FAQ 202

C S-Function Techniques

Keywords

C S-function; templates; size information; accessing inports and outports; persistent memory; multirate; enabled subsystems; MEX DLL file; S-Function block

Question

Where can I find condensed information on the standard S-function techniques that can be used with dSPACE software?

Solution

You can find the complete documentation of the various S-function techniques in *Developing S-Functions* by MathWorks: http://www.mathworks.com/help/pdf_doc/simulink/sfunctions.pdf.

This PDF contains an excerpt of aspects that are especially important when using S-functions in a dSPACE environment.

How to Use an S-Function Template

Since all S-functions use the same set of individual routines (C S-function callback methods), it is recommended that you start your programming with an S-function template.

- If you want to create a new S-function, take the S-function template sfuntmpl_basic.c file from the <MATLAB_ROOT>\simulink\src\ folder.
- If you want to modify an RTI-specific S-function, take the desired original S-function C file from the %DSPACE_ROOT%\MATLAB\RTI\RTI<XXXX>\SFcn\ folder.

The original S-functions are restored and updated during any new installation. Therefore, before you modify any template, copy it to the working folder that contains your model and rename the template. It is then available for all models located in that folder.

To get an S-function template

1. Copy the desired S-function template to the working folder that contains your Simulink model.
2. Choose a name for the S-function and rename the file accordingly. Enter the S-function name (without the .c extension) at the macro definition S_FUNCTION_NAME in the C file.

When you configure the S-Function block for the Simulink model, enter the S-function name (without .c extension) in the Block Parameters dialog.

Size Information

The size information is a vital piece of information for an S-function. It defines the number of inputs, outputs, states, and sample times. Simulink and Simulink Coder (formerly Real-Time Workshop) require this information to check whether the S-Function block has the correct number of ports, which sample time is used, etc. Therefore, you have to specify this information in the `mdlInitializeSizes()` and `mdlInitializeSampleTimes()` source code methods.

The following code excerpt shows the size information for an S-function that reads one Boolean input in the `mdlOutputs()` method. It has no parameters, no states, and no outputs. It has only one sample time and is not executed in the minor time steps of higher-order integration algorithms.

```
/* Function: mdlInitializeSizes =========================== */
static void mdlInitializeSizes(SimStruct *S)
{
/* This S-function has no parameters. */
ssSetNumSFcnParams(S, 0); /* No. of expected parameters */
if (ssGetNumSFcnParams(S) != ssGetSFcnParamsCount(S)) {
return;
}
/* Set the number of states to zero. */
ssSetNumContStates(S, 0);
ssSetNumDiscStates(S, 0);
/* Set one input port. */
if (!ssSetNumInputPorts(S, 1)) return;
/* Set width of input port to one. */
ssSetInputPortWidth(S, 0, 1);
/* Input is accessed in mdlOutputs() routine,
therefore set direct feedthrough flag. */
ssSetInputPortDirectFeedThrough(S, 0, 1);
/* Set the input port data type to boolean. */
ssSetInputPortDataType(S, 0, SS_BOOLEAN);
/* We have no output ports, therefore we must not
call ssSetOutputPortWidth()! */
if (!ssSetNumOutputPorts(S, 0)) return;
/* This S-function has one sample time. */
ssSetNumSampleTimes(S, 1);
/* No work vectors and other special features are used. */
ssSetNumRWork(S, 0);
ssSetNumIWork(S, 0);
ssSetNumPWork(S, 0);
ssSetNumModes(S, 0);
ssSetNumNonsampledZCs(S, 0);
/* No additional options are used. */
ssSetOptions(S, 0);
}
```

```
/* Function: mdlInitializeSampleTimes ===================== */

static void mdlInitializeSampleTimes(SimStruct *S)

{

/* Use inherited sample time. */

ssSetSampleTime(S, 0, INHERITED_SAMPLE_TIME);

/* Ensure that this S-function will not execute in

intermediate integration steps. */

ssSetOffsetTime(S, 0, FIXED_IN_MINOR_STEP_OFFSET);

}
```

Accessing the Inports and Outports of an S-Function Block

An S-Function block can have multiple inports and outports. They can be scalar or vectorized and have different data types. The following topics provide a detailed description of how you can access inports. The method for accessing outports is very similar (using `ssGetOutputPortRealSignal` and `ssGetOutputPortSignal`).

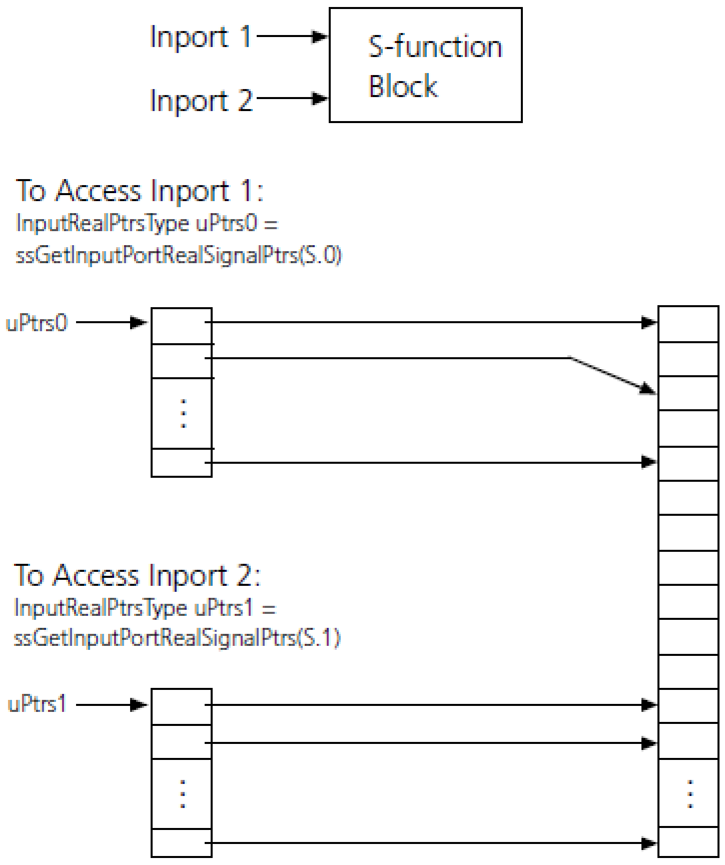
The following code excerpt shows how to access all the inports and their individual signals by using the `ssGetInputPortRealSignalPtrs` access macro. For example, you could use this code fragment in the `mdlOutputs()` S-function method. This example assumes that all inports have the ‘double’ data type.

```
int_T idxPort,idxSignal;

int_T nInputPorts = ssGetNumInputPorts(S);

for (idxPort = 0; idxPort < nInputPorts; idxPort++)

{

real_T input;

InputRealPtrsType uPtrs = ssGetInputPortRealSignalPtrs(S,idxPort);

int_T nPortWidth = ssGetInputPortWidth(S,idxPort);

for (idxSignal = 0; idxSignal < nPortWidth; idxSignal++)

{

input = *uPtrs[idxSignal];

SomeFunctionToUseInputSignalElement(input);

}

}
```

The pointer for each inport must be fetched separately via the `ssGetInputPortRealSignalPtrs(S,i)` macro. This macro is valid only for input signals of ‘real’. If you want to process a signal of another type, you have to use `ssGetInputPortSignalPtrs`.

If the port is vectorized, the retrieved pointer points to the first element of the vector. To reach the subsequent signals, you can simply increment the pointer as done with `*uPtrs[idxSignal]` in the example.

The input variables of the individual inports are not located one after another in the memory. Refer to the following illustration. Therefore, you cannot reach the signals of different ports only by incrementing the pointer to the first inport.


Inport 1
Inport 2
S-function Block
To Access Inport 1:
InputRealPtrsType uPtrs0 = ssGetInputPortRealSignalPtrs(S.0)
uPtrs0
To Access Inport 2:
InputRealPtrsType uPtrs1 = ssGetInputPortRealSignalPtrs(S.1)
uPtrs1

For more information, refer to *Accessing Signals Using Pointers in Writing S-Functions* by MathWorks.

Accessing Inport Signals in mdlOutputs()

If your S-function has inports and outports, you usually calculate the output signals in the `mdlOutputs()` method by using at least one of the input signals. For S-functions, such an inport has a direct feedthrough, which must be specified via the following entry in the `mdlInitializeSizes()` method:

```
void ssSetInputPortDirectFeedThrough(SimStruct *S, int_T port,int_T
dirFeed)
```

If the direct feedthrough flag is incorrectly set for an inport, the result of the calculation cannot be predicted and you might encounter run-time errors that are difficult to find.

For example, to set the direct feedthrough flag for inport 2, specify the entry as follows:

```
ssSetInputPortDirectFeedThrough(S, 2, 1)
```

How to Use Persistent Memory in S-Functions

Suppose you want to use the results from one calculation step in the next one, which means that you need to retain the values of variables between the successive calls of the S-function methods. If you want to use several copies (instances) of the same S-function in your model, you must ensure that the

S-function is re-entrant so that the execution of one instance does not influence the execution of another. In this case, you can use work vectors for data storage. Work vectors provide the necessary instance-specific storage for block variables and therefore grant re-entrancy for the S-function.

Work vectors must be initialized in `mdlInitializeConditions()` or `mdlStart(.)` They are updated in `mdlUpdate()` (discrete states), and used in `mdlOutputs()`.

To use work vectors in an S-function

1. Define the size and data types of the required work vectors in the `mdlInitializeSizes()` S-function method via the following macros:

```
ssSetNumRWork(S, <NUM_RWORK>); /* doubles typed*/

ssSetNumIWork(S, <NUM_IWORK>); /* integer typed*/

ssSetNumPWork(S, <NUM_PWORK>); /* pointer typed*/
```

2. Use the following macros to access the pointers that reference the work vectors:

```
ssGetRWork(S); /* doubles typed*/

ssGetIWork(S); /* integer typed*/

ssGetPWork(S); /* pointer typed*/
```

To observe the work vectors, for example, via ControlDesk, they must be available in the system description file. The easiest solution is to create additional outports in your S-function because outports are automatically generated into the system description file.

It is not recommended to use global or static variables to store S-function data, because global variables are used by all instances of an S-function. Therefore, such S-functions are not re-entrant. Suppose your model contains two instances (a and b) of an S-function that uses a set of global variables. If instance (a) writes data to the global variables and then (b) is called and writes data, (a) gets the wrong data the next time it is called.

For more information, refer to *Developing S-Functions* by MathWorks.

How to Use Sample Times in an S-Function

You can specify different sample times for the internal processes of the S-Function block.

Port based: You can define individual sample times for the inports and outports of the S-Function block. For more information, refer to the documentation of MathWorks.

Block based: If no sample times are specified for inports and outports, they are updated with the fastest sampling rate of the S-function. This method is most commonly used.

To assign a specific sample rate to a code block

1. Include the following lines in the `mdlInitializeSampleTimes()` S-function method for each sample time you want to use:

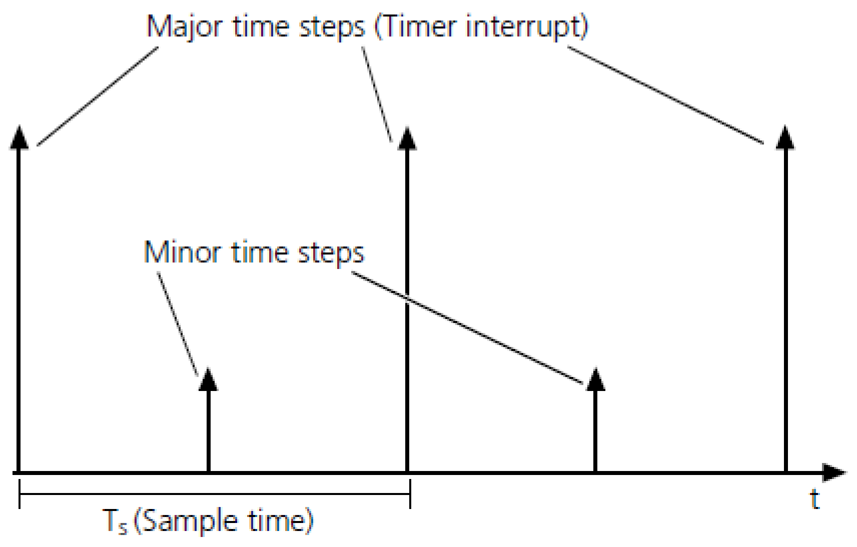
```
ssSetSampleTime(S, <SAMPLE_TIME_IDX>, <SAMPLE_TIME>);

ssSetOffsetTime(S, <SAMPLE_TIME_IDX>, <SAMPLE_TIME_OFFSET>);
```

2. Identify the code block you want to assign to a specific sampling rate and enclose it in an if statement using `ssIsSampleHit(…)`, for example:

```
if(ssIsSampleHit(S, sample_time_index, tid))
```

```
{
/* code block assigned to the sample time with
sample_time_index */
}
```

If you select a higher-order, fixed-step numerical integration algorithm for your model, e.g., ode2 … ode5, the `mdlOutputs()` method is called not only for the major time steps but also for the minor time steps to improve the precision of the simulation results. This is shown in the following diagram.



If you use an S-function to control hardware, you might need to suppress the calls to `mdlOutputs()` at the minor time steps because certain hardware has a limited maximum sampling rate. For example, an A/D converter needs a certain amount of time for each conversion process.

To exclude code blocks from the minor time steps

➤ Set the `FIXED_IN_MINOR_STEP_OFFSET` flag in the `ssSetOffsetTime` method, for example:

```
ssSetOffsetTime(S, 1, FIXED_IN_MINOR_STEP_OFFSET);
```

As a result, the code blocks assigned to the sample time with ID ’1’ are excluded from the minor time steps. In other words: the outputs are held constant during the minor time steps.

S-Functions in Enabled Subsystems

There are two options for setting the states when enabling a subsystem again. You can select them via the Block Parameters dialog of the Enable block.

Hold: The states of blocks in the subsystem remain constant when the subsystem is disabled. When the subsystem is enabled again, the held states are used for simulation. Any contained S-function is initialized once at simulation start (i.e., `mdlStart()` and `mdlInitializeConditions()` are executed).

Reset: The states of blocks in the subsystem are reset to their initial values. When the subsystem is enabled again, the simulation continues with the initial values. Any contained S-function is initialized at simulation start (i.e., `mdlStart()` and `mdlInitializeConditions()` are executed) and each time the subsystem becomes enabled (i.e., `mdlInitializeConditions()` is executed).

Place the initializations in the correct S-function method:

- `mdlStart()`. Use this method for initializations that need to be carried out only once, for example, when initializing I/O devices.
- `mdlInitializeCondition()`. Use this method for initializations that must be carried out each time the subsystem becomes enabled, for example, when initializing variables.

If an I/O device is initialized more than once, for example, if you place the initialization in `mdlInitializeConditions()` by mistake, it might not be possible to predict the behavior of the device. Therefore, use `mdlStart()` for initializations that must occur only during simulation start.

How to Generate the Corresponding MEX DLL File

In addition to the source C file of an S-function, Simulink and Simulink Coder require a compiled version of the S-function: the MEX DLL file. If you perform a Simulink simulation of your model, Simulink uses the MEX DLL file to calculate the S-function. If you generate real-time code, Simulink Coder needs the MEX DLL file to read the size information of the S-function. You can generate the MEX DLL file for an S-function via the MATLAB mex command. However, MATLAB must be set up properly before you can use the mex command.

To set up the MATLAB MEX command

1. Install an appropriate C compiler. In 32-bit installations of dSPACE, you can use the LCC compiler, which is part of the MATLAB installation. For 64-bit versions, you have to use the compiler that is included in Microsoft Windows SDK 7.1. This is the only supported MEX compiler for 64-bit releases. You can download Microsoft Windows SDK 7.1 from the Microsoft homepage. For more information, refer to the following document in dSPACE HelpDesk: Release > New Features and Migration > Compatibility Information > Supported MATLAB Releases.
2. Change to the MATLAB Command Window and enter the `mex -setup` command. Then follow the instructions on the screen.

Once the setup is done, MATLAB is ready to compile MEX DLL files. You can generate the MEX DLL file for an S-function in the following way:

To generate the corresponding MEX DLL file

➢ In the MATLAB Command Window, enter `mex <source>.c -v`. Replace `<source>` with the file name of your C source file.

The **-v** option makes the MEX compiler display the options used, and issue any warnings.

- If you created a new S-function, you always have to generate a MEX DLL file. However, if you modified an existing S-function, you might not need to recompile the MEX DLL file. You can reuse the old MEX DLL file if you want to use the S-function only for real-time simulation and you did not change its size information or sample time.
- If you want to keep your MEX DLL files in a separate folder, you have to add the folder to the MATLAB search path (via the `addpath` command or the path tool) and RTI's make search path (via the `<model>_usr.mk` file).

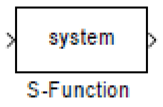
For information on the available options for the `mex` command, refer to *External Interfaces* (`apiext.pdf`) by MathWorks: https://www.mathworks.com/help/pdf_doc/matlab/apiext.pdf

How to Use S-Functions in a Simulink Model

Since the S-Function block has no function on its own, you have to handcode the desired functionality in C.

To include S-functions in a Simulink model

1. Place the S-Function block from the Simulink library in your model and open its Block Parameters dialog.

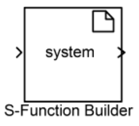
   If you want to include an S-function that was generated from a Simulink model, you can do so as well. For this, use the S-function target of Simulink Coder to generate the S-function from your model or subsystem.

   In the Name field of the S-function, enter the name (without the `.c` file name extension) you want to assign to the S-function. The underlying C file must have the same name. If the S-function requires any parameters, you can specify them in this dialog as well.

Once the MEX DLL file is available for the S-function, the S-Function block automatically has the correct number of ports.

S-Function Builder

As an alternative to a handcoded S-function, you can use the S-Function Builder block to implement simple C-coded S-functions. This Simulink block builds an S-function from specifications and C code that you supply. The block also serves as a wrapper for the generated S-function. The block is available from the User-Defined Functions library and is shown below.



Related dSPACE HelpDesk documents

- *Implementing S-Functions* in the *RTI and RTI-MP Implementation Guide*

Related FAQs

- *FAQ 255:* Implementing C coded S-Functions for RTI
- *FAQ 260:* Migrating a Hand coded Application into an S-Function

FAQ Overview

http://www.dspace.com/go/faq

Support

To request support, please use the form at http://www.dspace.com/go/supportrequest

Updates and Patches

Software updates and patches are available at http://www.dspace.com/go/patches.
dSPACE strongly recommends to use the most recent patches for your dSPACE installation.

Important Notice

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