

Elmo's **Gold** Line

Our Best Ever Motion Solutions

G-MAS – Gold Maestro Software User's Manual



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www.elmomc.com

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Chapter 1: About the G-MAS and this manual

This chapter describes the G-MAS product and the organization of this manual. Persons beginning to understand the G-MAS and program it, should read this manual carefully. However, experienced G-MAS users may omit this chapter.

1.1. What is the G-MAS

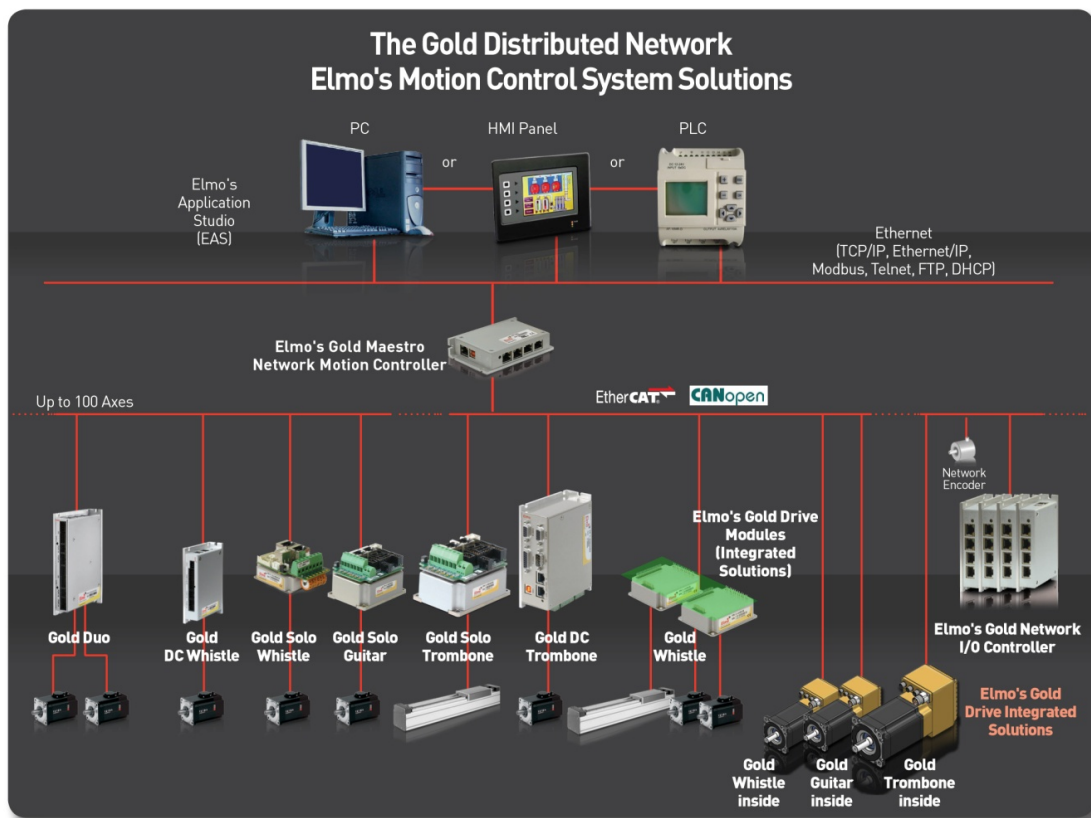
The Gold Maestro – G-MAS is an advanced multi-axis machine controller.

It is a programmable control unit, with built-in, ready-to-use, standardized functionalities for communications, motions, emergencies, timing, events and all that is required (and desired) to implement a complete multi-axis motion control system.

The figure below presents the structure of a motion control system based on the G-MAS and Elmo’s digital drives. This system is based on the following three layers:



- Host computer (or PLC or HMI Panel)
- G-MAS
- Devices (Digital Drives, I/O controllers, network encoders ...)



The machine’s host computer (or PLC, HMI panel) typically executes the interfaces to the machine operator and performs high-level management and machine algorithms, as necessary.

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Digital servo drives control and drive motors, with each drive generally responsible for a single axis (control, motions, safety, limits, etc.), as well as some I/Os that may be connected to the digital servo drive. With Elmo intelligent digital servo drives, each drive can be programmed to perform simple and advanced processes, which is only limited to axis level process (in contrast to machine, or multi-axes level).

I/O controllers and other devices can be added to the device network.

The host computer (or PLC, HMI panel) is responsible for user interfaces and high-level machine processes, whereas the digital servo drives (and I/Os controllers) execute axis or I/O level processes. Therefore, an intermediary layer is necessary to perform the machine’s sequences and multi-axis synchronized motions. This is exactly where the G-MAS comes in.

The G-MAS is located in the intermediary layer. It receives high-level commands from the host computer, performs the required machine sequences, calculates multi-axis motions and, opportunely, communicates via the device network to synchronously send commands to each axis. Obviously, the G-MAS also collects statuses from the network devices and in turn sends its own statuses to the host computer.

From the network devices view, the G-MAS is important, since each network device views only a very narrow (axis, I/O) portion of the overall system and therefore cannot create or control overall system sequences or multi-axis synchronized motions. The network devices require a device like the G-MAS to take this responsibility.

From the host computer (or PLC, HMI Panel) view, the G-MAS is not as important, as in theory, one can implement all the functions of the G-MAS into the host computer. However, this entails a variety of significant drawbacks e.g. huge development time, significant risks, non-modular implementation, “inventing the wheel” etc. that are easily and elegantly solved using the G-MAS.

With its turnkey, in-built functionality (standard implementation of: PLCopen motions, Ethernet communications, CANopen, CANopen over EtherCAT, etc.) and support for C user programs, to easily implement a multi-axis motion control system, you only need to write your first C program for the G-MAS. This is probably why you are now reading this manual...

1.2. G-MAS Features

The following presents some of the G-MAS features. You may refer to Elmo’s website at www.elmomc.com for additional detailed information and brochures.

- High performance, distributed multi-axis network controller, with real-time extension of the Linux operating system.
- Controls up to 100 axes over device network with a high level of synchronization and accuracy.
- Host communication channels and protocols:
 - Ethernet, TCP/IP, UDP (fast binary protocols, MODbus, Ethernet/IP, Telnet, FTP, HTTP)
 - USB 2.0
- Device networks (fieldbuses) and protocols:
 - EtherCAT real-time device networking (CoE, Distributed clock), or:

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- CANopen: DS-301, DS-305, DS-401 (I/O device profile), DS-402 (drive and motion control device profile)
- Built-in functional block libraries:
 - Communication with host
 - CANopen over CAN and EtherCAT
 - PLCopen motion
 - Events
 - Data recording
- Programming:
 - Native application 'C' programming on the target
 - IEC 61131-3, PLCopen (future feature)
- Package and power supply:
 - Very compact, space saving package. The Gold Lion for embedded military applications.
 - DC powered: 14 V to 196 V.

It is important to note that one of the main criteria that guided the G-MAS development (together with all Elmo’s Gold family products) was to use market-leading standards wherever possible. Furthermore, each standard was accurately implemented, ensuring mandatory complete implementation of the standard. With Elmo’s Gold product family, this can be found, for example, in the host communication (MODbus, Ethernet/IP), Device Network (CANopen, CANopen over EtherCAT), safety, PLCmotion library, I/Os interface circuits, etc.

1.3. What the Document Covers and How to Use It

This manual is organized to create a progressive path for the user starting from the G-MAS basics to gradually achieve the potential for advanced and complex systems programming.

The manual begins explaining the G-MAS structure and programming guidelines and continues with a detailed explanation of an Application program written for an XYZ robot.

The explanation starts with the top-level code structure and later, systematically, immerses into the code details. Therefore, for beginners, it is recommended to read this manual chapter-by-chapter.

The manual and its code examples are organized to allow the reader to learn, chapter by chapter, firstly about the G-MAS functions and ease of use, and then progressively, about the details of implementation, with increasing details revealed in later chapters or explanation.

Chapter 2: Just Before Starting Up

This chapter presents the required preparations before you can start using the G-MAS and its PC software environment.

In addition, it explains how the incorporated examples relate to Elmo’s demo suitcase, and how they can be adapted to match your specific system.

This chapter must be read, and the preparations described within, implemented, to be properly proficient in operating the G-MAS and developing user programs for it.



2.1. Preparing Your Computer

The PC software environment for the G-MAS includes the EAS (Elmo Application Studio) and the C programming development environment. These application modules must be installed to be able to operate with the G-MAS.

The EAS is Elmo’s setup and maintenance application for the Gold line products, including the G-MAS and Gold Drives. As a G-MAS user, you will need this application to configure your system (network, devices, etc.), communicate with the G-MAS, and to perform a variety of features incorporated within EAS, e.g. to create, record and display multi-axis motions.

The C programming development environment is necessary to develop (write, download, debug) C programs for the G-MAS.

Please refer to Chapter 7: PC Software Installation and how to use for details regarding the installation of the required G-MAS software process, and how to use these software modules.



Please continue using this manual only after properly installing the applications and understanding how to use them. The remainder of this manual assumes that the user is familiar with the application environments.

2.2. Using the Manual’s Examples

The entire C programs examples (unless specifically mentioned otherwise) included within this manual were developed for, and tested with Elmo’s demo suitcase. This suitcase consists of a G-MAS and two Elmo digital servo drives (and motors) connected to it over a device network.

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The Gold Line demo suitcase includes two Gold line digital servo drives connected to the G-MAS over EtherCAT while the SimplIQ Line demo suitcase includes two SimplIQ drives connected to the G-MAS over the CAN bus.

Therefore, the examples provided within this manual are adjusted to either configuration, whether Gold or SimplIQ demo system, and is mentioned within each example. However, not all examples may work for a different system configuration.



It is therefore recommended to consider purchasing of a demo suitcase (Gold or SimplIQ, depending on your needs) for conveniently practicing this manual’s examples. Please address your local Elmo’s sales channel to order a demo suitcase.

If you prefer to use your own system for practicing this manual’s examples, you will need to slightly modify them according to the structure of your own system. Use the guidelines described within the following the table to properly modify this manual’ examples.

Your System Structure	Necessary modifications for examples written for CAN	Necessary modifications for examples written for EtherCAT
G-MAS with 2xSimplIQ drives over CANbus	None	Resource file that represents the system. Should call the GetCommStatistics() API in order to check that the network setup is OK. This is instead of NetworkInfo() which is for CAN. Change operation mode to Cyclic Position mode and not Interpolated Position.
G-MAS with 1xSimplIQ drive over CANbus	New resource file. Or change the second axis to virtual mode.	As above plus the changes to the left for the single axis.
G-MAS with NxSimplIQ drives over the CAN bus (N>2)	As above	As above
G-MAS with 2xGold drives over the CAN bus	Currently, we use interpolation mode, as defined in DS402 ver. II. The new standard uses cyclic position instead.	Currently, we use interpolation mode, as defined in DS402 ver. II. The new standard uses cyclic position instead.

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Your System Structure	Necessary modifications for examples written for CAN	Necessary modifications for examples written for EtherCAT
G-MAS with 1xGold drive over the CAN bus	As above	As above
G-MAS with NxGold drives over the CAN bus (N>2)	As above	As above

Chapter 3: Programming Practices and Guidelines

This chapter describes the practices and guidelines used by Elmo’s team to developed examples and application programs for the G-MAS. These guidelines are based on worldwide common C programming practices with some expansions required to create a complete set of guidelines and concepts for the G-MAS C programming

Most of the guidelines do not really affect the execution of the code (do not directly improve code size, or speed, or performance in general), so, why is it so important to use them? For the following reasons:

1. Most of the guidelines relate to code readability, portability, ease of development, and debugging. This means that your development process is assumed faster and easier with these guidelines.
2. Some of the guidelines, especially those that relate to programming concepts, are more than just “how to make my code clearer”. They really affect the ease of implementation, execution performance, and the time-to-market of your project. One of these guidelines is the concept of States Machine programming, as you will see later on this manual. It is one of few possible methods to implement machine sequences, and practically, it proved itself the simplest and the most successful method to use.
3. You can better use the examples and Case Studies provided by Elmo, as they are all written according to these guidelines and programming concepts.
4. And most important, to enable the best support you can get from Elmo. Application programs may become large and quite complex for significant projects. Using your own programming concepts, as good as they surely are, will make it much more difficult for Elmo’s support engineers to perform in-depth analysis. You may need to send us your code, or parts of it, at some point in the future, and it may become impossible for us to analyze and track its details unless it is written according to the guidelines and concepts described in this chapter.

It is therefore strongly recommended to use these guidelines, practices and programming concepts when developing your own C programs for the G-MAS.



3.1. Projects and files

This section describes some guidelines regarding organization and naming of projects and files.

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3.1.1. Project Location and Naming

All projects (applications) shall be located under the C:\GMAS\MyGMASProjects directory, which is created during the software environment installation process. The root directory C:\ can be replaced with the actual name of your disk.

Each project should be located within a specific directory under the above location, with only one project within a given directory.

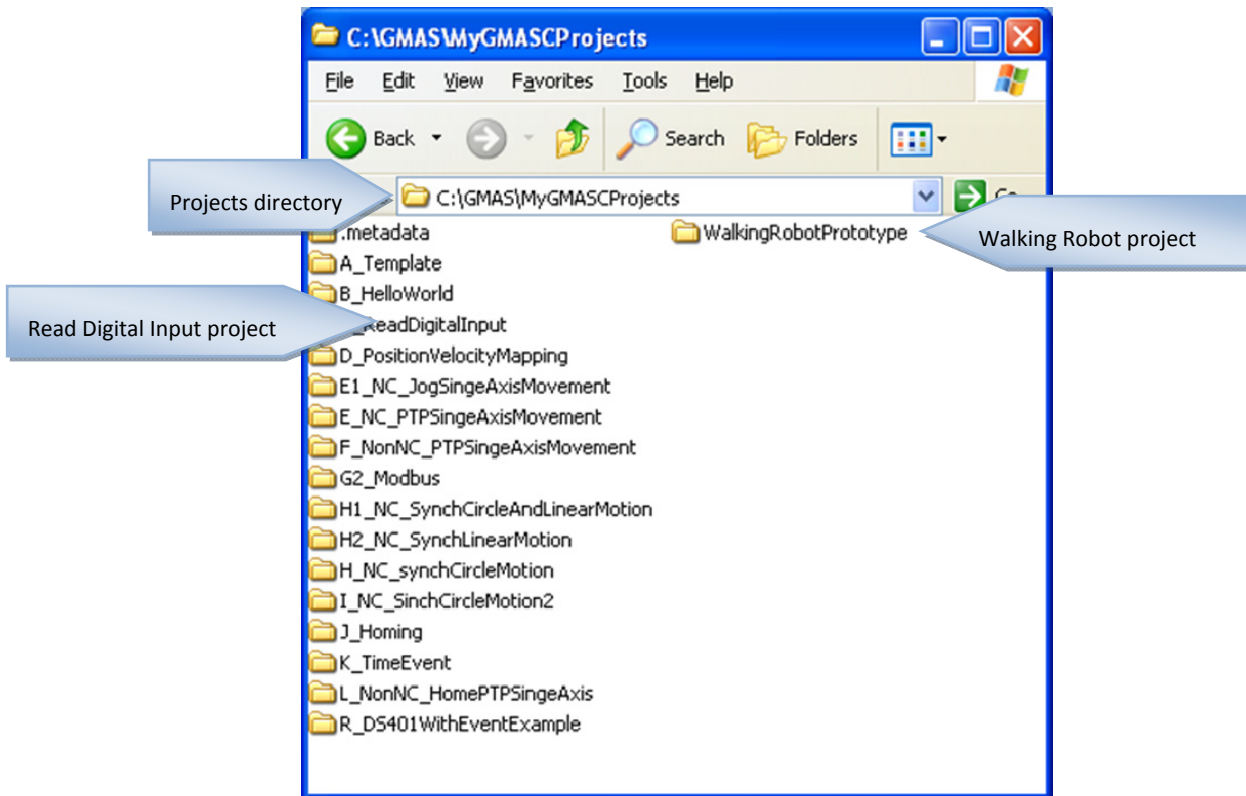
The name of a project’s directory should reflect the name of the project (application). For example, from Elmo’s set of C programs examples: “C_ReadDigitalInput” (see screen snapshot below). Note that the name of the project’s directory respects the following guidelines:

- It reflects the project/application contents.
- It has no spaces.
- If it consists of few words, each word starts with a Capital letter for easy reading.
- Finally, for convenience only, Elmo adds a prefix to the project’s name (in this case: “C_”) to force the list of the projects to appear in a given order within Windows explorer. This is done in order to organize our built-in examples in a desired order for the readers of this manual. You are not required to add this prefix (see customer’s project WalkingRobotPrototype within the screen snapshot below).



The above three guidelines for naming project’s directory, are also applicable for naming all of the project’s C and H files. The name must reflect the content of the file, include no spaces and each word in the name should start with a capital letter, e.g.: ReadDigitalInput.c

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3.1.2. Project’s Files

Each project will be based on a main C file, respecting the following guidelines:

- Its name will be identical to the project’s directory name (without the prefix, if used). For example: ReadDigitalInput.c
- It will include the main() function, which will be the first function within the file.

Each project will also include a main header (*.h) file, which will be also named with the name of the project (e.g. ReadDigitalInput.h) and will include all definitions which are specific for the project (such as constants, functions prototypes, etc.).

In addition, the developer can create additional code and header files, as may be needed to properly organize the various C functions. All files should be named using the above file naming guidelines.

3.1.3. Project’s Description Files

Elmo highly recommends that an application programmer should add some files to a project’s directory that explain the project goals, tasks, methods of implementation, etc. It can be a simple readme file or files that are more complex (machine specification, motion sequences, machine’s ATP, design reviews for the implementation, etc.). This information, if supplied with the overall project code files (for a new member in the development team, and/or for Elmo’s staff for support, etc.) can significantly improve processes e.g. learning, support for the project, etc.

Please refer to the project’s description files included with each of Elmo’s examples (located at C:\GMAS\MyGMASCPProjects as part of the Development Software installation process) for examples of such files.

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3.2. Functions, Variables and Constants

The naming and usage of functions, variables and constants should abide by the following guidelines:

- Functions should be named similarly to files. For example: MainTimer().
- Variables should also be named similarly, but should be preceded with the variable type in lower case, according to the table below. For example: *iSpeed* can be the name of an integer variable holding a value of speed.

Type	Prefix	Example
Integer	i	iMotorSpeed
Unsigned integer	ui	uiUpperLimit
Long	l	lPosition
Unsigned long	ul	ulLimitPosition
Short	s	sAnalogInput
Unsigned short	us	usDigitalInputs
Char	c	cErrorString
Unsigned char	uc	ucASCIICode
Enum	e	eTargetPositions
Struct	st	stHalt

- Constants shall be named using the following format: MY_CONSTANT (all capitals, “_” between each word).
- Global variables are allowed and recommended for variables accessed by more than one function. They should be defined at the top of a C file (in most cases, the project’s main C file). The Global variable’s name should have an additional “G” at its prefix, e.g. glPosition, gcErrorString. This will indicate to the programmer that the variable is Global.

3.3. C and Header Files

The code within the C files should respect the following guidelines:

- The main project’s C file should start with some comments lines describing the application.
- Each function should be preceded with some comments lines, providing as much details as possible about the function (what it does, input and output parameters, who wrote it, version, etc.).
- The main() function should be the first function within the project’s main C file. It should be typically defined as: Void main()
meaning, no arguments are expected when executing the project and no returned value to the operating system upon exiting the application.
In case arguments should be passed to the application code from the operating system, or if the

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application should return a value to operating system upon exiting, please refer to the relevant example included within the examples directory (c:\GMAS\MyGMASProjects).

- A C file should “include” only the header files necessary.
- The code should not include numbers. Constants should be defined within the relevant header file and the value of the constant should be defined only within the header file. For example: HOMING_SPEED.
- This includes values like “0” and “1”. Define OK and NOT_OK (and/or similarly, like TRUE, FALSE).
- Code should be vertically aligned and properly nested.
- Use TABS, not spaces to align the code vertically.
- Opening and closing brackets (“{” and “}”) should be each written in a separate line.
- Comments (files and functions titles, in-line comments, end of line comments, etc.) should use the format (or style) as shown with the sample code at the end of this chapter.

3.4. Wrapper functions

Wrapper functions files are files that hold a set of logically related functions (actually, a library of functions). Each function is written to “hide” a relatively complex process/code with a simple interface for the programmer. An example can be a Wrapper Functions file that will include a set of functions for motion. It may contain, for example, a function like MyMoveAbsolute(dSpeed, dPosition). This function has a very simple interface (can be easily used to create a motion, as all you need to enter are values for Speed and Position), but internally, it will use the less simple PLCopen Motion function, including parameters initializations, validity checks, etc.

Wrapper Functions help to keep the main code cleaner and more elegant. While reading (and debugging/modifying) the main code, one would like to easily see the implemented machine sequence (program flow) and this can be done only if the details of the code are hidden within function calls.

A call to a function named “MMC_InitSystem(…)” will be much clearer than placing the detailed code of the system initialization (axes, communication etc.) online within the main code. Therefore, if necessary, the developer can perform in-depth analysis on the detailed code in the wrapper function.

Wrapper Functions can be used for various proposes:

- Hiding Complex and/or Not Important Code Segments
- Hiding repeated segments of code
- Providing easier interfaces (“shortcuts”) for repeated calls to functions

3.4.1. Hiding Complex and/or Not Important Code Segments

When programming a complex synchronized distributed system, the overall code will typically include relatively complex, long and “non-interesting” segments of code. These segments generally deal with the detailed implementation of the system initialization, management, error handling, termination etc. This code is not necessarily related to the main goal of the project – to perform the machine sequence.

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If these segments of code remain within the main code, the main code will become too complex, blocking reasonable reading and tracking of what is most important; the implementation of the machine sequences and logic.

Wrapper Functions can be used to hide these segments of code. Such Wrapper Functions are supplied by Elmo so that our examples can be read and understood much easier.

3.4.2. Hiding Repeated Segments of Code

Repeated segments of code, even if not complex, and even if important to understand the program flow (the machine sequences), can be hidden inside a Wrapper Function to minimize the main code length.

3.4.3. Providing Easier Interfaces

Some of the built-in G-MAS Function Block functions have complex interfaces, i.e. a function with many arguments, with some of these arguments also complex structures. This complexity is necessary to maintain compatibility with standards like PLCopen Motion and to enable full operation of the function.

However, in most situations, and your case may be one of them, the application does not need full operation of the Function Block, but only needs a small subset of the Function Block interfaces. Under these circumstances, the programmer (or Elmo within its examples) may define a new function that will have a simple interface with the program and will internally assume some defaults for the remaining functions arguments.

An example can be a simple motion function (to be typically located within a Wrapper Functions file that will include many functions for simple motions), e.g. MoveAbs(iPosition).

This function accepts only one argument, the desired position, and creates a motion to this target position, using the full mechanism of the PLCopen Motion Function Blocks. It will assume default values for the additionally needed arguments, like speed and acceleration, or will keep the values used recently – depending on the actual coding of the MoveAbs() function (this of course must be clearly documented for the users of the wrapper function).

Assuming that the user understands what are the default actions taken by the wrapper function, it is much easier to call the MoveAbs() than the standard PLCopen Move Absolute function.

Another example may be:

```
int iEndMotionReason = MoveAbsWaitEndMotion(iPosition)
```

This is clearly a function to create motion and to wait to its end (whatever is the reason; reaching the target, limit, error, ...). The function returns only when the motion ends, returning the reason for the end of motion.

In general, Wrapper Functions are libraries of functions that are aimed to simplify the writing and the reading of the main code – the machine sequences.



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Elmo supplies a set of Wrapper Functions files as part of its set of examples. You can define and create your own set of Wrapper Functions files (starting from scratch or based on one of Elmo’s examples), as suitable for your projects and style of writing.

Wrapper Functions files should follow the following guidelines:

- Elmo’s supplied Wrapper Functions files should not be modified. Instead, if modifications are necessary, copy the file to a new file and modify it.
- Each Wrapper Functions file should include a set of functions that are logically related. Each function should have a simple user interface.
- Each Wrapper Functions file should be named to reflect its contents. For example: SimplifiedSynchronizedMotions.c.
- Each Wrapper Functions C file should have a header file (*.h), with the same name. The header file will include definitions relevant to the Wrapper Functions file, as well as prototypes for the wrapper functions included within it.
- The general (not example specific) Wrapper Functions files that are supplied by Elmo, are located under the G:\GMAS\GMASCWrapperFunctionsFiles.
- Additional Wrapper Functions files that are more specific to a given project/application should be located within the project directory.
- If a Wrapper Function acquires a number of assumptions (default values, keeping previous values, etc.), these assumptions must be clearly documented for the user.
- It is strongly recommended that a Wrapper Function (unless it was written to a very specific and fixed project) will not include default values for parameters. An easy mistake can be, for example, to assume a value of 100000 (for example) for a simplified motion function. This may work perfectly for a given example, but will not be suitable for a future example, when no one will remember this default decision. Other solutions are recommended (for example, to include a Wrapper Function within the file that will be used to initialize all this default values from the main code). Something like:
InitMotionsWrapper(iSpeed, iAcceleration, iDecelaration, iMode, iSmoothing, ...)
Then the programmer can freely use MoveAbs(iPosition) etc.

3.5. Implementing machine sequences

A program that handles machine sequences should answer the following requirements:

- Capable to handle a number of sequences in parallel.
For example, assuming that the G-MAS should handle a machine with three axes (e.g. X, Y and Z) together with an Automatic Loader that should load and unload the object to/from the machine, itself consisting of 4 axes.
Each of these sub-assemblies should be controlled in parallel, having sequences that are independent while necessarily synchronized.
A User Application at the G-MAS should be able to execute both sequences (the machine and the Loader) in parallel, and to synchronize them, when synchronization is required.

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- Capable to handle background system processes such as validation read, and handle statuses, emergencies, etc.
Many tasks should be continuously or more accurately, periodically, handled by the application. These tasks should be executed independently of the machine status and/or mode of operation.
- Capable to always be ready to receive incoming communication (typically, from the Host) with reasonable response time and more important, with pre-defined limited response time.
The application program should not be too busy (in terms of time) with any given task, and should always be able to obtain and properly respond to incoming communication.
- Determinism.
The application program should execute the same sequences, respond to incoming messages, and create communications to the device network, in a determined way, with little delays or jitters and within a predefined limit.
- Maintainability.
Finally, but not less important is the requirement for easy development and maintenance of the program. The program must be organized in a way that complex sequences can be easily written, controlled, and maintained.

There are numerous methods to write a program that will answer the above requirements. For example: multi-tasking and interrupts.

Elmo has an extensive experience in the development of user applications. We have acquired this experience during many years of customers support and during in-house development of user applications.

Based on this experience, we have concluded that the optimal method to write programs for machine sequences is a structure that is based on States Machines. This programming structure optimally answers the above requirements.

With a States Machine structure, a program does not need Multi-Tasking (a complex structure for most programmers, and obviously most Motion Control engineers) and in most cases even interrupts are not required. All that is needed is an understanding of the basics of States Machine programming. The code then becomes very simple to develop and to maintain.



All programs examples provided by Elmo are implemented using States Machine structure. It is strongly recommended to use this programming structure. It will enable easier use of Elmo’s examples, allow Elmo’s support team to provide better and faster support. In addition, it will shorten your time-to-market and reduce your development risks significantly.

This is a good point to start explaining the details of States Machine programming structure. The explanation is not simple, and is presented in a systematic procedure.

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3.5.1. The main() program structure

Elmo’s recommended structure for the main() function of a G-MAS User Application program is presented in [Figure 1](#):

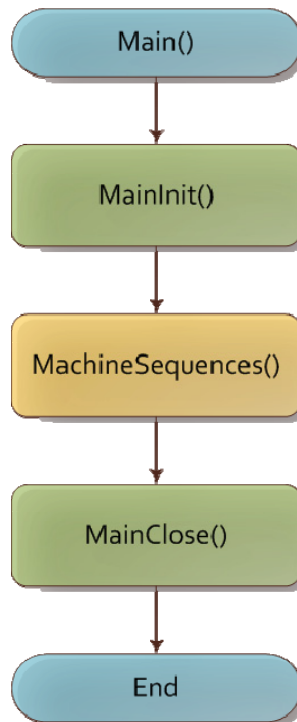


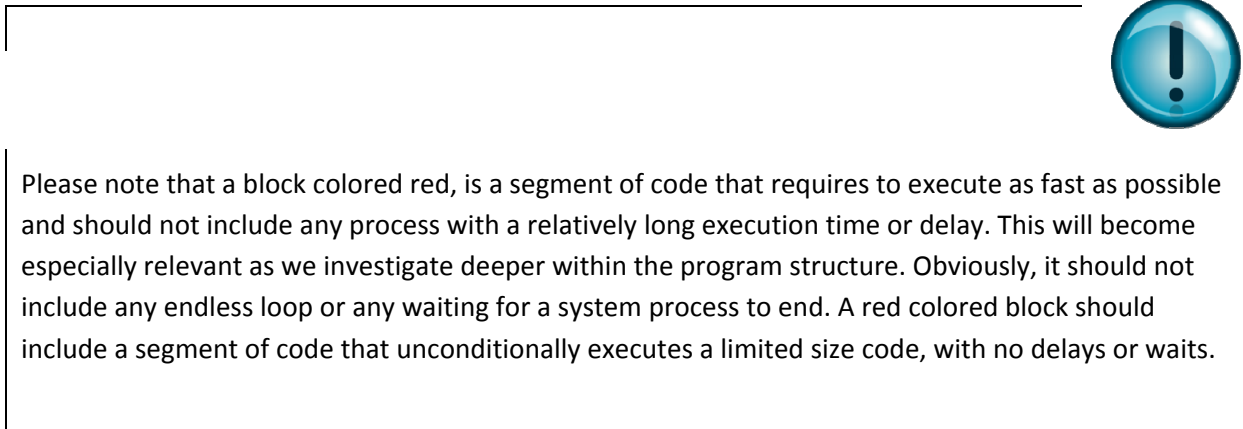
Figure 1: Main() program structure

The main() starts with a call to MainInit(), a function that performs all program and system initializations (more on this later within the manual’s examples). After all initializations are completed, the MachineSequences() function is called. This function intentionally starts the execution of the machine sequences and motions. During the machine operation, the MachineSequences() function does not return to the main(), until the program requests to terminate (due to, e.g. errors, user request to close, etc.). When the machine operation is complete, the Machine Sequences() function returns to the main(), which calls the MainClose() function to close everything that requires closing, before the program terminates.

This is the main() function of the program. Simple and clean as possible. Now we progress into the MachineSequences() function to find the implementation of the machine sequences, using the States Machine structure.

3.5.2. The MachineSequences() Function

Figure 2 presents Elmo’s recommended structure for the MachineSequences() function.



MachineSequences() starts with a call to MachineSequencesInit(). This function initializes all variables as may be required to activate the MachineSequencesTimer() and to manage the States Machine (refer to Figure 2).

Immediately after, MachineSequences() calls the EnableMainTimer(TIMER_CYCLE (Remember, the format (CAPITAL_LETTERS) refers to a constant defined by the programmer in the header file)) to start the execution of the MachineSequencesTimer() function and to define that it will be automatically executed by the Operating System (OS) each TIMER_CYCLE ms. As a typical value for these descriptions, let’s assume a TIMER_CYCLE = 20ms.

From this point on, the OS activates the MachineSequencesTimer() every 20ms. This timer function actually handles and manages the States Machine, as explained below.

The MachineSequences() function now enters an endless while loop, waiting for a global variable (giTerminate) to indicate that the MachineSequencesTimer() is asking to terminate the program. The giTerminate variable will initialize to FALSE when the MachineSequencesInit() function starts, and will optionally be set to TRUE, when and if needed (possible for a program to never terminate) by the MachineSequencesTimer() function.

Generally speaking, this endless while loop needs to do nothing except wait for a termination request. In order not to load the CPU just for running-in-loops-doing-nothing, a Sleep(SLEEP_TIME) is inserted in the loop. A typical value for the SLEEP_TIME is 100ms, meaning (in our example) that this background loop is activated approximately each 5 cycles of the timer function (which is activated every 20ms).

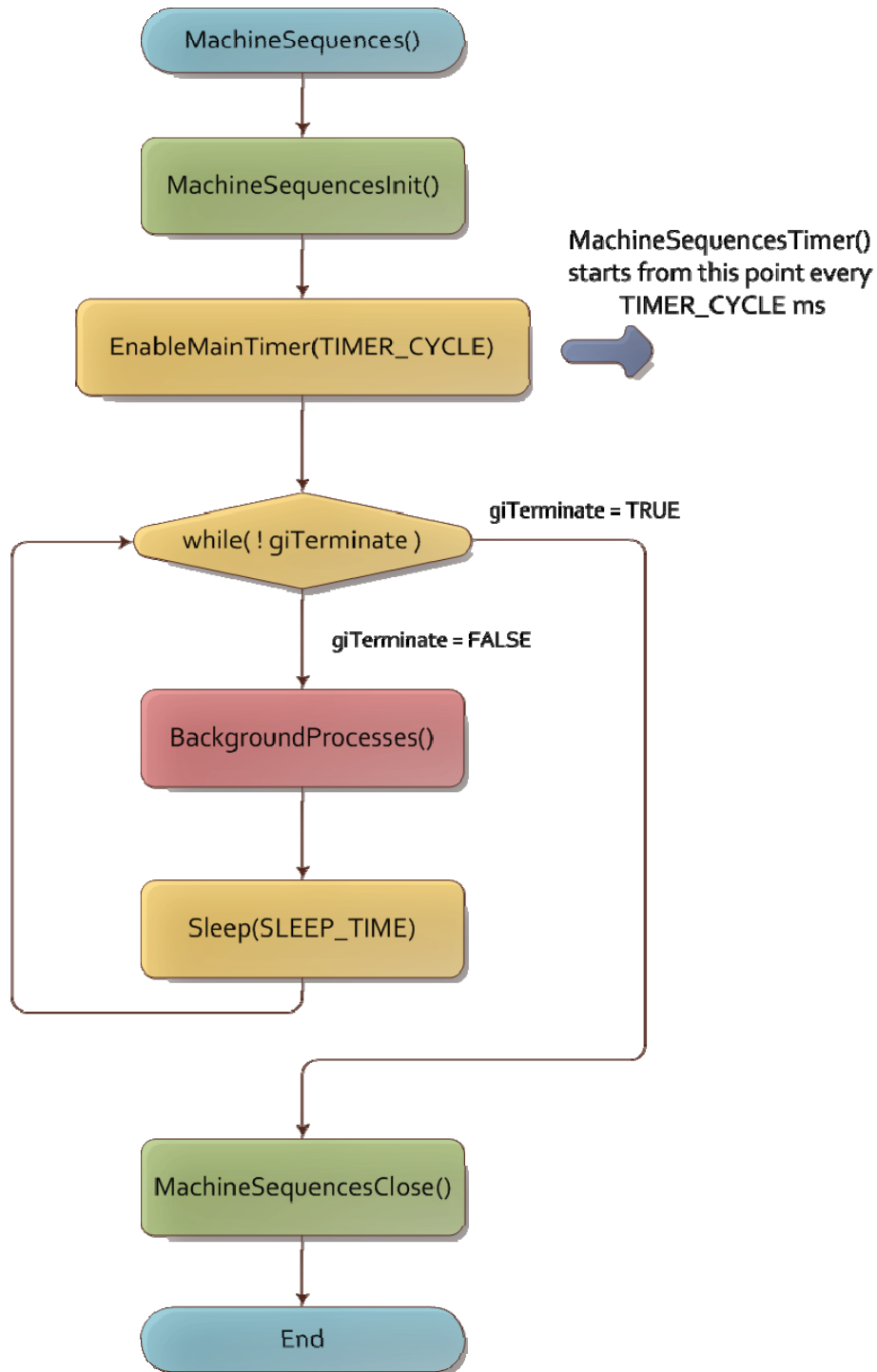
Note that the timer method is an accurate method to create calls to the timer function each given period. The Sleep() method is not accurate but timing accuracy is not an issue for this idle loop.

Finally, since we have here a background loop code that is activated periodically in a relatively low rate, we can use it to perform some less time-critical processes as may be required by the application. Processes, that you may not want to include in the main States Machine which is

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deterministically executed by the timer function. This is why we have the optional BackgroundProcess() function within this while loop.

“Immediately” after termination is requested, the while loop ends, and MachineSequences() calls to MachineSequencesClose() to close everything that needs to be closed, before returning to the main() function to terminate the program. Why “immediately” in quotation marks? Because the response time may be as long as the SLEEP_TIME of this loop. Nevertheless, response time should not be an issue when processing a termination request.



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Figure 2: MachineSequences() function

Now we have a program that is “slowly” looping in a background –an almost idle loop, while a timer function, MachineSequencesTimer() is triggered and executed each TIMER_CYCLE ms (20ms in our example), to execute the States Machine.

Let’s investigate the MachineSequencesTimer() function in-depth.

3.5.3. The MachineSequencesTimer() function

Figure 3 presents the general structure of a typical MachineSequencesTimer() function.

Why "general"? Because it does not present the details of the States Machines. This will be presented only later. First, understand the general structure of the MachineSequencesTimer() function.

Initially, upon a Timer event (each TIMER_CYCLE ms, as initialized above), the MachineSequencesTimer() function is triggered. Its first action is to call the ReadAllInputData() function.

The ReadAllInputData() function is an application dependent function. Its task is to read all inputs that may be necessary for the States Machines and to copy them into variables that are not accessible by the "external world".

This will ensure that all the States Machines code, as executed during this timer event, will use the same values of input variables.

Why this is needed?

As the timer event is not necessarily synchronized with "external world" operations, a host, for example, can access the MODBUS memory and modify one of the registers that are used by the States Machines code. Similarly, the G-MAS core can obtain a new reading of e.g. drive's speed over the device network. As such "input data" can be changed by the external world during the MachineSequencesTimer() execution, creating inconsistent operation of the code's flow. It is necessary first to copy all necessary values into "mirror variables" and only then start to use these mirror variables, which will remain unchanged until the next timer event.

This is exactly the task of the ReadAllInputData() function. Depending on the application, it should access all necessary variables (of the MODBUS memory, from the G-MAS firmware core, etc.) and copy them into "mirror variables".



It is extremely important to read and create a copy of all necessary "external world" variables at the beginning of MachineSequencesTimer() – using the ReadAllInputData() function – and to use only these copies, or mirrors, during the States Machines code. This will avoid difficulties in synchronization and inconsistent code behavior.

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Similarly, the State machine should not directly write to the "external world". The States Machines code should set internal variables (variables of the States Machines, not used outside of it) to reflect the "code decisions" or requirements to write to the "external world".

Only when a pass through all the States Machines (explained in detail later) is completed, the MachineSequencesTimer() calls (Figure 3) the WriteAllOutputData() that uses these internal variables to write what should be written into the external world variables (MODBUS, G-MAS firmware core, etc.).

The programmer should take care to properly update the "external world" variables (inside the WriteAllOutputData() function), as in some cases, the order of writing may be important. For example, (the programmer should) carefully define the Host handshaking over the MODBUS, to ensure synchronized and fully consistent communication.



Writing to "external world" variables should not be performed from within the Machines States code but only at the WriteAllOutputData() function, to ensure proper synchronized and consistent operation.

Now let's look at the States Machines themselves. Within Figure 3 below, you can see that in the general case, the MachineSequencesTimer() function can handle multiple independent States Machines. For example, for different sub-systems of the machine that require managing independently. Each State Machine has its own set of state variables and each state machine is independently managed (although a specific implementation can condition the behavior of a given States Machine with the status of another States machine and this is specific for the application).

For example, Each axis can have its own States Machine.

Another example of an implementation can be to have a State Machine for XYZ and a second Sate Machine for the Machine's Loader mechanism. Both are independent, although one can wait for the completion of a process at the second States Machine to start its own process, such as:

Status	XYZ State Machine States Machine 1	Loader/Unloader States Machine States Machine 2
Loading an object	Waiting for States Machine 2	Loading the object
Processing the object	Processing the object	Waiting for States Machine 1
Unloading the object	Waiting for States Machine 2	Unloading the object
Loading next object	Waiting for States Machine 2	Loading next object
Etc...

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Of course, this is just a simplified processing, but it explains why it will be easier to handle two independent States Machines, as shown in **Figure 3**(showing the general case of up to N States Machines). The example above also shows why a given implementation may need to condition the behavior of a given States Machine with another States Machine (they are managed independently, but may behave conditionally).

Figure 3 shows that each States Machine uses the following variables (where "N" starts at 1 for the first States Machine ...).

giStateN

Defines the current state of the States Machine. It is normally initialized by the MachineSequencesInit() function (see above) and then it can be modified over the MODBUS (Host requests to execute a task) or by the States Machine itself, while it steps from state to state (execution of a process).

giPrevStateN

Hold the state value as it was in the previous execution of the MachineSequencesTimer() function. Using this variable, the States Machine code (will be shown in later figures) can detect if the giStateN value is a "new" state and act accordingly (see later for details).

It is generally initialized together with the giStateN variable.

giSubStateN

In case a Sub State Machine (see later for details) is necessary, this variable defines the current state of the Sub State Machine. It is generally initialized by the MachineSequencesInit(0 function – just as the above to variables.

However, it is also reset to zero (or better to say: the value of the first Sub State), by the MachineSequencesTimer() every time a new state is requested (more on this later).

These variables are used to manage the States Machine and also a Sub State Machine, as we will see in later figures.

Why is there a need for Sub State Machine?

Assume a States Machines of XY axes. Also, assume that it needs to manage the following tasks: HomeXY, ScanObject and GoToIdle. The States Machine will have basically three states: HOME_XY, SCAN_OBJECT and GO_TO_IDLE.

But, executing HomeXY is by itself a process that consists of a sequence of motions and conditions, so it must be also implemented as a States Machine. This will be implemented as a Sub States Machine.

During Homing of XY, the Main States Machine (the one that appears in the next figure, in the MachineSequencesTimer() function) will be in the HOME_XY state, while the Sub States Machines (we will see figure later) will step inside the various steps of the homing process.

Theoretically speaking (and actually, even practically), this structure of multiple independent States machines running in parallel (as shown in the next figure) and also of nesting of States Machines one

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inside the other (as explained above and as we will see in later figures) can be extended as much as required and suitable for the application.

In the figures presented below, we show 1...N parallel States Machines and a depth of only two States Machine (the main States Machine and one Sub States Machine). This is just for the simplicity of the figures. However, the depth can be increased and the required changes of the variables names and handling are minor and should be easily handled by experienced programmers.

Note that while theoretically unlimited parallelism and depth can be implemented, the programmer is responsible to make sure that the worst case execution time of the overall MachineSequencesTimer() function will be shorter than the TIMER_CYCLE time, in order not to saturate the G-MAS CPU processing load (this is OK, if the code is written using our guidelines as described within these chapters, as the G-MAS processor can handle more States Machines than any practical application will need).

Remembering the giTerminate variable that we have described earlier in this chapter, it should be clear that any States Machine, required by any given application, can set this global variable in order to request (from the MachineSequences() function) to terminate the application program back to the operating system.

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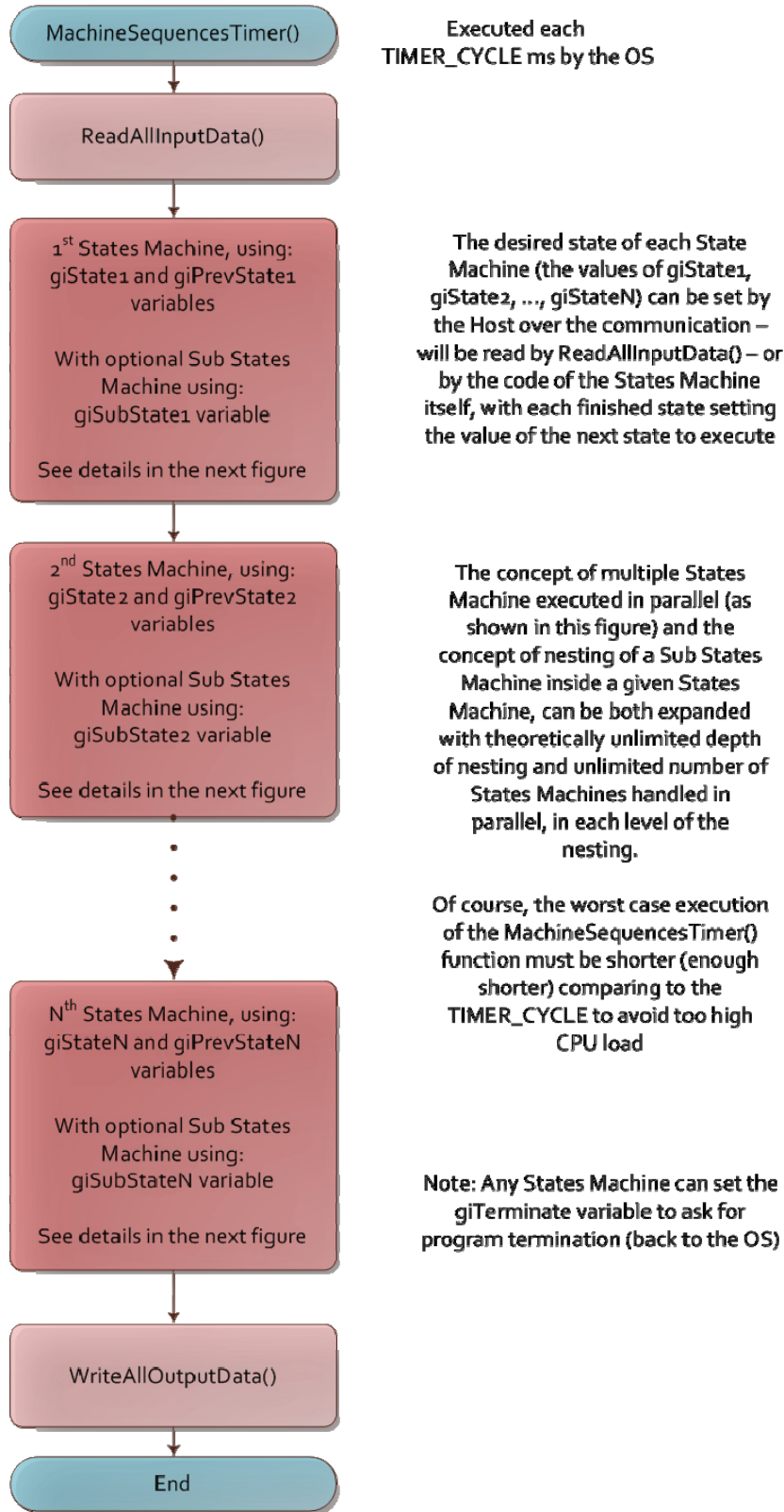


Figure 3: Typical MachineSequencesTimer() function

The next figure shows the details of the code within one of the States Machines:

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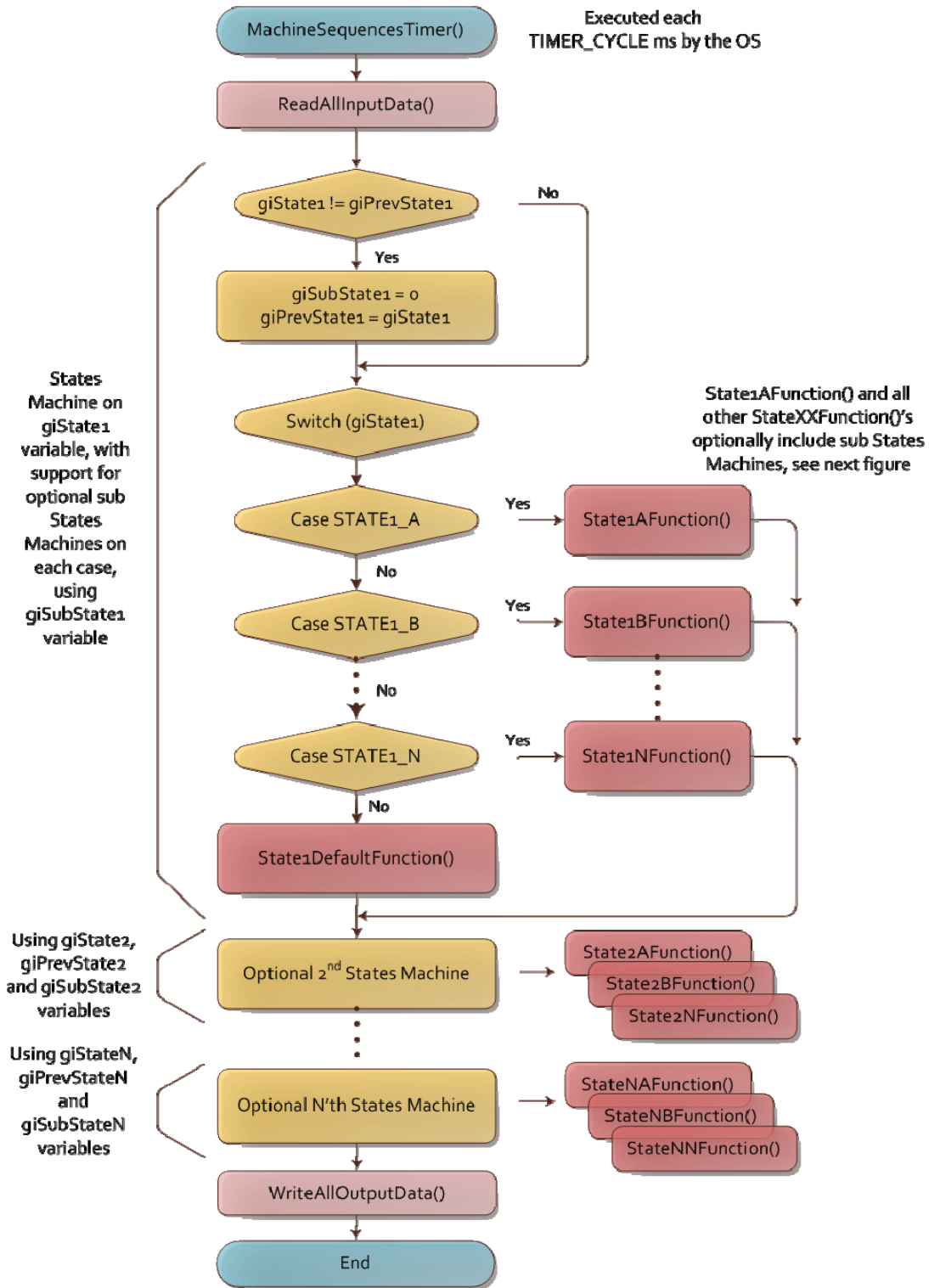


Figure 4: Code details within one of the States Machines

Please note that handling reentrancy and the termination request has been omitted from this drawing (compared to the previous example), in order to maintain simplicity. Of course, these two administrative processes, as explained above, are still handled as the first two tasks within the MachineSequencesTimer() function.

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You can still see the ReadAllInputData() and WriteAllOutputData() functions, and you can still see the blocks of the optional 2nd to Nth States Machines, but now the process of the 1st States Machine is presented with details.

It starts with handling the resetting of the giSubState1 (if necessary, which is the case when a new giState1 starts) and handling giPrevState1.

Why is this required?

New values for giState1 can be defined externally by the Host (over the MODBUS) or by the States Machine itself. Generally speaking (a given application can modify this behavior if needed), when a new main State starts, you would like the related Sub State to "start-from-zero". This is why giSubState1 is cleared if giState1 gets new value.

Following this handling, there is a simple switch case over the values of giState1. Each case calls for the proper function.

The default case, although should not happen, should be handled as well (probably with some error message and do nothing).

Note: Please note that the specific function that is called for each case is colored red. This means, as explained above, that it should not include any "waits" or "delays". It should execute what is requested and return.

If a wait is necessary (e.g. wait end of motion), it should be implemented as a State. Each time the States Machine is executed, it will reach the code relevant for this state and will check for end of motion.

If the axis is still moving, the code will return without changing the State value, so that the States Machine will return to the same code on the next timer event. If the motion ended, the code should properly change the State value, so that the next State (the next step in the overall sequence) will be automatically executed upon the next execution of the timer event.

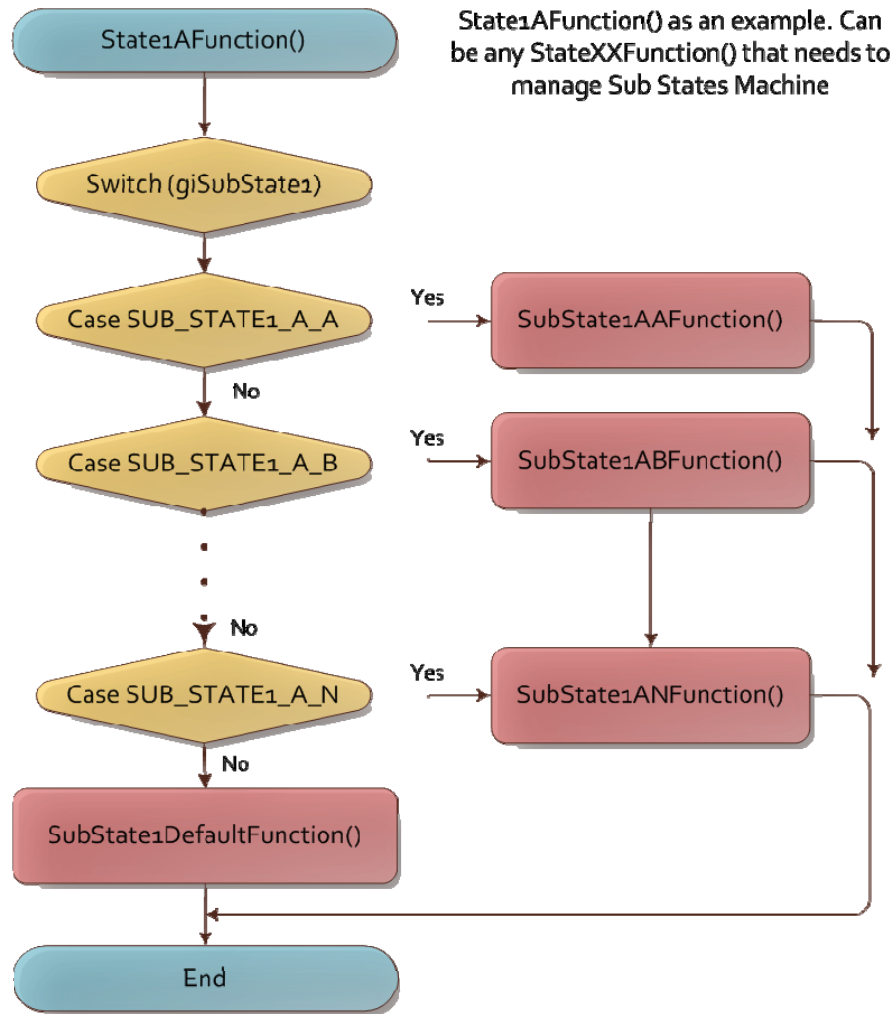


It is important to note and to understand that this means that the minimal resolution of time in this method (States Machine) is the TIMER_CYCLE. If it is, for example, 20ms, it means that the sequence can be managed in steps that cannot be shorter than 20ms. Similarly, the response time – or the time to detect an event and respond to it – may be, in the worst case, up to 20ms. Or even sometimes twice of the TIMER_CYCLE time (one cycle to detect, one cycle to respond).

It is the only single disadvantage of the States Machine code structure method, which has many advantages. For very simple application, with very simple process or sequence to handle, and if ultimate fast response time is needed, one may consider not to use the States Machine structure.

As explained below, nesting of States Machines is supported and is even a practical need (at least of depth of two States Machines). As a result, each of the cases functions that appears in [Figure 4](#) (like the State1AFunction() function, which is executed when giState1 = STATE1_A) can manage a Sub States Machine by itself. This is shown in [Figure 5](#):

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A simple structure is presented in this level (Sub States Machine). Theoretically, more Sub States Machines can be handled here in parallel (as presented in the upper level in previous figures). Theoretically, additional nesting can be also implemented (Sub-Sub States Machine), with unlimited nesting levels.

Figure 5: Nested States Machines example

Note that in this level there is no handling of any PrevState variable, as we have defined (in our example only) that the depth is only two nested States Machines. So there is no Sub-Sub States Machine of the Sub States Machine ...

Actually, this ends the explanation of the States Machines programming structure. Shortly within this chapter (after the next section about handling errors), you will find a section presenting a Sample Code. It is based on a simple States Machine structure that will help, we hope, understand and implement this approach.

Within this Sample Code, you will find actual processes and more "application related" names for the various states (instead of SUB_STATE1_A_N for example) that will make it easier to understand.

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Try to read the Sample Code and try relating it to the more "theoretical" explanation of this chapter. You will surely find that the suggested and recommended concept of States Machines is easy to understand and even more easy to adapt for the needs of your application.

3.6. Handling errors

This chapter focuses on errors during calls to Function Blocks (the functions supplied by Elmo within the G-MAS FB Library). Of course, many other machine-specific errors can be defined but those errors should be handled as specifically suitable for each machine and are typically handled as part of the States Machine that manages the machine sequences (see above).

Starting with the bottom line, handling errors (during calls to Function Blocks) is part of the responsibility of the User Application program’s developer (the user), as each machine calls for different response to different types of errors.

How are these errors detected? Where does a user place his functions to handle these errors? What is Elmo’s recommended good programming practices for handling these errors?

To clarify, it is impossible for us to provide a generic function to handle the errors, as each machine requires different error handling process. However, there is still a need to define where, when, and how such an error handling function is called. This chapter answers this requirement.

Each Function Block function returns a Return Code. Its value is 0 (zero) in case the Function Block call was executed without any error. If there is an error, the Return Code will get a value that is related to the type of the error.

As a result, a general segment of code that calls a Function Block function should look like (in this example, it is a call to Move Absolute function):

```
// Inserting the structure parameters:
sMove_Abs_in.fAcceleration = 100000.0;           // Value of the acceleration
sMove_Abs_in.fDeceleration = 100000.0;         // Value of the deceleration
sMove_Abs_in.fJerk         = 2000.0;           // Value of the Jerk
sMove_Abs_in.eDirection    = MC_POSITIVE_DIRECTION; // MC_Direction Enumerator type
sMove_Abs_in.eBufferMode   = MC_BUFFERED_MODE;  // MC_BufferMode Defines the behavior of
the axis
sMove_Abs_in.dbPosition    = 100000.0;         // Target position for the motion
sMove_Abs_in.fVelocity     = 5000.0;           // Velocity in
sMove_Abs_in.ucExecute     = 1;
//
rc = MMC_MoveAbsoluteCmd (hConn, iAxisRef, &sMove_Abs_in, &sMove_Abs_out);
if (rc != 0)
{
    HandleError();
}
```

Or, similarly:

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```
// Inserting the structure parameters:
sMove_Abs_in.fAcceleration = 100000.0;           // Value of the acceleration
sMove_Abs_in.fDeceleration = 100000.0;         // Value of the deceleration
sMove_Abs_in.fJerk         = 2000.0;           // Value of the Jerk
sMove_Abs_in.eDirection   = MC_POSITIVE_DIRECTION; // MC_Direction Enumerator type
sMove_Abs_in.eBufferMode  = MC_BUFFERED_MODE;   // MC_BufferMode Defines the behavior of
the axis
sMove_Abs_in.dbPosition   = 100000.0;         // Target position for the motion
sMove_Abs_in.fVelocity    = 5000.0;           // Velocity in
sMove_Abs_in.ucExecute    = 1;

//
if (MMC_MoveAbsoluteCmd (hConn, iAxisRef, &sMove_Abs_in, &sMove_Abs_out) != 0)
{
    HandleError();
}
```

The user is responsible to create the HandleError() function. This function can optionally get arguments, and, of-course, different functions can be used at different locations of the program.

Nevertheless, the code that should perform a sequence of calls, becomes a list of if-call (or call-if). This is a disadvantage of the C programming that Elmo is working to improve (see below).

Some programmers tend to bypass this difficulty using one of the following methods. We strongly recommend not using these bypasses.

- Call the library functions without checking the Return Code. Just ignoring it.
This will surely create a nicer and simpler code.
The assumption behind using this bypass is that the code is debugged and that there should be no errors in the calls to the library functions. Although this is correct, there is no way to ensure that errors will not happen in some given sequence which was not fully debugged by the user. In the case of an error, ignoring it and continuing the program as if there was no error (the program assumes that the function was executed properly and completely), will lead to unexpected machine’s behavior, which can be in some cases dangerous and critical.
As stated above, Elmo strongly recommends not to use this method. Errors should be checked and responded to, according to the suitability for the machine.

- A second bypass is to hide the library function within a user developed wrapper function (see above).

In this case, the wrapper function will have no return value, such as:

```
MyWrapperMoveAbs(..);
MyWrapperMoveAbs(..);
MyWrapperMoveAbs(..);
```

And the main code will indeed become simpler.

However, it is important to note that the wrapper function itself, which calls the library function, should handle the Return Code as specified above. Handling the error within the wrapper

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function will be nice (it is hidden from the point of view of the main code), but it creates another difficulty; Can an error be properly handled within a deeper layer of the code? Don’t we want the main code (the main States Machine, see later in this chapter) to handle the errors, or at least be aware of them?

From Elmo’s experience, trying to use this method (hiding the Return Code within the Wrapper Function) always ends with the need to return a value from the wrapper function, and again, this value needs to be checked – if (...) – in the code with each call to a function.

So, is this structure of if-call (or call-if) a must?

For now, yes it is. However, Elmo is working to develop a new C++ based interface to all of the functions included within its G-MAS FB Library. With this C++ based interface (using unique features of the C++), the user will not need to check the return code of each function, but instead will be able to just call the function. The above lines of code will change into:

```
// Inserting the structure parameters:
sMove_Abs_in.fAcceleration = 100000.0;           // Value of the acceleration
sMove_Abs_in.fDeceleration = 100000.0;         // Value of the deceleration
sMove_Abs_in.fJerk         = 2000.0;           // Value of the Jerk
sMove_Abs_in.eDirection   = MC_POSITIVE_DIRECTION; // MC_Direction Enumerator type
sMove_Abs_in.eBufferMode  = MC_BUFFERED_MODE; // MC_BufferMode Defines the behavior of the
axis
sMove_Abs_in.dbPosition   = 100000.0;         // Target position for the motion
sMove_Abs_in.fVelocity    = 5000.0;           // Velocity in
sMove_Abs_in.ucExecute    = 1;
//
MMC_MoveAbsoluteCmd (hConn, iAxisRef, &sMove_Abs_in, &sMove_Abs_out);

sMove_Abs_in.dbPosition   = 200000.0;         // Next target
MMC_MoveAbsoluteCmd (hConn, iAxisRef, &sMove_Abs_in, &sMove_Abs_out);
```

This new interface will be available within few months and will enable the G-MAS C programmers to enjoy from even a simpler code development.

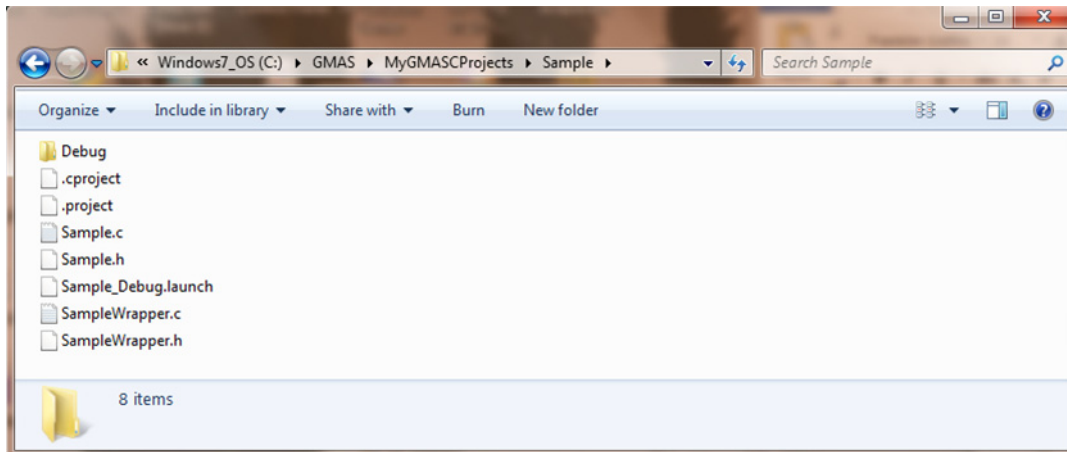
3.7. Sample code

The Sample project shown below is a project only created to demonstrate the implementation of the above programming guidelines. It is quite an empty code that does nothing specific besides being ready for the implementation of an application program based on states machine. We have included some basic states in the Sample application, to demonstrate how variables/states should be named, initialized and managed. Since it is a “clean” project, it is easier to show how all the guidelines described in previous sections, are implemented.

You can call Elmo office to receive a Sample project code (it may also be included as part of the Elmo PC Suite environment installation, in which case you should be able to find it on your computer, at the same location as appears in the next figure.

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Below is a snapshot of the Sample project directory. You can see the location and the name of the folder, the names of the C and header files (including the wrapper functions), that are always in pairs.



Exploring (using the Eclipse) the `Sample.c`, the main source file of the project, we can see the file's header, describing the project, the file, version, date and a short description of the application. This is followed by the include files (system files, Elmo MMC library file and project's specific include files).

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```

1 /*
2 =====
3 Project:   Sample
4 File:     Sample.c
5 Author:   Sapir Eyal
6 Date:    06 December 2010
7 Version:  1.00
8
9 Description:
10
11 This file is a sample code, showing the implemntation of the GMAS C
12 programming guidelines.
13 =====
14 */
15
16 /*
17 =====
18 Includes
19 =====
20 */
21 #include <stdio.h>           // C header files
22 #include <sys/time.h>       // For time structure
23 #include <signal.h>         // Needed for using the system timer
24
25 #include "MMC_definitions.h" // Header file for all Elmo's GMAS Functions Blocks
26
27 #include "Sample.h"         // Application header file
28 #include "SampleWrapper.h" // Header file for the application wrapper function
29 */
30 =====
31 Application global variables
32 =====
33 */
34 int    giTerminate;        // Flag to request program termination
35 int    giState1;           // Holds the current state of the 1st main state machine
36 int    giPrevState1;      // Holds the value of giState1 at previous cycle
37 int    giSubState1;       // Holds teh current state of the sub-state machine of 1st
38 int    giReentrance;      // Used to detect reentrancy to the main timer function
39
40 int    giXReverseLimit;    // Examples for data read from the GMAS core about the X, Y
41 int    giYReverseLimit;
42 int    giXIndexActivated;
43 int    giYIndexActivated;
44 int    giXInMotion;
45 int    giYInMotion;

```

After the include files; the global variables are defined, using the naming convention we defined above. Variables are defined clearly, with a short explanation and, preferably, one per line. Initialization of variables can occur at this phase (as part of the definition), but we prefer to perform all initialization within the suitable initialization functions, as described in the next section.

Immediately after the Application global variables, we define the structure variables required for the interfaces with the MMC function blocks. In the Sample example, these structures are initialized as part of their definition. We do recommend performing it as part of the initialization functions, as suggested in earlier sections.

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```

C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
29 /*
30 =====
31 Application global variables
32 =====
33 */
34 int giTerminate; // Flag to request program termination
35 int giState1; // Holds the current state of the 1st main state machine
36 int giPrevState1; // Holds the value of giState1 at previous cycle
37 int giSubState1; // Holds the current state of the sub-state machine of 1st
38 int giReentrance; // Used to detect reentrancy to the main timer function
39
40 int giXReverseLimit; // Examples for data read from the GMAS core about the X, Y
41 int giYReverseLimit;
42 int giXIndexActivated;
43 int giYIndexActivated;
44 int giXInMotion;
45 int giYInMotion;
46 /*
47 =====
48 Global structures for Elmo's Function Blocks
49 =====
50 */
51 MMC_AXIS_REF_HNDL giCRef = {0}; // indexes of IO
52 MMC_AXIS_REF_HNDL gAxisRef[3] = {0,0,0}; // indexes of axes
53 MMC_AXIS_REF_HNDL gGroupRef = {0};
54 MMC_AXIS_REF_HNDL gGroupRef2D = {0};
55 /*
56 =====
57 Function: main()
58 Input arguments: None.
59 Output arguments: None.
60 Returned value: A dummy value of 1 to avoid compilation error.
61 Version: Version 1.00
62 Updated: 06/12/2010
63 Modifications: N/A
64
65 Description:
66
67 The main function of this sample project.
68 =====
69 */
70 int main()
71 {
72 //
73 // Initialize system, axes and all needed initializations

```

We recommend using global variables, although it should be done with care, as it enables access to these variables anywhere within the application code, avoiding the need for multiple arguments for each function.

After all the global variables are defined, the main() function appears. Please note the comments header above the main() function, as well as above any other function in the code. It provides details about the function, such as version, inputs/outputs, description, etc.

The main() function is of type "int" (although in this example, has no value to return) as the Eclipse compiler asks for this function type.

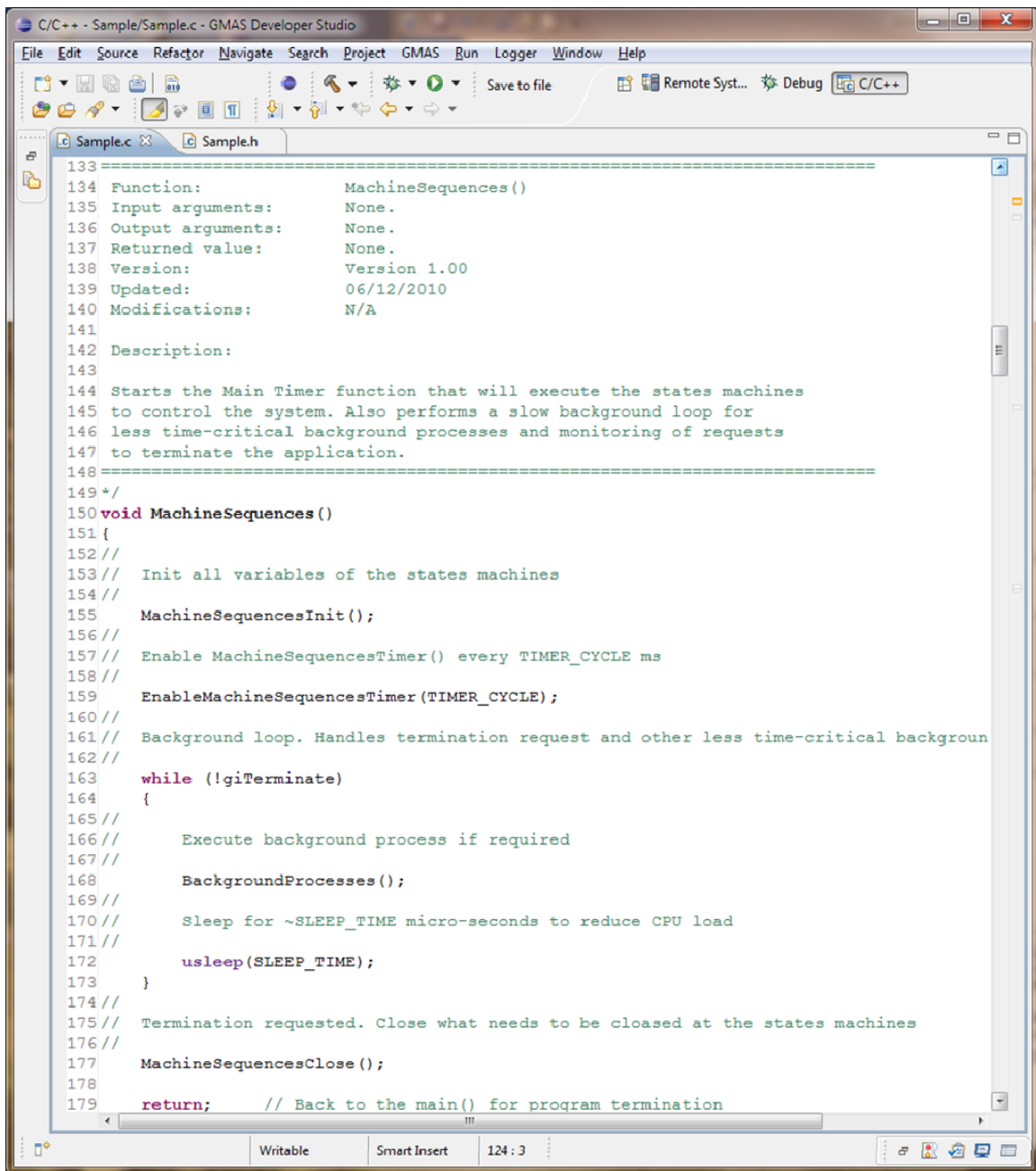
The main() function is as simple as it appears in the flow charts above: Initialization, Execution of machine sequences and Closing. Note the format of the comments, as the same format is used throughout the Sample project code.

```
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C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
55 /*
56 =====
57 Function:          main()
58 Input arguments:   None.
59 Output arguments:  None.
60 Returned value:    A dummy value of 1 to avoid compilation error.
61 Version:           Version 1.00
62 Updated:           06/12/2010
63 Modifications:    N/A
64
65 Description:
66
67 The main function of this sample project.
68 =====
69 */
70 int main()
71 {
72 //
73 // Initialize system, axes and all needed initializations
74 //
75 MainInit();
76 //
77 // Execute the state machine to handle the system sequences and control
78 //
79 MachineSequences();
80 //
81 // Close what needs to be closed before program termination
82 //
83 MainClose();
84 //
85 return 1;          // Terminate the application program back to the Operating System
86 }
87 /*
88 =====
89 Function:          MainInit()
90 Input arguments:   None.
91 Output arguments:  None.
92 Returned value:    None.
93 Version:           Version 1.00
94 Updated:           06/12/2010
95 Modifications:    N/A
96
97 Description:
98
99 Initilaize the system, including axes, communication, etc.
```

The empty main initialization and closing functions appear just after the main. They are to be filled with application related code. The initialization function can be used to initialize communication and axes, while Closing can be used to close them, closing log files, printing some message to the standard output, etc.

Following these functions, we see the MachineSequences(). It is documented and commented in a similar way. Actually, it is a very simple function built just as described in the flow charts in this chapter. The details are "hidden" within specific functions, like MachineSequencesInit() and EnableMachineSequencesTimer() shown in the next diagram.

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```
133
134 Function:           MachineSequences ()
135 Input arguments:   None.
136 Output arguments:  None.
137 Returned value:    None.
138 Version:           Version 1.00
139 Updated:           06/12/2010
140 Modifications:     N/A
141
142 Description:
143
144 Starts the Main Timer function that will execute the states machines
145 to control the system. Also performs a slow background loop for
146 less time-critical background processes and monitoring of requests
147 to terminate the application.
148
149 */
150 void MachineSequences ()
151 {
152 //
153 // Init all variables of the states machines
154 //
155 MachineSequencesInit();
156 //
157 // Enable MachineSequencesTimer() every TIMER_CYCLE ms
158 //
159 EnableMachineSequencesTimer (TIMER_CYCLE);
160 //
161 // Background loop. Handles termination request and other less time-critical background
162 //
163 while (!giTerminate)
164 {
165 //
166 // Execute background process if required
167 //
168 BackgroundProcesses ();
169 //
170 // Sleep for ~SLEEP_TIME micro-seconds to reduce CPU load
171 //
172 usleep (SLEEP_TIME);
173 }
174 //
175 // Termination requested. Close what needs to be closed at the states machines
176 //
177 MachineSequencesClose ();
178
179 return; // Back to the main() for program termination
```

This function is followed by the functions that it calls (the order of the various functions appearing in the file is the order they will be called/used), starting from main() to the other functions it calls, and so forth.

The MachineSequencesInit() initializes all variables required to manage the states machines. Note that constants are used and not numbers (e.g. IDLE and not 0), as defined in the programming guidelines above.

```
xxxxxxxxxxxx(0.01)
C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
181 /*
182 =====
183 Function:          MachineSequencesInit ()
184 Input arguments:  None.
185 Output arguments: None.
186 Returned value:   None.
187 Version:          Version 1.00
188 Updated:          06/12/2010
189 Modifications:    N/A
190
191 Description:
192
193 Initilaize the states machines variables
194 =====
195 */
196 void MachineSequencesInit ()
197 {
198 //
199 //  Initializing all variables for the states machines
200 //
201     giTerminate = FALSE;
202
203     giState1 = IDLE;
204     giPrevState1 = IDLE;
205     giSubState1 = IDLE;
206
207     giReentrance = FALSE;
208
209     return;
210 }
211 /*
212 =====
213 Function:          MachineSequencesClose ()
214 Input arguments:  None.
215 Output arguments: None.
216 Returned value:   None.
217 Version:          Version 1.00
218 Updated:          06/12/2010
219 Modifications:    N/A
220
221 Description:
222
223 Close all that needs to be closed at the states machines before the
224 application program is terminated.
225 =====
226 */
227 void MachineSequencesClose ()
```

Omitting some empty functions (whose tasks are described in earlier chapters), the next interesting function is EnableMachineSequencesTimer(). This uses system functions to enable the timer, and to define the function triggered periodically by the timer. The user should not change this function unless non-standard behavior is required.

xxxxxxxxxxxx(0.01)

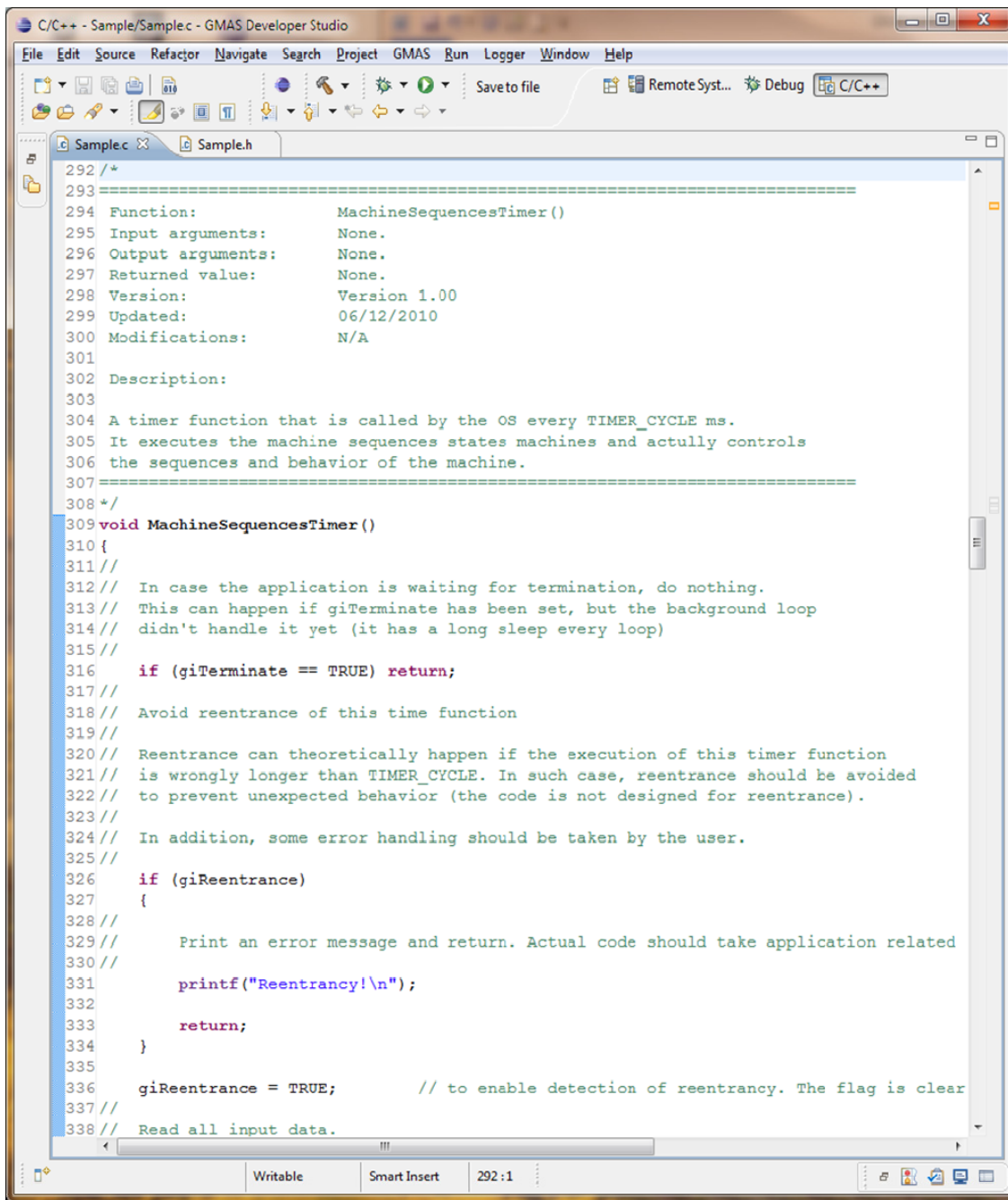
```

C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
259 /*
260 =====
261 Function:          EnableMachineSequencesTimer()
262 Input arguments:   None.
263 Output arguments:  None.
264 Returned value:    None.
265 Version:           Version 1.00
266 Updated:           06/12/2010
267 Modifications:    N/A
268
269 Description:
270
271 Enables the main machine sequences timer function, to be executed each
272 TIMER_CYCLE ms.
273 =====
274 */
275 void EnableMachineSequencesTimer(int TimerCycle)
276 {
277     struct itimerval timer;
278     //
279     // Enable the main machine sequences timer function
280     //
281     timer.it_interval.tv_sec = 0;
282     timer.it_interval.tv_usec = TimerCycle * 1000;           // From ms to micro sec
283     timer.it_value.tv_sec = 0;
284     timer.it_value.tv_usec = TimerCycle * 1000;           // From ms to micro sec
285
286     setitimer(ITIMER_REAL, &timer, NULL);
287
288     signal(SIGALRM, MachineSequencesTimer); // every TIMER_CYCLE ms SIGALRM is received
289
290     return;
291 }
292 /*
293 =====
294 Function:          MachineSequencesTimer()
295 Input arguments:   None.
296 Output arguments:  None.
297 Returned value:    None.
298 Version:           Version 1.00
299 Updated:           06/12/2010
300 Modifications:    N/A
301
302 Description:
303
304 A timer function that is called by the OS every TIMER_CYCLE ms.
305 It executes the machine sequences states machines and actually controls

```

The next function is the MachineSequencesTimer(). It is the function triggered periodically by the timer that actually executes the machine sequences (the states machines). It initially checks if Termination was requested and if reentrance incorrectly occurred. If all OK, input data is collected (all "external" data required for the states machines) and the main states machine is executed.

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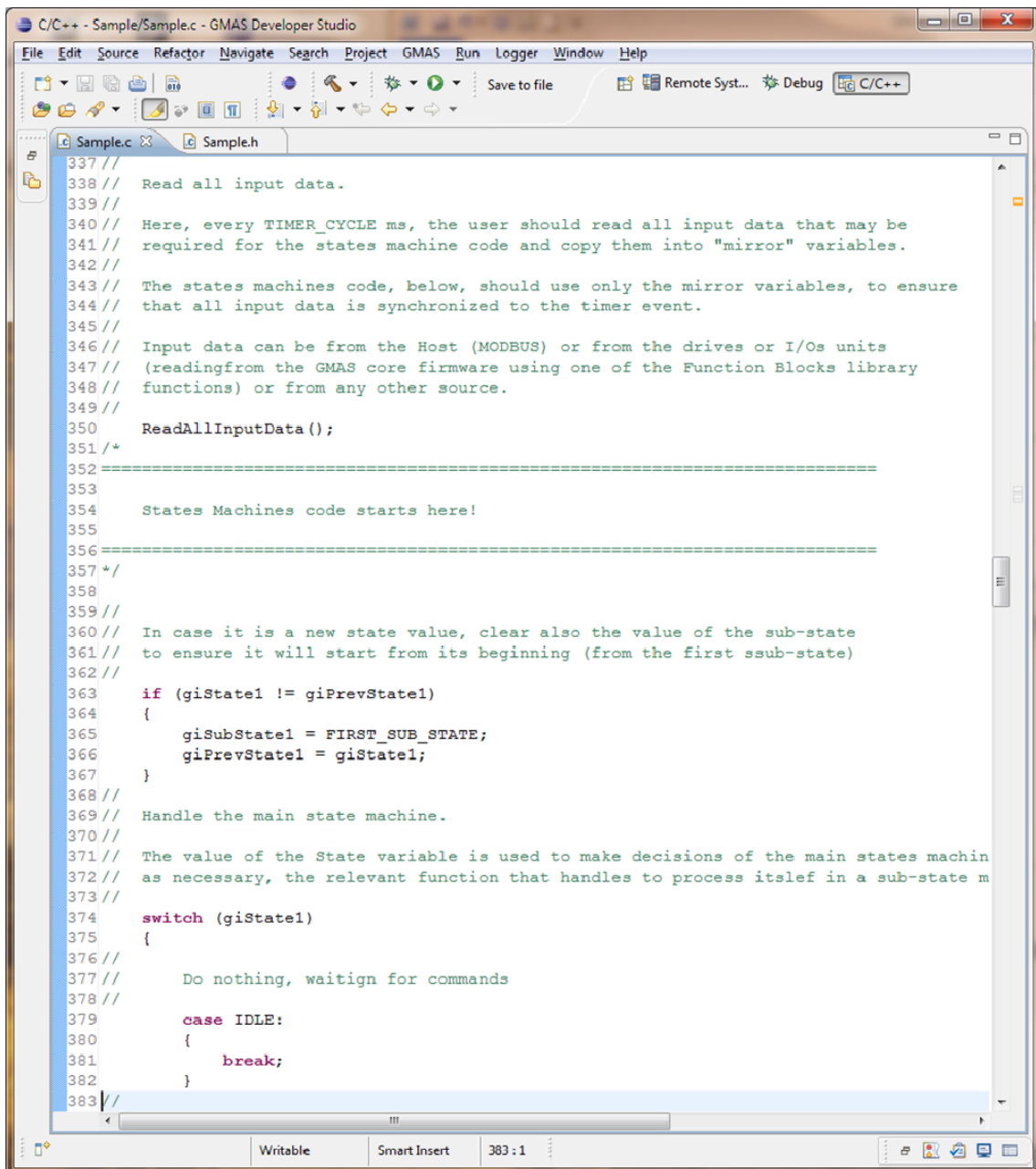


The screenshot shows the GMAS Developer Studio interface with a C++ source file open. The code defines a function named `MachineSequencesTimer()`. The function's metadata includes: Function: `MachineSequencesTimer()`, Input arguments: None, Output arguments: None, Returned value: None, Version: Version 1.00, Updated: 06/12/2010, and Modifications: N/A. The function description states: "A timer function that is called by the OS every `TIMER_CYCLE` ms. It executes the machine sequences states machines and actually controls the sequences and behavior of the machine." The function implementation includes a reentrancy check and a termination check.

```
292 /*
293 =====
294 Function:          MachineSequencesTimer()
295 Input arguments:   None.
296 Output arguments:  None.
297 Returned value:    None.
298 Version:           Version 1.00
299 Updated:           06/12/2010
300 Modifications:     N/A
301
302 Description:
303
304 A timer function that is called by the OS every TIMER_CYCLE ms.
305 It executes the machine sequences states machines and actually controls
306 the sequences and behavior of the machine.
307 =====
308 */
309 void MachineSequencesTimer()
310 {
311 //
312 // In case the application is waiting for termination, do nothing.
313 // This can happen if giTerminate has been set, but the background loop
314 // didn't handle it yet (it has a long sleep every loop)
315 //
316 if (giTerminate == TRUE) return;
317 //
318 // Avoid reentrance of this time function
319 //
320 // Reentrance can theoretically happen if the execution of this timer function
321 // is wrongly longer than TIMER_CYCLE. In such case, reentrance should be avoided
322 // to prevent unexpected behavior (the code is not designed for reentrance).
323 //
324 // In addition, some error handling should be taken by the user.
325 //
326 if (giReentrance)
327 {
328 //
329 // Print an error message and return. Actual code should take application related
330 //
331 printf("Reentrancy!\n");
332
333 return;
334 }
335
336 giReentrance = TRUE; // to enable detection of reentrancy. The flag is clear
337 //
338 // Read all input data.
```

Then, the next stage is.....

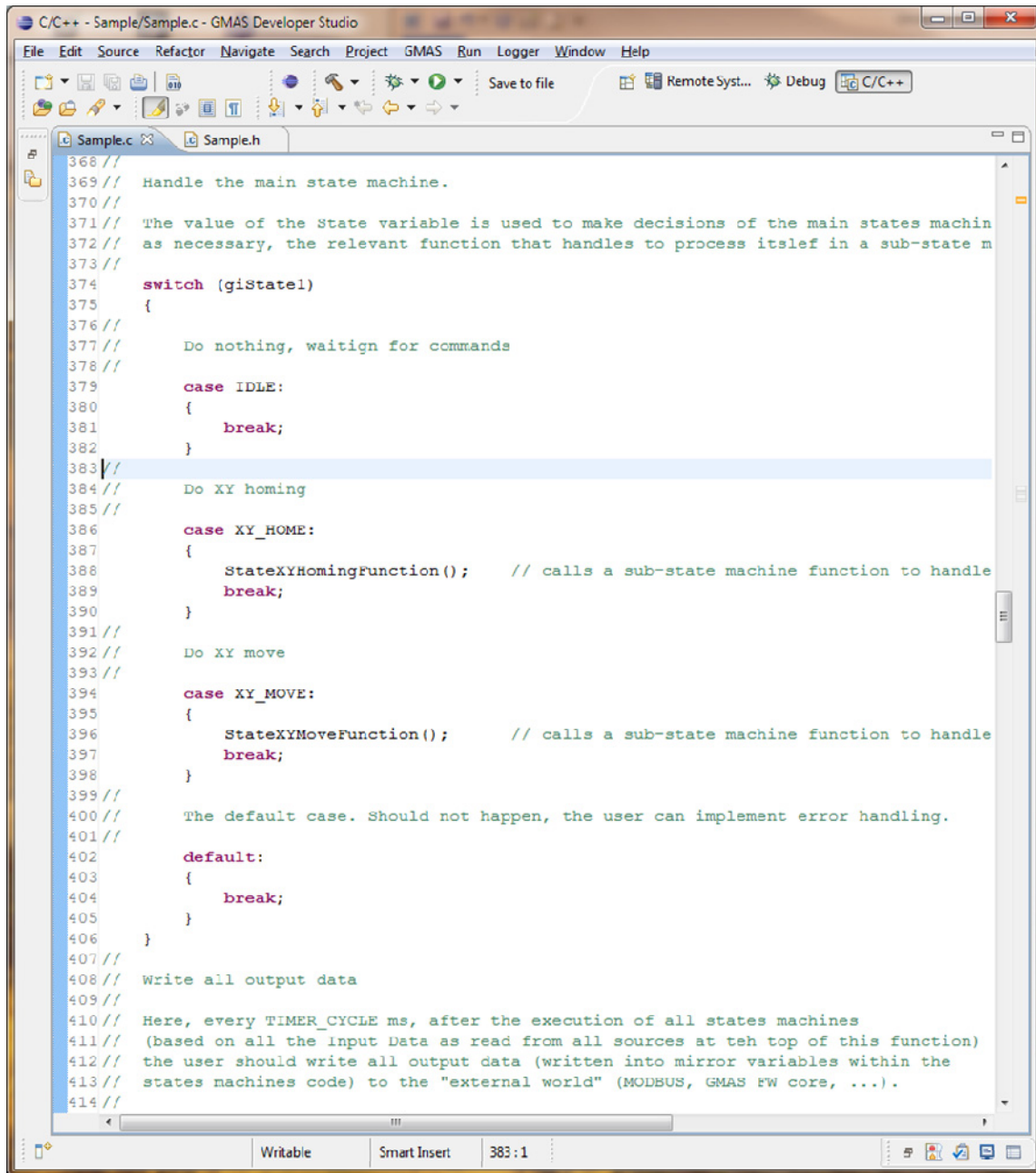
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```
C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
337 //
338 // Read all input data.
339 //
340 // Here, every TIMER_CYCLE ms, the user should read all input data that may be
341 // required for the states machine code and copy them into "mirror" variables.
342 //
343 // The states machines code, below, should use only the mirror variables, to ensure
344 // that all input data is synchronized to the timer event.
345 //
346 // Input data can be from the Host (MODBUS) or from the drives or I/Os units
347 // (reading from the GMAS core firmware using one of the Function Blocks library
348 // functions) or from any other source.
349 //
350 ReadAllInputData();
351 /*
352 =====
353
354 States Machines code starts here!
355
356 =====
357 */
358
359 //
360 // In case it is a new state value, clear also the value of the sub-state
361 // to ensure it will start from its beginning (from the first ssub-state)
362 //
363 if (giState1 != giPrevState1)
364 {
365     giSubState1 = FIRST_SUB_STATE;
366     giPrevState1 = giState1;
367 }
368 //
369 // Handle the main state machine.
370 //
371 // The value of the State variable is used to make decisions of the main states machin
372 // as necessary, the relevant function that handles to process itself in a sub-state m
373 //
374 switch (giState1)
375 {
376 //
377 // Do nothing, waitign for commands
378 //
379 case IDLE:
380 {
381     break;
382 }
383 //
```

The main states machine is handled exactly as we described in the flow charts above. In the Sample project you can see that the main states machine supports two states (two "tasks"): XY_HOME and XY_MOVE. Each one of these states, in turn, handles a sub-states machine, that will execute the action sequences required to perform the task.

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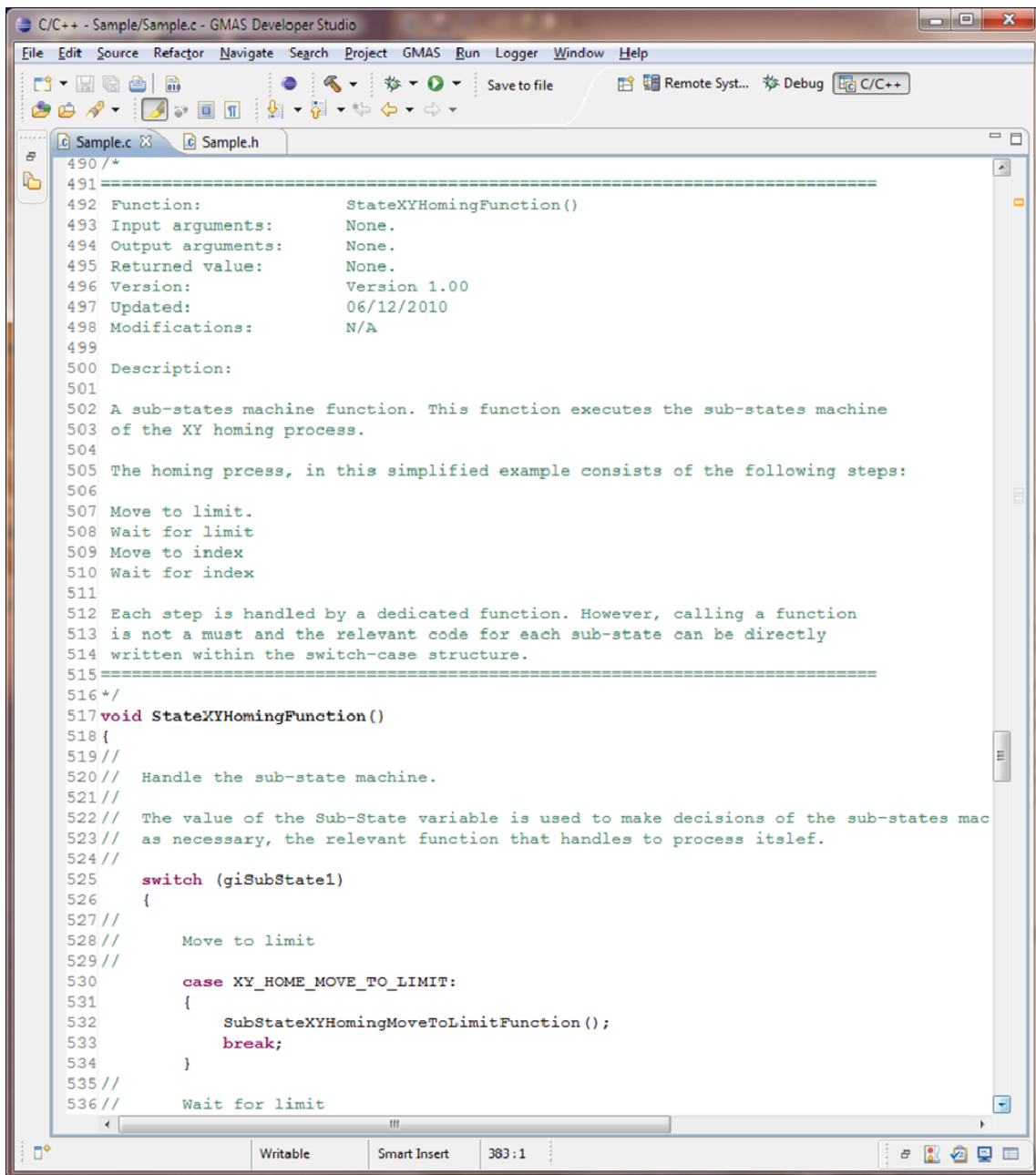
```
366 //
369 // Handle the main state machine.
370 //
371 // The value of the State variable is used to make decisions of the main states machin
372 // as necessary, the relevant function that handles to process itslef in a sub-state m
373 //
374 switch (giState1)
375 {
376 //
377 // Do nothing, waitign for commands
378 //
379 case IDLE:
380 {
381 break;
382 }
383 //
384 // Do XY homing
385 //
386 case XY_HOME:
387 {
388 StateXYHomingFunction(); // calls a sub-state machine function to handle
389 break;
390 }
391 //
392 // Do XY move
393 //
394 case XY_MOVE:
395 {
396 StateXYMoveFunction(); // calls a sub-state machine function to handle
397 break;
398 }
399 //
400 // The default case. Should not happen, the user can implement error handling.
401 //
402 default:
403 {
404 break;
405 }
406 }
407 //
408 // Write all output data
409 //
410 // Here, every TIMER_CYCLE ms, after the execution of all states machines
411 // (based on all the Input Data as read from all sources at teh top of this function)
412 // the user should write all output data (written into mirror variables within the
413 // states machines code) to the "external world" (MODBUS, GMAS FW core, ...).
414 //
```

Note the function `ReadAllInputData()` that must be modified by the user to actually access the sources of all required input data, and create a copy (mirror) of their value. This is to be used within the states machine code, ensuring that no variable changes while executing a given cycle of a states machine code.

The `StateXYHomingFunction()` is a good example for a sub-states machine code. While the machine is in `XY_HOME` state (the main states machine's value is `XY_HOME`), this function will be run each timer event and will handle its sub-states machine to manage the `XY_HOME` process.

Of course the example described in the Sample project is a very simplified homing process. It only demonstrates the programming concept, and does not show how a complete homing process should be written. However, this keeps the Sample application clean and simple as possible.

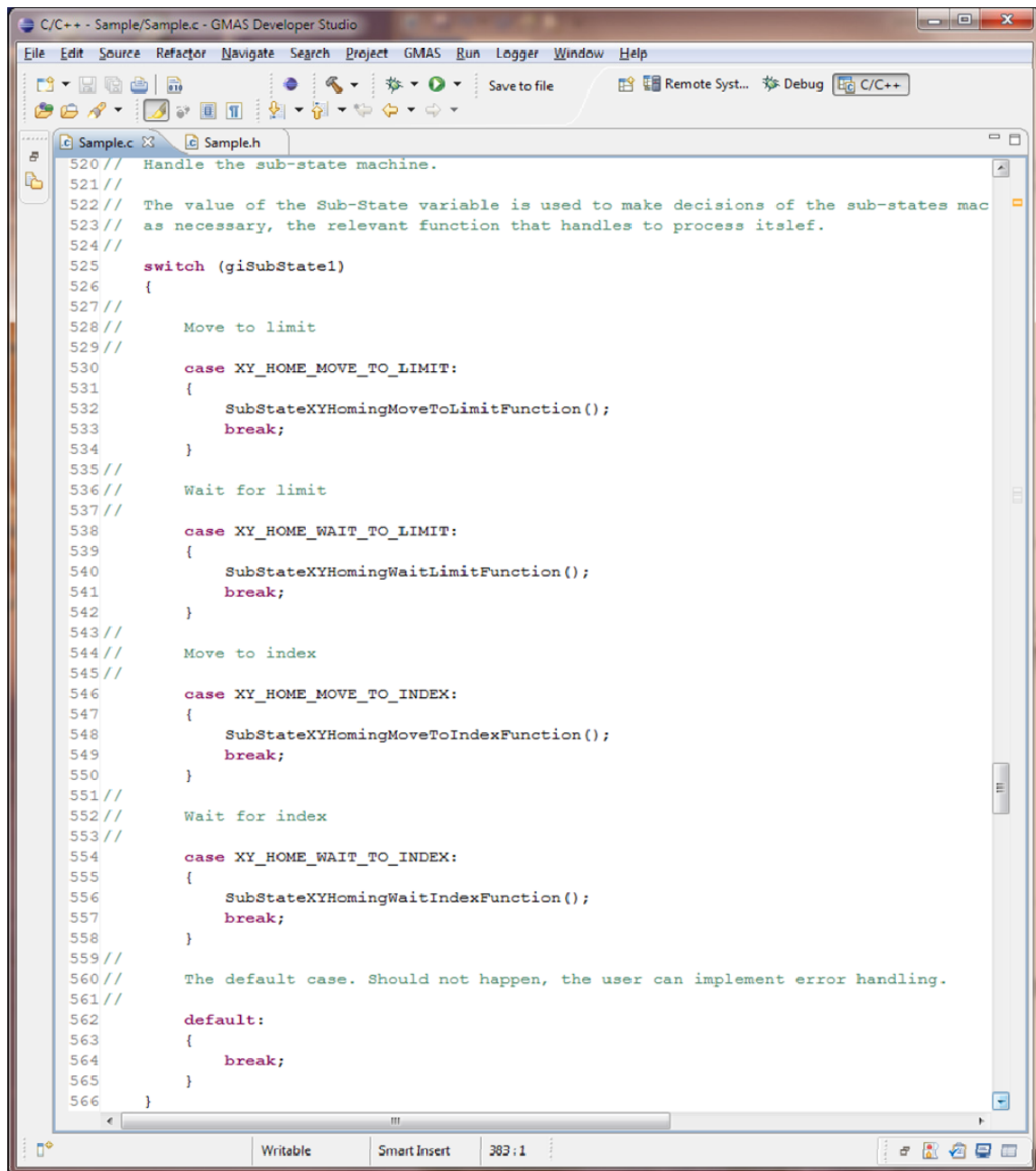
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```
C/C++ - Sample/Sample.c - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
490 /*
491 =====
492 Function:          StateXYHomingFunction ()
493 Input arguments:  None.
494 Output arguments: None.
495 Returned value:   None.
496 Version:          Version 1.00
497 Updated:          06/12/2010
498 Modifications:   N/A
499
500 Description:
501
502 A sub-states machine function. This function executes the sub-states machine
503 of the XY homing process.
504
505 The homing process, in this simplified example consists of the following steps:
506
507 Move to limit.
508 Wait for limit
509 Move to index
510 Wait for index
511
512 Each step is handled by a dedicated function. However, calling a function
513 is not a must and the relevant code for each sub-state can be directly
514 written within the switch-case structure.
515 =====
516 */
517 void StateXYHomingFunction ()
518 {
519 //
520 // Handle the sub-state machine.
521 //
522 // The value of the Sub-State variable is used to make decisions of the sub-states mac
523 // as necessary, the relevant function that handles to process itself.
524 //
525     switch (giSubState1)
526     {
527 //
528 // Move to limit
529 //
530         case XY_HOME_MOVE_TO_LIMIT:
531         {
532             SubStateXYHomingMoveToLimitFunction ();
533             break;
534         }
535 //
536 // Wait for limit
```

Then the next stage is.....

xxxxxxxxxxxx(0.01)



```
520 // Handle the sub-state machine.
521 //
522 // The value of the Sub-State variable is used to make decisions of the sub-states mac
523 // as necessary, the relevant function that handles to process itslef.
524 //
525 switch (giSubState1)
526 {
527 //
528 // Move to limit
529 //
530 case XY_HOME_MOVE_TO_LIMIT:
531 {
532     SubStateXYHomingMoveToLimitFunction();
533     break;
534 }
535 //
536 // Wait for limit
537 //
538 case XY_HOME_WAIT_TO_LIMIT:
539 {
540     SubStateXYHomingWaitLimitFunction();
541     break;
542 }
543 //
544 // Move to index
545 //
546 case XY_HOME_MOVE_TO_INDEX:
547 {
548     SubStateXYHomingMoveToIndexFunction();
549     break;
550 }
551 //
552 // Wait for index
553 //
554 case XY_HOME_WAIT_TO_INDEX:
555 {
556     SubStateXYHomingWaitIndexFunction();
557     break;
558 }
559 //
560 // The default case. Should not happen, the user can implement error handling.
561 //
562 default:
563 {
564     break;
565 }
566 }
```

Finally, reaching the lower level functions, which create motions, wait for end of motions, etc., we find the function (as an example): `SubStateXYHomingMoveToLimitFunction()`.

Please note how this function creates motion (and not waiting for end of motion or any other "wait") and changes the sub-state immediately, so that in the next cycle, the `XY_HOME_WAIT_TO_LIMIT` state is detected, and the `SubStateXYHomingWaitLimitFunction()` is reached.

XXXXXXXXXXXX(0.01)

```

662 /*
663 =====
664 Function:          SubStateXYHomingWaitLimitFunction()
665 Input arguments:   None.
666 Output arguments:  None.
667 Returned value:    None.
668 Version:           Version 1.00
669 Updated:           06/12/2010
670 Modifications:    N/A
671
672 Description:
673
674 Waits for X and Y limits and only then change to the next sub-state.
675 =====
676 */
677 void SubStateXYHomingWaitLimitFunction()
678 {
679 //
680 // Changing to the next sub-state only if both limits are activated.
681 //
682 // Note that a faster implementation could be to put here the code of sub-state XY_HOME
683 // This means that if X and Y limits are detected, we can start the motion to the inde
684 // waiting for the next timer event.
685 //
686 // One can also wonder if we should not first wait for end of motion before moving to
687 // This is also correct.
688 //
689 // However, this is only a sample project to demonstrate programming guidelines and co
690 // so we preferred to keep it as simple as possible.
691 //
692 if (giXReverseLimit && giYReverseLimit)
693 {
694     giSubState1 = XY_HOME_MOVE_TO_INDEX;
695 }
696 return;
697 }
698 }
699 /*
700 =====
701 Function:          SubStateXYHomingMoveToIndexFunction()
702 Input arguments:   None.
703 Output arguments:  None.
704 Returned value:    None.
705 Version:           Version 1.00
706 Updated:           06/12/2010
707 Modifications:    N/A
708

```

Within the `SubStateXYHomingWaitLimitFunction()`, you can see how the limits statuses are checked (assuming that the limits statuses are read and that `giXReverseLimit` and `giYReverseLimit` variables are set/cleared accordingly within `ReadAllInputData()` at the beginning of the timer cycle).

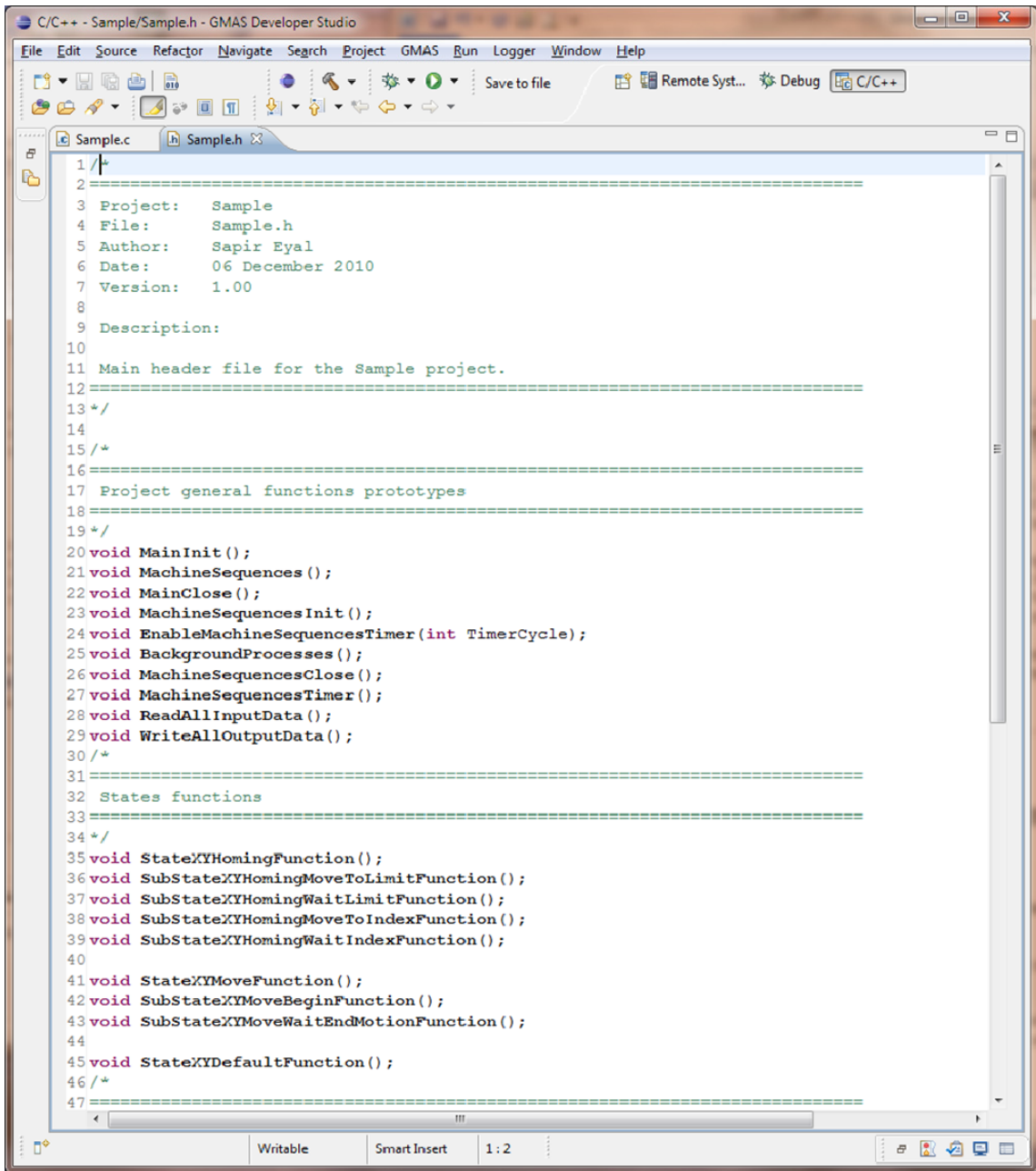
If the limits are not reached, the sub-state is not changed and the function ends (no "delays", no "waits"). It will be called again at the next timer cycle (20ms in this example) and so on. Once both limits are set, the sub-state is modified to the next state and the function ends. This will force the sub-states machine to execute the next sub-state (`MOVE_TO_INDEX`) in the next timer cycle.

All functions are as short as possible. Waiting for an event is not a part of a function, but is implemented as a state (`WAIT_TO_LIMIT` for example). According to the structure of the states machine code, this is called every timer cycle, to check if the wait condition is satisfied. Once it is, the state value is changed to the next state .

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This actually ends the Sample.c code. It includes some more states functions, but they are all written according to the above guidelines.

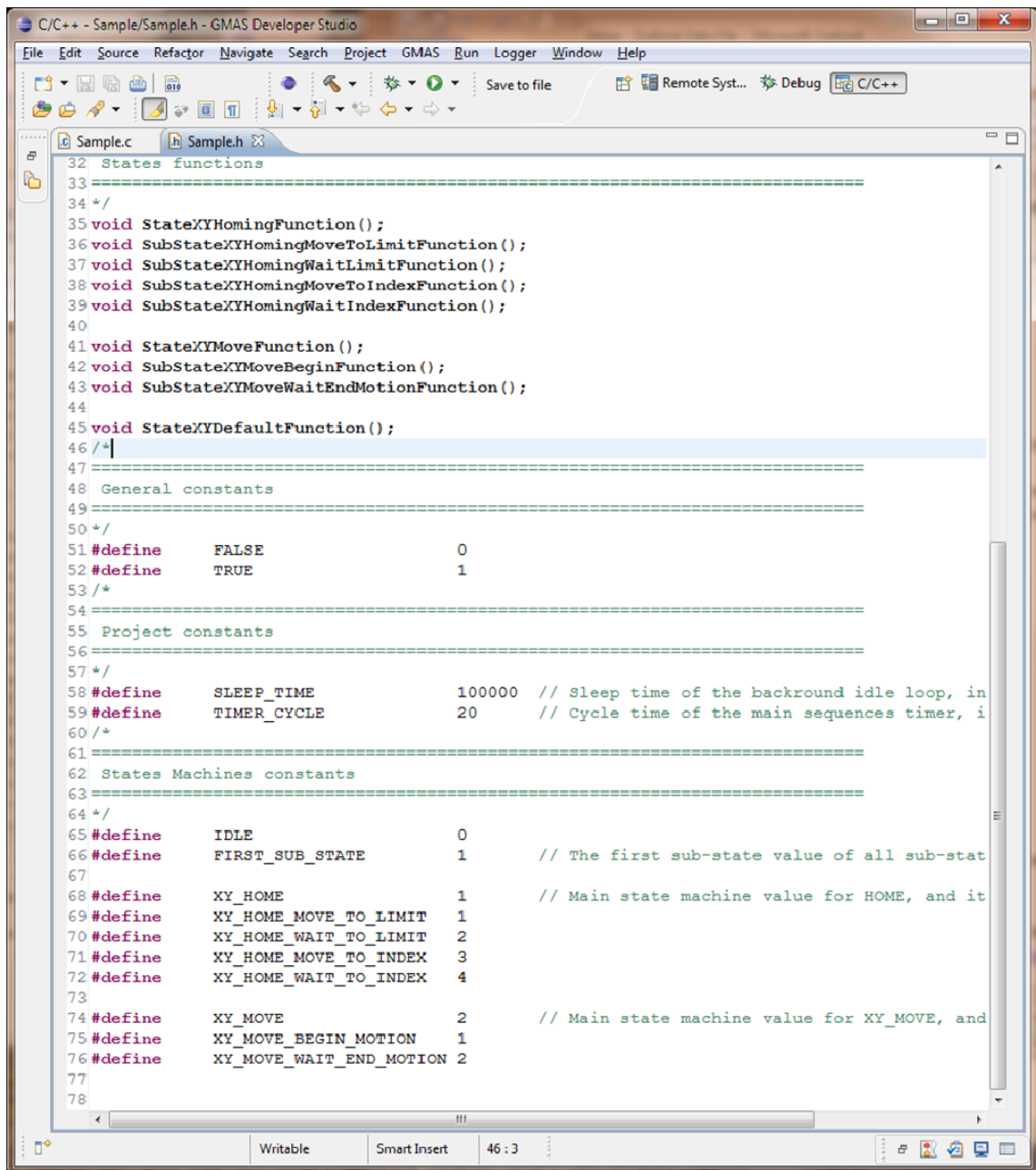
The Sample.h is shown in the two diagrams below. Note the functions prototyping (general functions and states functions, as well as the definition of constants (and the format used, such as: XY_HOME) to replace each number in the code.



```
1 /+
2
3 Project:   Sample
4 File:     Sample.h
5 Author:   Sapir Eyal
6 Date:     06 December 2010
7 Version:  1.00
8
9 Description:
10
11 Main header file for the Sample project.
12
13 */
14
15 /*
16
17 Project general functions prototypes
18
19 */
20 void MainInit ();
21 void MachineSequences ();
22 void MainClose ();
23 void MachineSequencesInit ();
24 void EnableMachineSequencesTimer (int TimerCycle);
25 void BackgroundProcesses ();
26 void MachineSequencesClose ();
27 void MachineSequencesTimer ();
28 void ReadAllInputData ();
29 void WriteAllOutputData ();
30 /*
31
32 States functions
33
34 */
35 void StateXYHomingFunction ();
36 void SubStateXYHomingMoveToLimitFunction ();
37 void SubStateXYHomingWaitLimitFunction ();
38 void SubStateXYHomingMoveToIndexFunction ();
39 void SubStateXYHomingWaitIndexFunction ();
40
41 void StateXYMoveFunction ();
42 void SubStateXYMoveBeginFunction ();
43 void SubStateXYMoveWaitEndMotionFunction ();
44
45 void StateXYDefaultFunction ();
46 /*
47
```

Together with the next diagram...

XXXXXXXXXXXX(0.01)



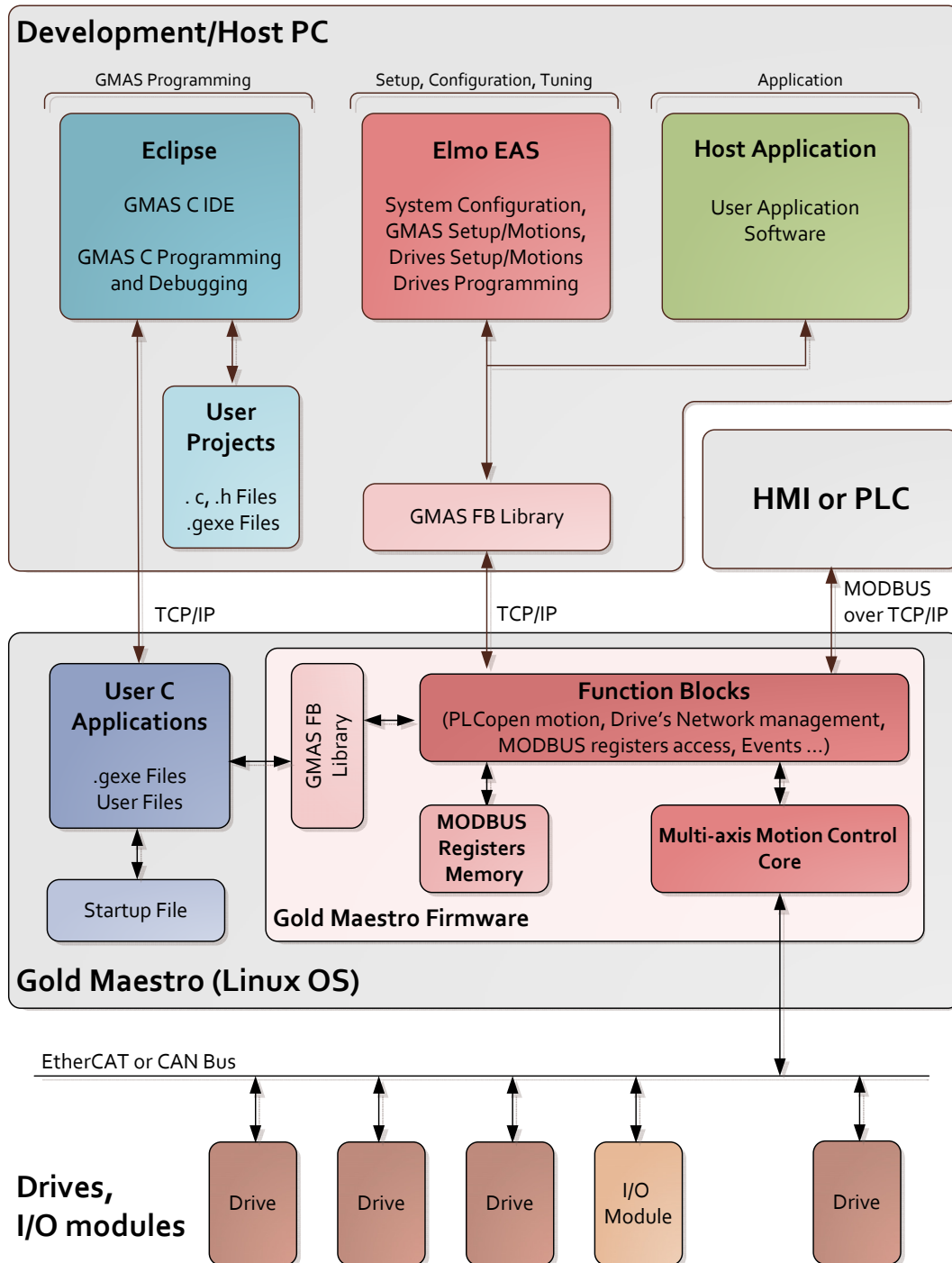
```
C/C++ - Sample/Sample.h - GMAS Developer Studio
File Edit Source Refactor Navigate Search Project GMAS Run Logger Window Help
Save to file Remote Syst... Debug C/C++
Sample.c Sample.h
32 States functions
33 =====
34 */
35 void StateXYHomingFunction();
36 void SubStateXYHomingMoveToLimitFunction();
37 void SubStateXYHomingWaitLimitFunction();
38 void SubStateXYHomingMoveToIndexFunction();
39 void SubStateXYHomingWaitIndexFunction();
40
41 void StateXYMoveFunction();
42 void SubStateXYMoveBeginFunction();
43 void SubStateXYMoveWaitEndMotionFunction();
44
45 void StateXYDefaultFunction();
46 /*
47 =====
48 General constants
49 =====
50 */
51 #define FALSE 0
52 #define TRUE 1
53 /*
54 =====
55 Project constants
56 =====
57 */
58 #define SLEEP_TIME 100000 // Sleep time of the backround idle loop, in
59 #define TIMER_CYCLE 20 // Cycle time of the main sequences timer, i
60 /*
61 =====
62 States Machines constants
63 =====
64 */
65 #define IDLE 0
66 #define FIRST_SUB_STATE 1 // The first sub-state value of all sub-stat
67
68 #define XY_HOME 1 // Main state machine value for HOME, and it
69 #define XY_HOME_MOVE_TO_LIMIT 1
70 #define XY_HOME_WAIT_TO_LIMIT 2
71 #define XY_HOME_MOVE_TO_INDEX 3
72 #define XY_HOME_WAIT_TO_INDEX 4
73
74 #define XY_MOVE 2 // Main state machine value for XY_MOVE, and
75 #define XY_MOVE_BEGIN_MOTION 1
76 #define XY_MOVE_WAIT_END_MOTION 2
77
78
```

This actually completes the review of the Sample project's code. The SampleWrapper.c and SampleWrapper.h files are skeleton, almost empty files, to be filled with functions and definitions as may be required for an actual application (you will find one later on within this manual).

Chapter 4: G-MAS software structure and interfaces

The following figure presents the software structure of a G-MAS based motion control system.

GMAS Based Motion Control System



XXXXXXXXXXXX(0.01)

Note:

Two additional software modules, that are not included in the above diagram, are used with the G-MAS. These are the KPA Studio and a Terminal for IP configuration over the TCP/IP. These two modules were omitted from the above figure to keep it as simple as possible and are described later within this chapter.

The overall motion control system is divided into three main layers:

- Host.
- G-MAS.
- Drives (and optionally also I/O controllers or any other valid device on the drive’s network).

The following chapters describe the software modules and the interfaces of each of the above layers.

4.1. The Host

The Host can be a PC Computer, a HMI, or PLC.

During machine operation, the Host (in this case, it can be a PC computer or a PLC or HMI) typically executes the application program developed by the user.

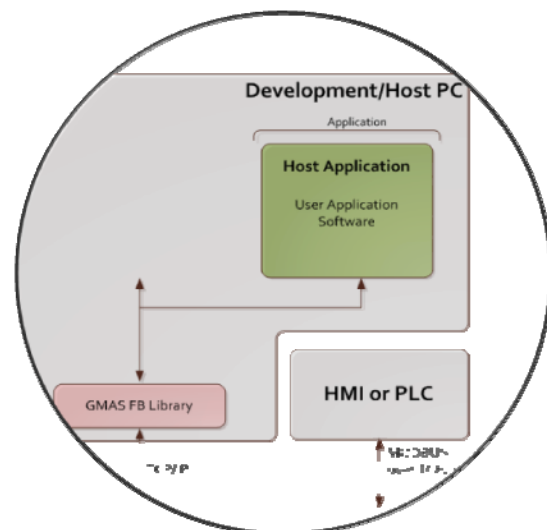
This application program performs the top level machine sequences and optionally also other tasks, that are not closely related to the axes motion sequences, such as user interfaces, image analysis, barcode interfaces etc., as maybe required for the machine.

In the situation where the host is a PC computer, Elmo provides the G-MAS Function block library, a static library with all function blocks to access via TCP/IP, the various functionalities of the G-MAS. The user links this library with his application program and as a result can easily access the G-MAS using any of the functions included in the library.

Where the host is based on a PLC or a HMI (Elmo does not provide any library for these devices), the user should use one of the G-MAS supported standard protocols via TCP/IP (currently Elmo supports MODBUS over TCP/IP).

During the development or maintenance phases, the Host (in this case, a PC computer) runs the special development and maintenance/configuration software modules that are supplied by Elmo to support the configuration/setup/programming of the G-MAS and the drives.

The EAS – Elmo Application Studio software is an all-in-one environment that supports all the tasks involved with the system configuration, setup, tuning, motions and programming. It is used both, for



the overall system (configuration), the G-MAS (setup, multi-axis motions) and the end units – the drives (configuration, setup, tuning wizards, motions and programming).

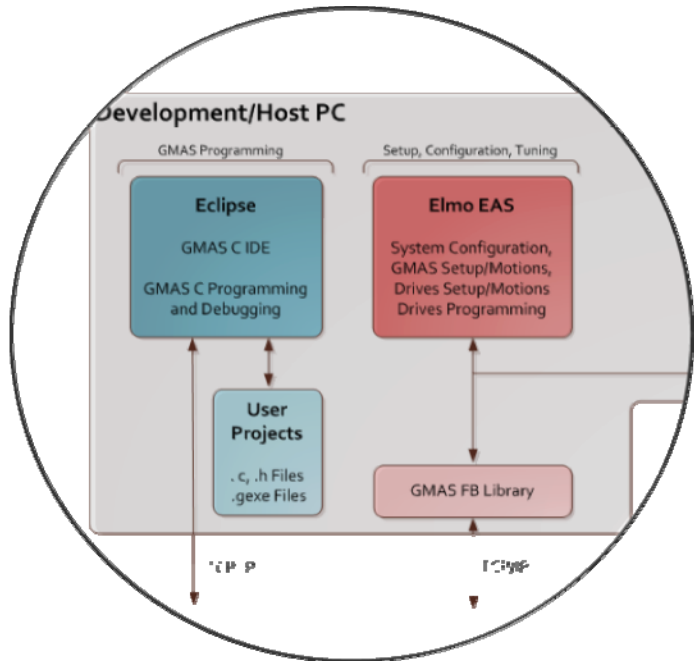
The EAS uses the same static library (G-MAS Function Block Library) that is used by the application program to access the G-MAS functionality over the TCP/IP.

While the EAS is an all-in-one environment, there is one task that is handled using a separate software module, Eclipse.

Eclipse is used to develop and debug User C and C++ Programs for the G-MAS.

Elmo decided to use the market-leading Eclipse environment (and not to integrate this task to the EAS) in order to provide its user with the best programming experience and minimal development time.

Using Eclipse, the user can write C and C++ programs (applications) for the G-MAS. The user’s projects are saved in the computer’s disk. Using this application, the user can also compile the project, link it with Elmo’s library and create an executable file for the G-MAS (*.gexe). In addition, while remaining in the application, the user can easily download the new executable file to the G-MAS, where it can be executed and/or debugged, all from within the Eclipse environment.

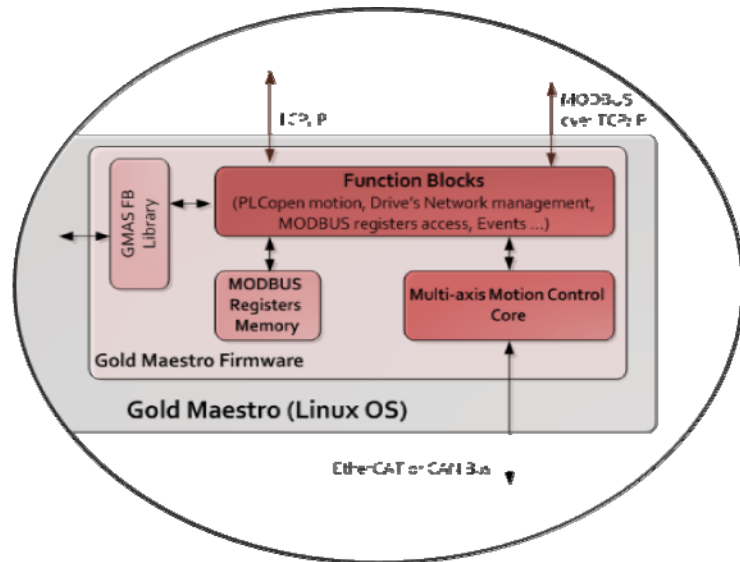


4.2. The G-MAS

The G-MAS is a Network Multi Axis Motion Controller. It obtains high-level motion or operational mode requests from the Host (over TCP/IP), and manages the actual machine’s motions and sequences, accordingly. The G-MAS accesses the end-units (drives, I/O controllers, etc.) over the device network, that can be CAN (using CAN Open standard protocols) or EtherCAT (using CANopen over EtherCAT – CoE – standard protocols).

The G-MAS is an embedded computer that runs the LINUX operating system and at least one software process: the built-in G-MAS firmware that is provided by Elmo as part of the G-MAS. It automatically runs the G-MAS firmware when power ON, which is responsible for the following tasks:

- TCP/IP communication with the Host.
- Process-to-Process communication with the optional User Application program running at the G-MAS (see below).
- Management of all calls for Function Blocks (see below) that may arrive from the Host (over the TCP/IP) and/or from the User Application program (running at the G-MAS itself).



Understanding the structure of the Multi-Axis Motion Control core is critical for optimal operation of the G-MAS. Please refer to the dedicated section below to learn details of the Multi-Axis Motion Control core.

- **Multi-Axis Motion Control.** This is the core of the G-MAS firmware, which is responsible to perform all trajectories, control, events and synchronization algorithms to create a multi-axis motion controller.

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Understanding the structure of the Multi-Axis Motion Control core is critical for optimal operation of the G-MAS. Please refer to the dedicated section below to learn details of the Multi-Axis Motion Control core.

- Management of the device network (CAN or EtherCAT) and communication with the end-units.

4.2.1. Function Blocks Interfaces

Function Blocks refer to the library of interface functions that are available for the users through the library supplied by Elmo: Elmo’s G-MAS Function Block Library. The same set of functions are available for the Host programmer (who is developing the Host Application, see above) and for the G-MAS programmer (who is developing the User Application for the G-MAS, see below). The Function Blocks’ library includes functions to create motions, manage the device network, create and manager events, etc.

Please refer to the G-MAS Administrative and Motion API User’s Manual for a detailed description of each of the available Function Blocks.

Here is some brief information about the Function Block interfaces:

- The API consists of a list of functions with input and output values.
- For instance - the MC_MoveAbsolute is as follows:

```
int  MMC_MoveAbsoluteCmd(Connection handle, Axis Reference, MMC_MOVEABSOLUTE_IN
    structure, MMC_MOVEABSOLUTE_OUT* structure);
```

Where:

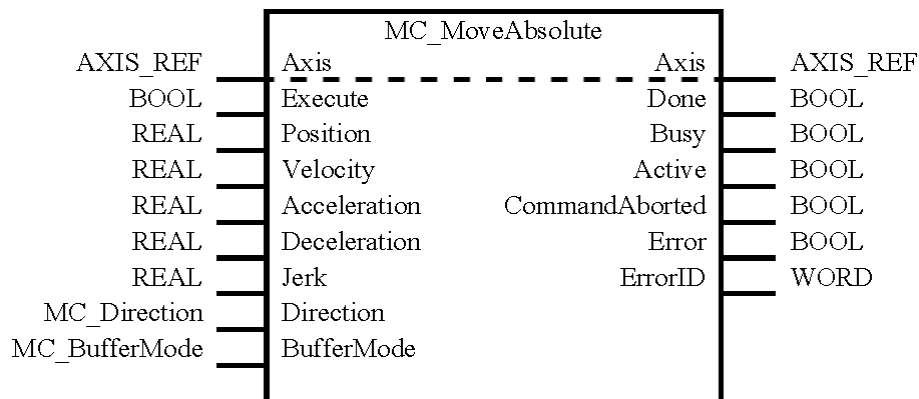
- All functions include a connection handle.
- Motion Functions include a reference to an axis (Group or single axis). Obtained by GetAxisRef().
- All functions include an ‘In’ structure and an ‘Out’ structure.
- The ‘In’ structure will include information regarding the motion.
- The ‘Out’ structure will include information regarding whether the function call succeeded or not.
- If the API function is to return data (such as ReadActualPosition()) – then the ‘Out’ structure will of course include the designated information.
- **All** function calls return immediately. This does not mean that the functionality is complete. Function calls **sometimes** initiate a background sequence (MoveAbsolute() for instance ...).
- All motion function blocks return a status register, which reflects the function CALL only. If an error occurs by sending incorrect parameters(range) / state machine – the function block call returns an error.

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- This is not the case if an error occurred during motion. The axis status is to be read by calling the ReadAxis() Status API. Also to obtain the PLCopen SMachine status.

4.2.2. Multi-Axis Motion Control Core Structure

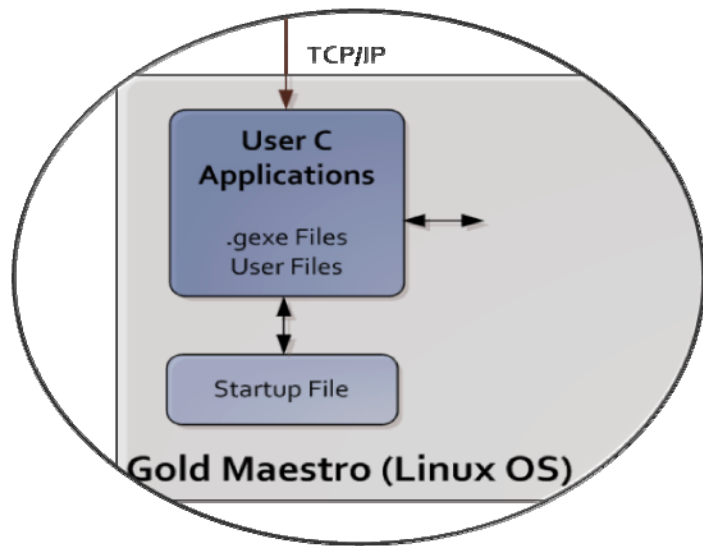
- PLCopen defines an axis reference to be used for each motion function.
- The AxisREF is the correlation between the user defined resource file axis name to the actual axis.
- Instead of sending the axis name to each function, the AxisREF is sent.
- The AxisREF is obtained via the GetAxisByNameCmd() API function. This function is to be called once per axis.



- The user program, either Internal or Remote, can receive events that occur in the G-MAS:
 - Emergencies sent from the drive.
 - PDO and PDO receive
 - General system failures
 - On Motion End
 - On Heartbeat Error
 - Emit
- These events must be preregistered per connection.
- An internal connection and a remote connection may both receive an event stating that an emergency occurred in Drive #N
- Mirror memory:
 - The DS402 state machine per axis is handled in the nodes cycle time.
 - Depending on the axis Mode Of Operation and user configuration, PDO’s are sent and received.
 - PDO’s that are received, are automatically updated in a memory variable.

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- This variable is actually the mirror variable of the drive, for the current cycle.
- When the user, from an Internal or Remote connection, requests the value of the variable, the mirror value is returned. No actual Communication request to the drive is performed (as a result, the response time to the request is very fast and the communication, as well as the variables values, are always synchronized),
- This is how PLCs work. The information is valid for the last cycle time.



The G-MAS can optionally execute a second process. This is the User Application program.

The User Application is a C program that is developed by the user. The development process is performed using a Host PC and the Eclipse environment (see above about the Eclipse environment).

A machine can work without having a User Application running on the G-MAS. In these circumstances, the Host will manage the machine sequences and motions and will send commands to the G-MAS (over TCP/IP) accordingly.

However, most applications are based on a User Application program at the PC, since such a program reduces the computational load of the Host, reduces the TCP/IP network load, and includes enabling modular implementation of the overall machine software (Host manages user interfaces, image analysis, top level machine sequences; while the G-MAS manages axis related sequences and motions).

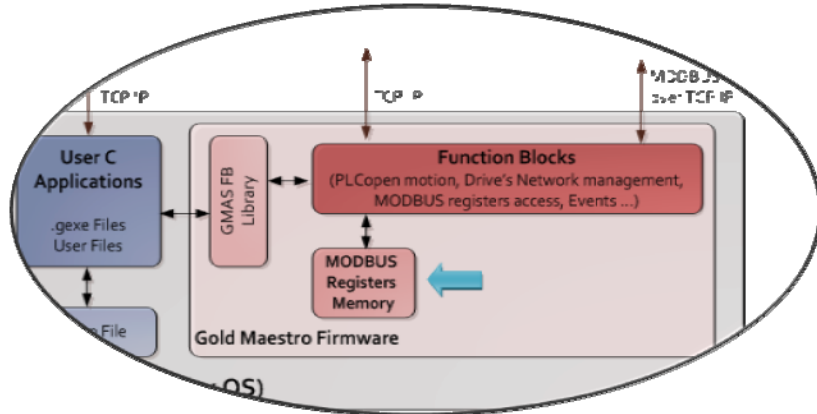
Using Eclipse, the User Application is developed and finally its executable file (*.gexe) is downloaded to the FLASH memory of the G-MAS (into an area dedicated for the User). During the download, the user can define that the application will run automatically at power ON (a suitable Startup File will be created by the Eclipse).

The user can download as many executable files as there is space within the FLASH memory. Typically, a default User Application program is executed upon power ON, using the Startup File, which is a Linux script file which is automatically executed upon power on or reset.

While typically most applications will use only one executable file (*.gexe) which will manage the application, the user can create any conditional execution of a set of executable files, using the Startup script file (an executable file can get arguments and can return a value). This, however, requires some knowledge of Linux script files.

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The User Application program, when executed, communicates with the G-MAS Firmware, using the G-MAS Function Block Library, to create motions, control events, read statuses, communicate with the device network units and any task that is available through this library of G-MAS Function Blocks.



A typical G-MAS User Application program also needs to communicate with the Host (and/or the Host needs to communicate with it). For example, the Host would like to transfer the required mode of operation, motion commands, etc., or to receive machine/motion statuses, etc.

Such a communication is typically implemented using the MODBUS over TCP/IP communication. As shown in the figure above, the G-MAS Firmware includes a memory area that is dedicated to MODBUS registers, and organized according to the MODBUS standard. The Host (a PC or a PLC/HMI) can access this memory area using standard MODBUS over TCP/IP which is supported by most of the Host devices. The User Application program can access this memory area using dedicated functions included in the G-MAS Function Block Library. As a result, this memory area is actually a shared memory of the Host and the User Application program and they can communicate over it.

It is the user’s responsibility to define the communication items (what is to be communicated, in what areas of the memory, and what the expected values are) and to implement this communication both at the Host side and at the User Application. Elmo only provides the means to access this shared memory by the Host and by the User Application program. You will find more about communicating over the MODBUS memory within the relevant example later in this manual.

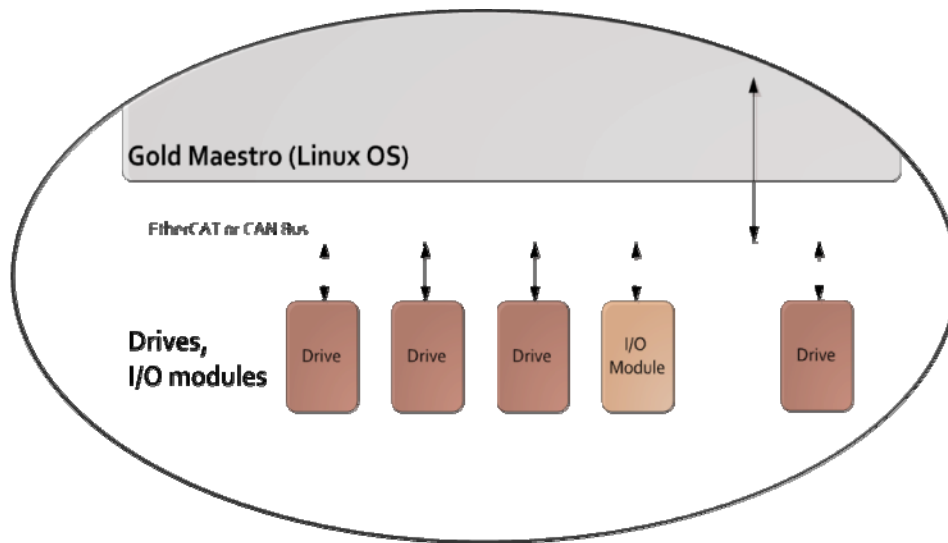


It is important to note that the G-MAS supports the execution of no more than one User Application at any given time. The current version of the G-MAS firmware does not protect the system from such cases. As a result, executing two or more User Applications simultaneously will have unexpected results and should be avoided by the user.

Finally, it is important to note that a User Application program can use the FLASH memory of the G-MAS (only the space allocated for the user). The Application Program can open files (e.g. files with parameters), create files (e.g. log files), write to files, etc., just as a C program running on a PC can access files on a Hard Disk. The user should take care for the response time when accessing the FLASH for writing. A user can copy files (such as parameters files) from the PC to the G-MAS Flash memory using suitable utilities.

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4.3. The device network



In general, the overall motion control system is designed to move motors and, if necessary, to control the machine’s I/Os.

Motors and I/Os are interfaced to the system using Servo Drives and I/O controllers (only if required, as each of the Servo Drives supports a number of I/Os for general purposes).

These end-units (servo drives, I/Os controllers, network encoders, etc.) are connected to the G-MAS over a Device Network. The G-MAS supports one of two Device Networks: CAN or EtherCAT.

The G-MAS Firmware is responsible to manage the Device Network and to perform all required communications in a synchronous manner and according to the standards of this network. Generally speaking, the user does not need to know the details of the device network as all the details are automatically handled by the G-MAS.

The exact list of protocols supported by each of these two networks, as well as the specifications of each protocol (minimal update time, delays, etc.) is included within the G-MAS User’s Manual.

4.4. Additional tools

The above-described structure of a G-MAS based system is a simplified structure. It does not include some additional software tools that may be required for setup and configuration of the G-MAS.

This chapter describes these additional tools.

4.4.1. KPA Studio

The G-MAS EtherCAT Configuration is used to initially scan the EtherCAT bus and locate the controllers on the bus, configure the Input / Output process cycle parameters, check the EtherCAT bus (CRC errors) and download the EtherCAT configuration resource file to the G-MAS.

4.4.2. IP Configuration over USB

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Chapter 5: The XYZ robot example

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Chapter 6: Further Programming Examples

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Chapter 7: PC Software Installation and how to use

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