefficient b will be saved as a file with extension. h, which will be called by DSP program.

The software CCSLink supplies several components, which complete the link process between MATLAB and DSP. One of these is the connecting object, by means of it, a number of debugging features are available, including running DSP program under MATLAB environment, pausing or halting the running program, setting breakpoints, modifying or receiving data from DSP and so on. The other component is the embedded object, which can directly call variables embedded in the memories or registers of DSP target that is, we can revalue the variables in MATLAB to change that in the C program on the chip. By use of these two objects, controlling DSP in MATLAB is as convenient as in the CCS.

Parts of the MATLAB codes are as follows:

```
cc = ccsdsp('boardnum',0,'procnum',0);%create the object to connect CCS
file = fullfile('d:','foa','foa.pjt');%obtain address of project
open(cc, file); %open the project
inp_buffer = createobj(cc,'bpsk'); %create the embeded object to input variable
out_buffer = createobj(cc,'result');%create the embeded object to output variable
write(inp_buffer, x);%write the data to buffer of dsp
build(cc);%build all files in the project
run(cc) ;%run the program in dsp
```

In the system, the input data, filter coefficient and operation of CCS are all realized in MATLAB. In the course of program developing, the GUI tool of MATLAB can be used to developing the graphic user interface so as to avoid a series of redundant operation,. The GUI controls the realization of MATLAB procedure and conveniently realizes the following function: modifying the SNR for beacon signals (SNR is -8.8~17.2 dB), simulating the beacon signals, designing filter, importing the data to DSP, controlling the operation of DSP program, displaying the results of FOA estimate and so on; As well as drawing up the results of DSP filter and comparing with the results of MATLAB filter. At the same time, the DSP procedure can be further confirmed and optimized, according to the comparison of FOA estimate results between MATLAB and DSP.

The GUI of system as shown in Fig. 3.

Result analysis: When the SNR is -8.8~17.2 dB, one hundred times simulations with FOA synthetic estimation algorithm are performed for the beacon signal of 160 m sec at a certain integer SNR. After computing the standard deviation of the certain frequency, the average error of frequency estimator can be obtained. Figure 4 is the DSP estimate precision schematic drawing, Fig. 5 is the MATLAB estimate precision schematic drawing, the corresponding results are listed in Table 2 and 3. It may be known, when the SNR is -2 dB, the error = 0.0944 Hz, the precision and the stability of frequency synthesis algorithm is obviously higher. The

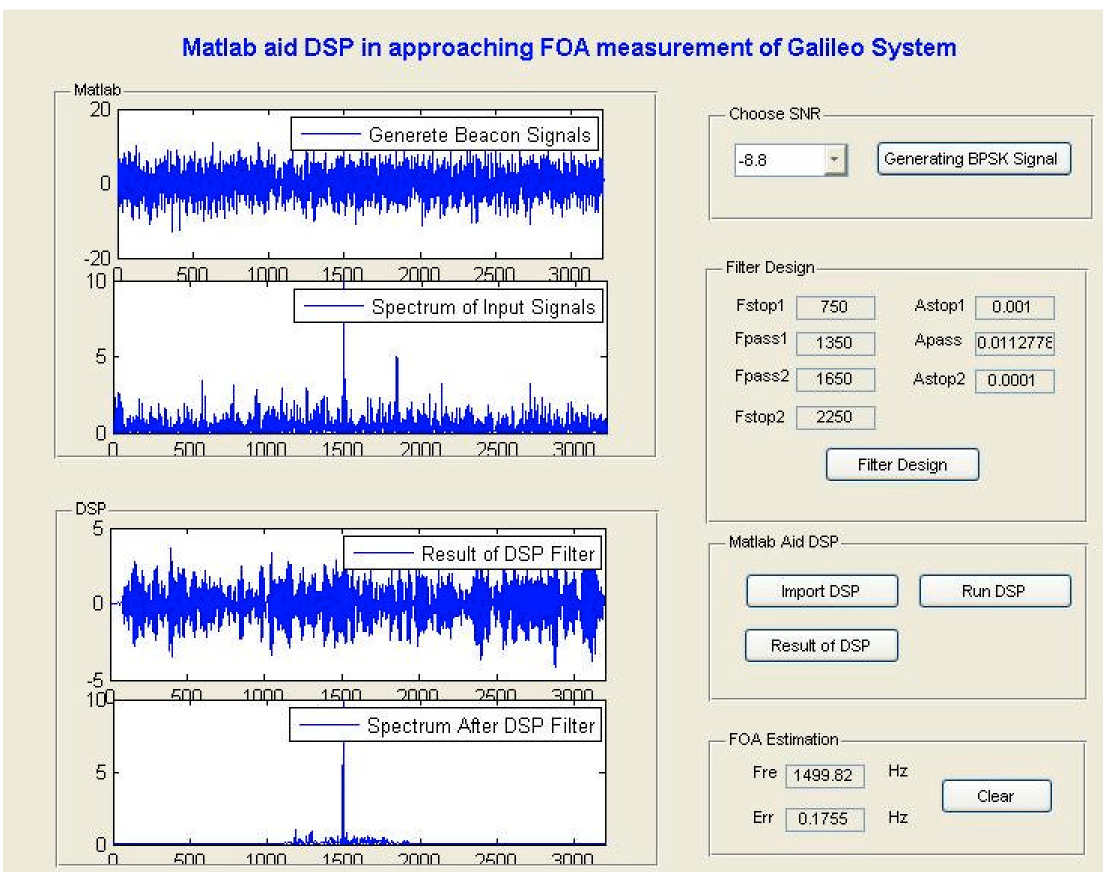

Fig. 3: GUI of system

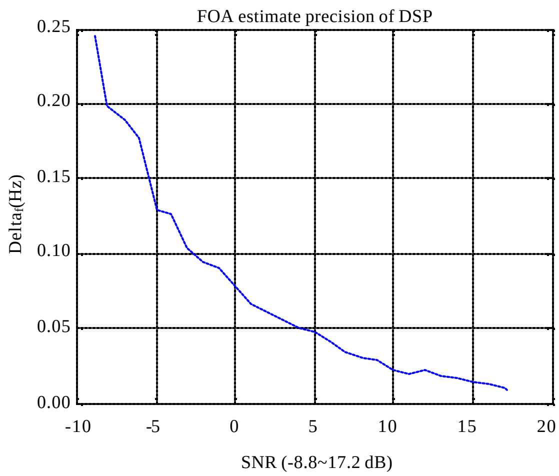

Fig. 4: DSP estimation accuracy when SNR is -8.8~17.2 dB

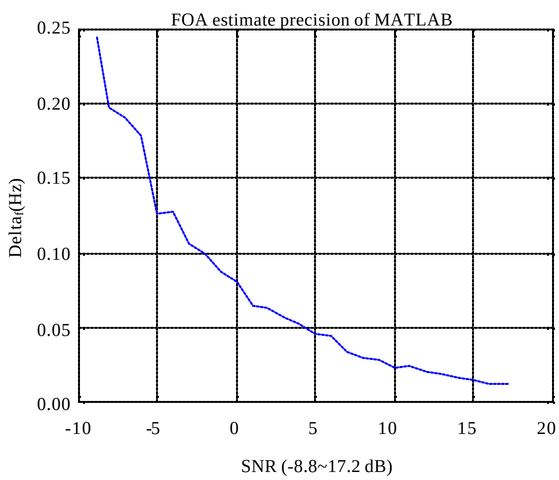

Fig. 5: MATLAB estimation accuracy

Table 2: Estimation accuracy of DSP simulation, when SNR is -8.8~17.2 dB

SNR (dB)	-8.8	-8	-6	-4	-2
Delta_f (Hz)	0.2443	0.1978	0.1773	0.1269	0.0944
SNR (dB)	0	2	4	6	8
SNR _f (Hz)	0.0783	0.0604	0.0499	0.0415	0.0305
SNR (dB)	10	12	14	16	17.2
Delta_f (Hz)	0.0214	0.0224	0.0161	0.0125	0.0093

Table 3: Estimation accuracy of MATLAB simulation, when SNR is -8.8~17.2 dB

SNR (dB)	-8.8	-8	-6	-4	-2
FOA (Hz)	0.2443	0.1978	0.1791	0.1279	0.0988
SNR (dB)	0	2	4	6	8
FOA (Hz)	0.0807	0.0622	0.0521	0.0435	0.0290
SNR (dB)	10	12	14	16	17.2
FOA (Hz)	0.0228	0.0202	0.0161	0.0121	0.0111

FOA estimation accuracy achieves 0.1 Hz when the SNR is above 0 dB, which satisfies the SAR/Galileo system requirement. The simulation results of DSP system surpasses MATLAB slightly, which has a better practical value.

CONCLUSION

This study put forwards a methodology for implementing DSP with MATLAB in approaching FOA measurement of Galileo System. The DSP system based on TMS320C6713 can be designed and realized utilizing CCSLink as an assistant tool, which can achieve the FOA estimate of Galileo system. With the aid of the high-productivity, high-creativity computing power and visualization function of MATLAB, the operation to CCS and the DSP target may be operated conveniently and nimbly under the MATLAB environment and taking advantage of MATLAB GUI tool, the graphical and interactive user interface can be developed, which enables the system to have the user-friendly interface, the nimble parameter establishment and the highly effective processing speed. It strengthened the serviceability of the DSP system, achieved the purpose of designing DSP aided by MATLAB and completed the requirements of the system.

Based on this article mentality, when developing other parameter estimation and signal demodulation units of the SPS of Galileo/SAR system, some work can be completed by MATLAB, such as generating data, validating results, drawing user interface, which can reduce the development time of the DSP application procedure Significantly and simplify the procedures for the algorithm analysis, debugging and verification process, improve design efficiency.

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